WORLD SURVEY OF CITRUS IRRIGATION

Walter Reuther[1]

World citrus production has risen during the past century from less than 1 million to more than 44 million metric tons in 1973. Around 6 million tons of fresh fruit of this total found its way into international trade, about 14 million tons were processed, and the rest were consumed fresh within the country of origin. The 1973 world production of all deciduous tree fruits combined (apples, pears, peaches, plums, apricots, sweet and sour cherries) totalled about 42 million tons, to put this into perspective with other fruits. The next most important table fruit with respect to total worldwide tonnage is bananas, with about 35 million metric tons in 1973, of which about 6.7 million tons were exported (1). Thus, citrus has now surpassed all other fruits to become not only the most important fresh table fruit on a worldwide basis, but also is second only to bananas in volume of international trade.

Citrus is produced in a large number of countries (FAO lists about 90) in a belt extending approximately between 40° N and 40° S latitude around the world, with the heaviest concentration in the subtropical regions between 20° and 40° N latitude (Fig. 1). Large-scale intensive culture of citrus is heavily concentrated in frost-prone, irrigated subtropical areas, despite its origins in frost-free tropical regions with favorable annual rainfall distribution (Table 1). The reasons for this are complex, and involve human as well as climatic, soil, and varietal factors (5). I predict that tropical regions will gradually begin to contribute more significantly to world citrus production in the future, mostly in areas where supplemental irrigation will be required (6).

The popularity of citrus as a fruit crop seems to continue to soar, despite the more rapid rise in production costs than market prices in recent years in most of the major producing countries. Projections of the Food and Agriculture Organization of the United Nations suggest that total world production may rise to 56 million tons by 1980 (10). This would be an incredible increase of a third in less than a decade!

[1]Professor of Horticulture, Department of Plant Sciences, University of California, Riverside.

The above background information indicates that citrus, as the most important tree fruit crop, amply justifies international training programs such as this short course on irrigation. Your Florida hosts are to be commended on their vision and desire to serve citrus growers everywhere in arranging these sessions—especially considering that citrus in Florida was largely unirrigated until recently. I am proud to be invited to participate.

I will discuss briefly here the origin and natural habitat of citrus, summarize the history of citrus irrigation, survey the current worldwide citrus irrigation picture, and discuss the possible implications of some of the newer irrigation methods for the future.

ORIGIN AND NATURAL HABITAT

Most of the cultivated species within the genus *Citrus* appear to be indigenous to the more humid tropical and near-tropical regions of China, southeast Asia, including the eastern areas of India and Bangladesh, and the islands of Philippines and Indonesia. Primitive man undoubtedly played an important role in selectively disseminating and planting seed of the most attractive edible species and varieties in this general area before the dawn of history (8). The humid tropical origin of citrus is supported by its general mesophytic nature. It has a moderately shallow and spreading rooting habit not well adapted to withstanding long droughts. Its flat, broad evergreen leaves and thin, succulent bark of its twigs do not have specialized xerophytic features for greatly limiting transpiration or withstanding temperature extremes. The absence of a cool temperature—induced dormancy requirement for flowering and its susceptibility to damage by freezing also indicate its tropical origin.

There are no citrus species indigenous to the New World, and hence it is of interest to note the ecological conditions which favor natural spread of introduced species without cultural attention by man. Feral groves of sour oranges and sweet oranges and to a lesser extent rough lemons and West Indian limes gradually developed in certain specialized habitats as a result of seed spread by man or animals from cultivated sources after the introduction of citrus to Florida in the sixteenth century.

