

Chapter 1 — Background and Aims

1.1 Citrus

Citrus has been cultivated for thousands of years (Reuther et al., 1967). The fruit is popular for consumption as fresh produce and in processed products like juices and jams. It is one of the most important fruit crops in world trade and globally, in terms of volume, it is the second biggest fruit crop (after grapes) (Spiegel-Roy & Goldschmidt, 1996).

In South Africa, the citrus industry significantly contributes to the economy and it is the second largest earner of foreign exchange in terms of agricultural exports (Mabiletsa, 2003). South Africa is also the third largest exporter of fresh citrus (FAO, 2002) and fruit is exported to more than 50 markets (Mabiletsa, 2003).

1.2 Citrus Black Spot

Citrus Black Spot (CBS) is a fungal disease of citrus leaves and fruit that causes superficial lesions on the rind of fruit. It is caused by *Guignardia citricarpa* Kiely (Brodrick, 1969; Kotzé, 1981). The disease was first described from Australia by Benson (1895), and has since spread throughout many of the citrus cultivation areas of South Africa (Kotzé, 1981; Wager, 1952) and around the world (European Union, 1998, 2000a).

1.3 Phytosanitary barriers to trade and Pest Risk Assessments

As a result of international travel and commerce, plant pathogens may be dispersed throughout the world. When these pathogens are introduced into a new area, and find a susceptible crop, they can have devastating consequences. Agricultural systems with an impoverished diversity are particularly vulnerable to new pathogens (Baker et al., 2000) and such introductions have had significant economic impacts (Pimentel et al., 2001).

Historically, invasive species have caused dramatic declines in citrus production and threatened citrus industries. Cottony-cushion scale (*Icerya purchasi* Maskell) arrived in California in 1869 from Australia and almost closed the Californian citrus industry. This pest was only brought under control by the introduction of an exotic ladybird beetle (*Rodolia cardinalis* Mulsant), a predator of the scale endemic to Australia (McKimmie, 2000). Citrus tristeza virus (CTV), a viral disease of citrus, was introduced into Spain between 1930 and 1935 through nursery trees imported from California. Since then, this virus has killed an estimated 40 million citrus trees in Spain, and caused major losses in Argentina, Brazil, California and South Africa. The planting of CTV resistant rootstocks and healthy nursery trees has reduced the incidence of CTV, and it is no longer a threat to the Spanish citrus industry (Cambra et al., 2000).

To prevent introductions of alien species, phytosanitary barriers to trade restrict the movement of citrus fruit, plants and plant products world-wide (Anonymous, 1986; Baayen et al., 2002;

European Union, 1998). However, countries may not impose unnecessary restrictions and these barriers are required to be based on scientifically justifiable principles (WTO, 1993). Ideally, the risk of pathogen introduction should be determined through a Pest Risk Assessment (PRA) that is supported by scientific research (IPPC, 1996).

Pest risk assessments evaluate the potential risks of introduction and establishment of a plant pest or pathogen into a new geographical location and assess the management options to reduce those potential risks (Rafoss, 2003). Pest Risk Assessments consider, amongst other things, the life-cycle, host specificity, and current and potential geographical distribution of the organism (McKenney et al., 2003). If findings suggest that the risk of introduction is very low, phytosanitary measures may be removed in part or all together.

Presently, phytosanitary barriers to trade restrict the export of citrus fruit from CBS infected areas in South Africa, and several other citrus producing countries where the disease occur, to the European Union (Bonants et al., 2003; European Union, 1998, 2000b) and the United States of America (Anonymous, 1986; Baayen et al., 2002). Whole consignments of fruit may be rejected at packinghouses or ports if, during inspection, they are found to contain affected fruit (Bonants et al., 2003). Consequently, CBS has a great impact on the global citrus trade, and is of great concern to growers.

1.4 Bioclimatic modelling of plant disease distribution

The survival and proliferation of a plant disease depends on favourable climatic conditions. In particular, temperature and rainfall strongly influence the occurrence of diseases (Booth et al., 2000a). This correlation between climate and disease occurrence means that the potential for a disease to occur in a particular area can be estimated from climate.

Bio-climatic modelling refers to the geographic modelling of the potential occurrence of a species as determined by climate (McKenney et al., 2003). These models may partly elucidate complex underlying climatic mechanisms that influence the geographical occurrence of plant pathogens and have proved useful tools in estimating the potential geographical ranges of exotic species (Baker et al., 2000; MacLeod et al., 2002; Rafoss & Saethre, 2003; Vera et al., 2002).

Bio-climatic modelling techniques are broadly divided into two categories: mechanistic and correlative models. Mechanistic models, also termed ecophysiological models or process models, are based on physiological characteristics of the species and aim to simulate the mechanisms that underlie species interaction with climate (Beerling et al., 1995; Peter et al., 2003). These models are difficult to build, complex, and time consuming, and rely on knowledge of the biology of the organism (Robertson & Palmer, 2002). Mechanistic models are very rarely used to predict species distributions because of the complexity in describing the species ecophysiological response to a variety of climate variables. Correlative models are based solely on observed correlations between climate and the known distribution of the species (Beerling et

al., 1995). These models rely on distribution data and a set of predictor variables and they are easier to build than mechanistic models, less time consuming (Peter et al., 2003) and have been used extensively to predict the distributions of species (Beerling et al., 1995; Hill et al., 2002; Hill et al., 1999; Huntley et al., 1995; Leathwick, 1995). Correlative models that make use of species presence and absence data are referred to as group discrimination techniques and those that use only species presence data are referred to as profile techniques (Robertson & Palmer, 2002).

A large variety of correlative modelling techniques exist, all of which have different strengths and weaknesses. At its simplest, a correlative model is used to compare the climate in an organism's home range to the climate of another area to determine whether the other area is climatically suitable for the organism. More complex models infer the climatic requirements of the species from the known distribution and then assess the suitability of climatic conditions at thousands of locations. These locations are often represented using a regular grid (Baker et al., 2000).

These models require distribution data and suitable climate variables that are correlated to the species distribution. Methods that predict the potential distributions using climatic variable values inferred from the known distribution may prove fairly accurate, but greater precision can be achieved when selecting bioclimate variables or thresholds according to predetermined biological responses (Baker et al., 2000; Huntley et al., 1995; Prentice et al., 1992). Often these bioclimate variables and thresholds are in accord with the known distribution of the species (Baker et al., 2000).

Brasier and Scott (1994), gave one of the first examples of the bio-climatic modelling of plant disease distribution. They showed how the current distribution of a European disease of oak, caused by the fungus *Phytophthora cinnamomi* (Rands), was likely to shift northward under climate change. Since then, many other studies have modelled the geographical distributions of plant pathogens (Booth et al., 2000a; Booth et al., 2000b; Brasier, 1996; Ekins et al., 2002; Hoddle, 2004; Lanoiselet et al., 2002; Meentemeyer et al., 2004; Pethybridge et al., 2003; Pivonia & Yang, 2004; Van Staden et al., 2004; Yonow et al., 2004).

It should be stressed that bio-climatic modelling is an exploratory approach. It does not consider whether a species range is defined by biological interactions (Baker et al., 2000; McKenney et al., 2003) or physical barriers. Bio-climatic modelling may also not take human influences into consideration, for example agricultural environments allow more extensive distribution and spread of pathogens than would take place in a natural environment (Baker et al., 2000). Finally, bioclimatic models may not always take fundamental aspects of biology into account. The distribution of an obligate pathogen is limited by the distribution of its host regardless of climate (McKenney et al., 2003). Therefore, outputs from these models should be interpreted with caution, and should always be considered taking into account the input data (Nelson et al., 1999).

With these potential limitations in mind, bio-climatic modelling can be a valuable tool in estimating the potential distribution of organisms under current and future climates. It may be particularly relevant to studies in the agri-environment where competitors and natural enemies are limited by crop management techniques and the structure of the agro-ecosystem (Baker et al., 2000). Bio-climatic modelling can support PRAs and management decisions by providing a best estimate as to whether a pest or pathogen can occur in a given region. If an area may be vulnerable to infestation, resistant or tolerant crops can be planted, or an early detection system can be put in place to prevent the pathogen from becoming established. On the other hand, if the risk that a pathogen may become established in an area is extremely low, quarantine and preventative measures can be removed.

Unfortunately, the different modelling approaches can give different results (Robertson et al., 2003). Most studies that estimate potential distributions of pathogens only rely on the outcome of a single modelling approach without investigating different approaches. In this thesis two different modelling approaches are used to model the distribution of CBS.