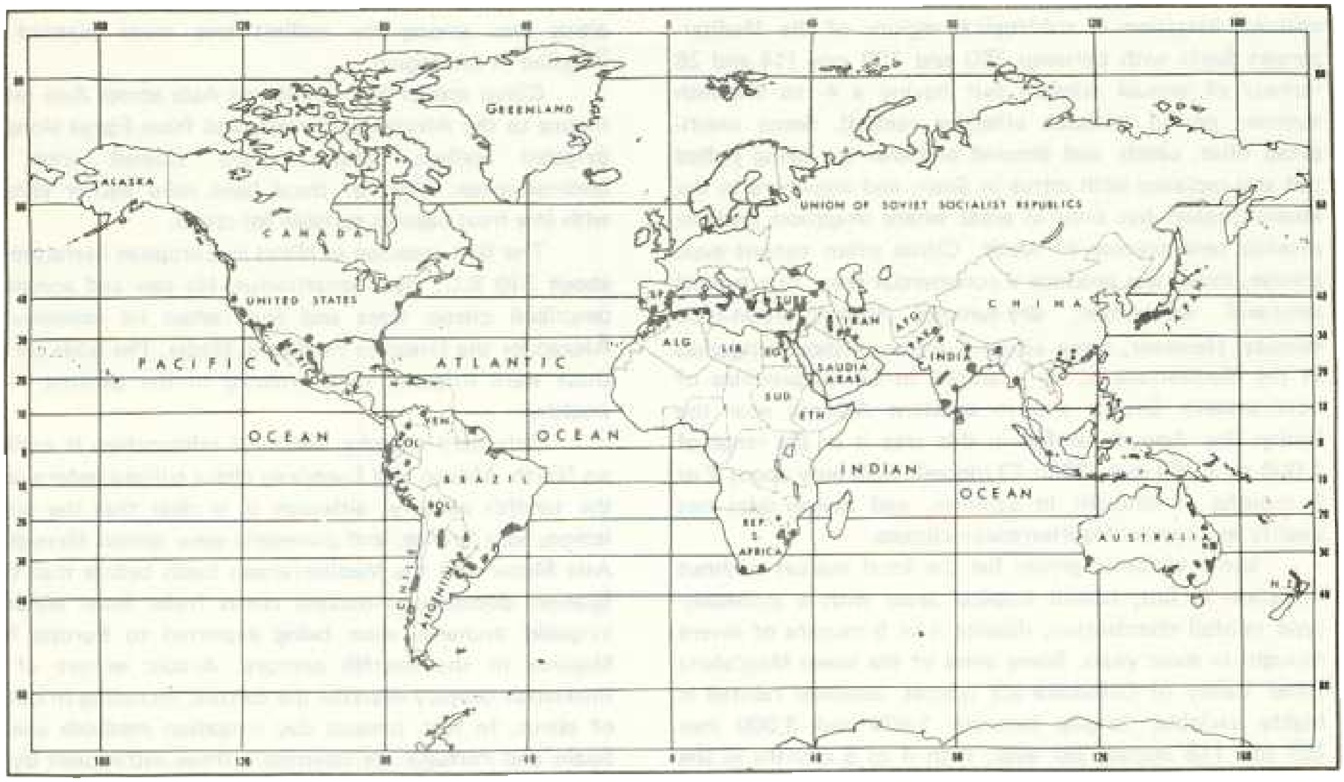

Fig. 1. Distribution of intensive commercial citrus-producing areas of the world.

These "wild" groves were invariably located on comparatively rich, low but well-drained moist lands found in the vicinity of rivers or lakes known locally as "hammocks". Such habitats in their native state supported good stands of tall hardwood trees (oak, magnolia, hickory, etc.) and an admixture of sabal palms and pines in many situations. The topsoil was porous, acid, high in organic matter and fertility, and often overlaid a calcareous subsoil. Citrus trees tended to form a dense undergrowth under the shading canopy provided by the foliage of the taller native hardwoods and palms in such natural groves, varying from 1 to 100 or more hectares (9). The main attributes of this hammock environment favoring feral citrus growth were a reasonably uniform year-round supply of moisture in the first meter of topsoil, but without prolonged periods of water-logging, and a protective canopy of forest trees. Such a protective leaf canopy not only reduces the transpirational demand for soil moisture, but also affords significant protection against moderate frosts. My observations in Florida, Central and South America, the Caribbean Islands and Southeast Asia indicate that citrus species must have substantially the environment of a tropical rain forest to successfully invade native plant communities. The key factors for survival of seedlings appear to be a fairly well-drained and fertile topsoil with a fairly uniform year-round moisture supply, and freedom from extremes of temperature, wind velocity and fluctuations in water table.

Of course, neither the native habitats nor adopted ones are infallible indications of optimal conditions for commercial exploitation of crop plants, but merely indicate the basic requirements for survival. But it is clear that citrus cannot be placed in the class of such drought-resistant tree crops as the olive, almond, or carob. Millions of hectares of these crops have been grown for centuries

Table 1. Estimated distribution of world citrus production, 1973.

Group	World production (tons x 1000)	Subtropical regions	Tropical[z] regions
		% of total	
Oranges	29,338	91	9
Mandarins	6,128	97	3
Lemons and limes	4,008	75	25
Grapefruit	3,727	95	5
Unclassified	752	25	75
Total	43,953	90	10

Source: FAO Production Yearbook (1).