1.4.1 CLIMEX

CLIMEX is a tool for estimating the potential distribution of invasive species. It has previously been applied to predict the occurrence of insect pests (D'Adamo et al., 2002; Kriticos & Wharton, 2004; Rafoss & Saethre, 2003; Robinson & Hoffmann, 2001; Venette & Hutchison, 1999; Vera et al., 2002; Worner, 1988) and some plant pathogens (Hoddle, 2004; Pivonia & Yang, 2004; Yonow et al., 2004). For a comprehensive list of previous studies see Sutherst et al. (2003).

CLIMEX contains two different climate-matching tools. The CLIMEX 'Match Climates' function and the CLIMEX simulation model also known as the 'Compare Locations' function. The Match Climates function compares the climate in the home range of the species to other areas to determine the similarity in climate and make a rough first assessment of the risk of establishment. To apply the CLIMEX model, the user infers the climatic conditions that the species can tolerate from the known geographical distribution of the species.

1.4.2 Response surface modelling

Predictions made using response surface modelling rely on the assumption that the present distribution of the species being modelled is determined by the bioclimate variables to which a correlation is demonstrated (Huntley et al., 1995). These techniques relate species distribution to environmental variables, which include climate and elevation data, by using a locally weighted regression. This approach has mainly been used to study the potential distribution of plants (Beerling et al., 1995; Huntley et al., 1995; Shafer et al., 2001) and butterflies (Hill et al., 2002; Hill et al., 1999) in the northern hemisphere, but recently it has also been used to predict the potential distribution of birds in Africa (BirdLife International, 2004).

1.5 The impact of climate change on plant pathogens

Human activities are changing the climate of the world. The emission of radiatively active gasses, in particular, are changing the composition of the atmosphere (IPCC, 2001). Global Climate Models (GCMs) that simulate the earth's climate system estimate that over the next century the mean surface air temperature will increase by 1.4–5.8°C and rainfall intensity and timing will become more variable (IPCC, 2001). These changes are already affecting ecosystems and species (Hughes, 2000; Parmesan & Yohe, 2003).

However, there have been few studies into the effect that climate change will have on the distribution of plant diseases (Coakley et al., 1999). Of these studies, most researchers concentrate on fungal plant pathogens (Baker et al., 2000; Bergot et al., 2004; Brasier, 1996; Brasier & Scott, 1994; Chakraborty & Datta, 2003; Chakraborty et al., 2000; Manning & Tiedmann, 1995).

Fungal growth and infectivity depend basically on temperature and moisture. An increase in humidity, dew, rainfall or temperature may directly affect the pathogen and its viability. The ecology of soil and plant surfaces may also be altered and a new climate may favour the development and survival of one microbe over another (Chakraborty et al., 1998).

In general, predicting the consequences of climate change remains very complicated and speculative, especially as predictions cannot be validated (Chakraborty et al., 1998; Dukes & Moony, 1999). Nevertheless, bioclimatic models can help give a best estimate as to how the geographical distribution of pathogens may change (Scherin & Coakley, 2003). Results obtained from these models may assist with the timely implementation of plant disease management strategies (Rafoss & Saethre, 2003).

1.6 Thesis aims

In 2000, a PRA study was undertaken by South African researchers to estimate the potential risk of CBS introduction into European countries through commercial citrus fruit exports (Hattingh et al., 2000). Results suggest that the risk of introducing CBS based on the etiology of the pathogen and epidemiology of the disease is low. In response, the European Commission stated that there is not enough scientific evidence to support a final decision to amend current phytosanitary regulations (European Union, 2001). They required more research on the climatic conditions necessary for the establishment of CBS. This project was designed, in part, to address this question.

The main aim of this study is to model the geographical distribution of CBS primarily in South Africa, Australia and Europe under current and future climates. The premise is that CBS currently only occurs in areas that are climatically suitable for disease development. An underlying objective was to clarify where CBS does not occur and where it is unlikely to establish.

To gain confidence in the results, two different correlative modelling approaches are used to map the potential distribution of CBS; the climatic modelling program CLIMEX, a profile technique correlative model (Hearne Scientific, Melbourne, Australia) (Sutherst & Maywald, 1985), and response surface modelling, a group technique correlative model (Beerling et al., 1995).