[z]Between 20 N and 20 S latitude.

without irrigation in subtropical regions of the Mediterranean Basin with between 350 and 700 mm (14 and 28 inches) of annual rainfall, but having a 4- to 6-month summer period without effective rainfall. Some unirrigated olive, carob, and almond orchards are being pulled out and replaced with citrus in Spain and elsewhere in the Mediterranean but only in areas where irrigation projects provide new sources of water. Citrus often cannot even survive, much less produce a commercial crop, in a typical semi-arid wet-winter, dry-summer Mediterranean-type climate. However, some citrus is grown without irrigation in the Mediterranean, for example, in Epirus province of northwestern Greece and in adjacent Albania near the Ionian Sea. Annual rainfall in this area is in the range of 1,000 to 1,100 mm (39 to 43 inches), with only about 2 or 3 months of drought in summer, and hence does not qualify as a typical Mediterranean climate.

Some citrus is grown for the local market without irrigation in hot, humid tropical areas with a monsoon-type rainfall distribution, despite 4 or 5 months of severe drought in most years. Some areas of the lower Magdalena River Valley of Colombia are typical. Seasonal rainfall is highly variable, ranging between 1,000 and 3,000 mm (39 and 118 inches) per year, with 4 to 5 months in the December-April period devoid of effective rainfall in 2 years out of 3. Citrus is grown without irrigation on some exceptional deep, well-drained retentive soils but the trees are usually partially or completely defoliated by the end of the dry period, as are the native trees. The trees produce a flush of new leaves and bloom profusely about 30 days after effective rains start, but fruit set is usually low. However, fruit quality may be fairly good if the fruit reach almost full size before the next drought becomes severe. Most varieties mature in this hot climate about 6 months after petal fall.

EARLY HISTORY OF IRRIGATION

Some evidence, but none of it conclusive, suggests that irrigation of citrus was practiced in various parts of the world before the dawn of recorded history, perhaps even as far back as 5,000 years ago. There is some sketchy evidence from excavated seed, preserved wall paintings, and sculptured models, that the citron at least, may have been in Egypt and Mesopotamia from the time of the Pharoahs about 3,500 years ago (9). We can definitely conclude that it was grown under irrigation if it was grown in these regions at such an early date, since basin irrigation was practiced in Egypt at least 5,000 years ago (2).

Citrus was mentioned in Chinese literature as early as 4,000 years ago, and the scant evidence available suggests it was introduced from India and southeast Asia. Irrigation has been practiced in river valleys and deltas at least for the past 3,000 to 4,000 years in India and China. Doubtless, citrus was among the earliest tree crops planted and irrigated in this region.

Citrus spread from southeast Asia across Asia Minor, thence to the African continent, and from Egypt along the irrigated valleys whose rivers flowed into the Mediterranean. Most of these have mild winter climates with low frost hazards suitable for citrus.

The first mention of citrus in European literature was about 310 B.C., by Theophrastus. He saw and accurately described citron trees and fruit when he accompanied Alexander the Great to Persia and Media. The odds are that these were irrigated trees growing in the gardens of the wealthy.

Only very sketchy historical information is available on North African and European citrus culture before about the twelfth century, although it is clear that the citron, lemon, sour orange, and pummelo were spread throughout Asia Minor and the Mediterranean Basin before that time. Spanish documents indicate citrus fruits from windmill-irrigated orchards were being exported to Europe from Majorca in the twelfth century. Arabic writers of the thirteenth century describe the culture, including irrigation, of citrus. In fact, present day irrigation methods used in Spain and Portugal are essentially those introduced by the Moors from North Africa beginning in the eighth century. Present-day water rights and water laws throughout the Iberian peninsula have their origin in customs and laws introduced by the Moslem invaders. These same irrigation methods and legal traditions were introduced by the Spanish to the New World by the early sixteenth century, especially Mexico, Peru and California, along with citrus seed. Moslem irrigation influences are still discernible in the southwestern United States.

Government-sponsored projects during the past century to build large-scale storage dams and distribution canals in many parts of the subtropical world is one of the factors which has greatly stimulated the expansion of commercial citrus growing. Technological developments involving machines and cheap energy for drilling deep wells and pumping water also have contributed greatly to the expansion of citrus growing in many semi-arid regions.

The last several decades have been a golden era for irrigation research and development. We have a far better understanding of the economy of water in soils and plants and its relation to yield and quality of the product as a result. Technological innovations have given us an array of tools for better distribution and control of water applied to the soil. Research workers and growers working with citrus have played a very significant role in all of these developments so that today citrus, considered worldwide, represents perhaps the most advanced crop in use of irrigation technology and physiological principles of water use.

Table 2. Estimated percentage of 1973 world citrus production that is irrigated.

Region	Total production[y] (tons x 1000)	Est. irrigated[z] (%)	Calculated tonnage irrigated[z] (tons x 1000)
North America	12,722	76	9,668
Asia	10,346	59	6,104
South America	7,215	19	1,371
Europe plus USSR	6,299	97	6,110
Africa	4,057	81	3,286
Central America and Caribbean	3,030	37	1,121
Australia and Oceania	385	71	273
World Total	44,054	63	27,897

[y]Tonnage figures for North America are calculated from Tables 2, 4, 6, 10, 14, 16 of Shuler et al (7). Other tonnage figures are from FAO Production Yearbook (1). All classes of citrus fruits that are grown commercially are included in the totals.

[z]Rough estimations were made by the author, taking into account available literature information, personal knowledge gained from visits, rainfall distribution data, and relative proportion of arable land irrigated as listed for each of the 89 citrus-producing countries in FAO Production Yearbook (1).

CURRENT WORLD PICTURE

Extent of Irrigation

Citrus, as with most other tree fruits, cannot be grown as a commercial crop unless a fairly uniform year-round supply of soil moisture is available. Its demand for moisture even in the cooler winter months is appreciable since the tree is evergreen (3). Only in a few favored regions of the low frost-hazard subtropical zone can citrus be grown successfully without supplemental irrigation. Florida, and parts of Brazil, Argentina, Japan, China and southeast Asia are outstanding examples. Estimates presented in Table 2 show that roughly 2/3 of all citrus is irrigated. Supplemental irrigation will be used more and more in areas with a rainfall pattern like that of Florida in countries like Brazil, Argentina, and Japan. It becomes profitable to apply even 1 or 2 supplemental irrigations per year to attain maximum yield every year as land and other investment costs per hectare increase and fertilization, crop protection, and other cultural practices improve.

Estimates of states or countries presented in Table 3 are quite rough, and based on much indirect information. No data on extent of irrigated *vs* nonirrigated citrus is generally available, even in the United States. The estimate of 67% for Florida is based largely on my own "horseback" observations in visiting citrus people in Florida over the years, and various undocumented statements found in the literature.

Common Practices

It is not my purpose in this paper to present a detailed description of citrus irrigation systems, methods and tools, or to discuss the physiology of water use by the tree. A thorough coverage of these topics may be found in an excellent paper by Marsh (4) and in other presentations of this Short Course.

The most common irrigation practices by far in citrus orchards around the world are surface methods involving the use of basins, borders or furrows. Gravity basin irrigation from dams, diversions and wells was the most common method in the Mediterranean 100 years ago. Water was often elevated into channels along banks of rivers by means of water wheels, windmills or animal power, then led by gravity channels to the orchards. A water wheel still functions to fill a small diversion canal from a stream near Valencia, Spain.

Extensive terraces with masonry retaining walls and irrigation channels were constructed on the steeper slopes in the Mediterranean area before the advent of sprinkler irrigation. This is still going on to some extent in Spain, Italy and Greece, despite the obvious economic advantage

Table 3. Estimated percentage of 1973 citrus production that is irrigated in the major citrus-producing countries of the world.

Country	State	Total production (tons x 1000)	Est. irrigated (%)
	Fla.	9,303	67
	Texas	729	100
USA	Ariz.	425	100
	Calif.	2,265	100
	Total	12,722	76
Brazil		4,463	5
Japan		3,744	20
Spain		2,818	100
Italy		2,808	100
Mexico		2,153	40
Israel		1,602	100
Argentina		1,462	30
India		1,396	90
China		1,180	50
Egypt		918	100
Morocco		918	100
S. Africa		710	100
Turkey		695	85
Greece		640	85
Algeria		536	100
Australia		366	75

Sources: Same as Table 2.

of sprinkler systems on such terrain.

The use of the newer sprinkler and drip irrigation systems for citrus culture is confined largely to the United States, Israel, South Africa, and Australia. However, a beginning is being made with these systems on terrain unsuitable for traditional methods in the Mediterranean Basin, Central America and South America. Experiment stations concerned with citrus problems are beginning to take on projects involving sprinkler or drip irrigation in other countries.

Citrus is grown in some parts of the world on raised beds in imperfectly drained delta areas or seasonally flooded savannas, as in Florida. Citrus is irrigated or drained by regulating tidal action and flood levels by pumps and gates to retain water in the drainage channels during the dry season, and remove it during the wet season, for example, in the Chao Phya river delta area near Bangkok in Thailand. Many of Florida's east coast groves are merely highly engineered and mechanized versions of ancient methods used in the delta plains and savannas of many early civilizations. A major aim on these low-lying soils is to provide citrus trees with a rooting zone reasonably well-supplied with oxygen and available moisture throughout the season.

NEW TECHNIQUES AND THE FUTURE

Traditional surface irrigation systems involving gravity flow directly to the soil surface will continue worldwide to be the most economic and practical method for irrigation of citrus on suitable soil and terrain for the foreseeable future in my opinion. The use of modern instrumentation and distribution systems, together with the application of our rapidly improving knowledge of the fundamentals of soil-plant-water-environment interrelations will combine to steadily increase the efficiency of surface methods for several decades to come. The result will be higher yields, better fruit quality, and in some tropical regions, a greater capacity for manipulation of the season of harvest.

The same generalizations can be made for the newer sprinkler and drip irrigation techniques, except that these methods have the potential to control soil moisture with even greater precision, and to enable citrus to be grown on soils and terrain, or with water, that would be marginal or unsuitable for commercial citrus culture without sprinkler or drip systems. Two major factors are the key to the increasing use of sprinkler and drip systems of irrigation in California, at least. First, more and more of the level valley floor orchards are being removed to make way for urbanization. Replacement orchards are being planted increasingly on sites with soils of less favorable texture, depth, infiltration rate, or other physical characteristics, or with water of marginal salinity, or on terrain too sloping or undulating for use of a surface irrigation system. Second, the higher requirement of surface systems for labor, with its increasingly high cost and scarcity, have driven growers to systems involving more capital investment but less labor. Sprinkler systems can be managed with less labor per hectare, and usually in greater conformity with preferred daily working hours. In addition, a greater degree of automation may be achieved with sprinkler and drip systems, further reducing labor requirements by increasing fixed investments when necessary. Ultimately both of these advantages of sprinkler and drip may be reduced as advances in surface distribution systems permit greater mechanization and automation. Beginnings in this area are well underway.

Currently, drip irrigation is having a great surge of interest and enthusiasm, and at times some hard economic factors are ignored in the rush to adopt this system. Sprinkler and drip irrigation belong in the same family in my opinion. At one extreme, water is applied rapidly and fairly uniformly to the entire area occupied by the tree by means of overhead high-volume jets or sprinklers or surface lines of perforated pipe. At the other extreme, only a part of the area occupied by the tree is wet slowly by very low volume mini-sprinklers or by even lower volume drip emitters, all located on or near the soil surface. Other systems are intermediate. All have in common the distribution of water under pressure to individual trees through pipeline systems. Decisions to use low volume mini-sprinklers or drip systems, over surface or high-volume sprinkler systems, should take into account comparative water and labor costs, investment per hectare, management difficulties, cost of operation and maintenance, as well as soil texture, depth, drainage and terrain factors. I believe that experience will ultimately clearly identify the low volume mini-sprinkler and drip systems as making economic sense with problem soils, difficult terrains, saline water, special labor problems, or various combinations of these factors. That is not to in any way minimize the importance of these techniques in the future of citrus culture, or similar technology-intensive crops. They provide the tools, together with ancillary instrumentation aids, for utilizing soil, terrain, or water completely unsuitable for commercial citrus culture with surface or high volume sprinkler irrigation methods. In fact, these new irrigation techniques may well prove to be a major technological breakthrough, significantly augmenting the world food-producing potential.

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QUESTIONS

Q: You say there are applications where drip irrigation does not make economical sense. Exactly where would this fit in?

Reuther: On soils that are well-adapted to surface methods of irrigation, where you don't have the high investment per acre in developing irrigation systems, drip irrigation isn't economical. Where you have a problem soil, that's a different matter. For steep terrain, poorly drained soil, or salinity problems, drip makes economical sense. But if you could use much cheaper methods of surface irrigation, why go to the expense of this kind of investment? I know automation and labor costs are one of the attractions of drip irrigation, but I'm saying, in spite of all of these things, at times there has not been proper consideration given to the economics of it. Every situation is an individual economic problem.