The approach is to:

1. review citrus and map areas of cultivation (Chapter 2);
2. review Citrus Black Spot (Chapter 3);
3. estimate the potential geographical occurrence of CBS under current climate [Chapter 4 (CLIMEX — Match Climates), Chapter 5 (CLIMEX — Compare Locations), Chapter 8 (Response Surfaces)];
4. estimate the potential geographical occurrence of citrus under current and projected future climates [Chapter 7 (Response Surfaces)]; and
5. model the potential occurrence of CBS under climate change [Chapter 6 (CLIMEX — Compare Locations), Chapter 8 (Response Surfaces)].

A summary of the conclusions is presented in Chapter 9.

Since this study is novel within the field of citriculture, it may serve as an example for future applications of bio-climatic modelling. When considering climate change, similar research applied to pathogens that globally threaten citrus cultivation could support the sustainability of citriculture.

1.7 References

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Chapter 2 — A review of citrus and of global citrus production

2.1 Abstract

Citrus has been cultivated and enjoyed by people for thousands of years. It is a diverse crop with many different kinds and varieties of fruit that can be consumed in different ways. Today, it is the second largest fruit crop in the world and the largest in global trade. In this chapter, the history, taxonomy and production of citrus, and the citrus industry in South Africa are reviewed. Then the current global citrus production areas of the world are reviewed and mapped.

2.2 Origin and history

Citrus has an important place in human history, featuring in the religion and mythology of many cultures. In India, a reference to citrus appears in a collection of devotional texts dated *circa* 800 B.C. In China, sweet oranges have been grown for centuries and were mentioned in a poem written in 314 B.C. Roughly in the same period, citrus fruits are mentioned for the first time in European literature (Reuther et al., 1967). The spread of citrus is well documented as travellers mentioned trees and fruit in their narratives. As humans explored the world, citrus — popular for its fruit, its fragrant flowers and as an ornamental — accompanied them (Reuther et al., 1967).

The exact origins of citrus are uncertain, but it is speculated that species of the genus *Citrus* is native to the tropical and subtropical regions of Asia and the Malay Archipelago. The oldest citrus growing area in the world is probably between south-east China, the Malay Peninsula and Burma. It is thought that mandarins, pummelos and limes originated from this region. From here, citrus appears to have been first taken south-east through the Philippines and the Pacific Islands (Spurling, 1969). Citrus was subsequently introduced to Europe around 310 B.C. and only arrived in the southern parts of Africa around 1650 A.D. (Reuther et al., 1967).

Citrus cultivation entered a period of rapid expansion around the start of the twentieth century, in response to a growing market demand and improvement of market quality as a result of refrigeration. The discovery of vitamin C and its importance in the human diet also increased the positive consumer attitudes towards citrus (Reuther et al., 1967).

Today, in terms of volume, citrus is the second largest fruit crop in the world, and the most important fruit in world trade (Spiegel-Roy & Goldschmidt, 1996). In 2002, the total world-wide annual citrus production was estimated at 104 505 157 metric tons (FAO, 2002a), and, in 2000, the value of global exports was 4000 million US dollars (FAO, 2004).

2.3 Uses of fruit

Citrus is mainly consumed as fresh fruit or juice (either fresh or processed). However it has many other uses. Processed citrus products include citric acid, essential and distilled oil, jams, jellies, gel products and citrus alcohol, wines and brandies (Spiegel-Roy & Goldschmidt, 1996). By-products from juice extraction are important in soft drink, pectin and cattle feed production. Citrus fruit is also popular as an ingredient in confectionary (Ray & Walheim, 1980); and several flavonoid compounds are used by the pharmaceutical and food industries (Spiegel-Roy & Goldschmidt, 1996).

2.4 Taxonomy and commercially important groups

The genus *Citrus* belongs to the order Geraniales and family Rutaceae (Davies & Albrigo, 1994). The Rutaceae contain about 150 genera, 1600 species, and is divided into seven subfamilies. True citrus and related genera are part of one of the seven subfamilies called the

Aurantioideae (Spiegel-Roy & Goldschmidt, 1996). Citrus hybridise naturally and therefore there is no clear reproductive separation among species (Davies & Albrigo, 1994; Spiegel-Roy & Goldschmidt, 1996).

World-wide there are five major groups that are of commercial significance: sweet oranges (*Citrus sinensis*. [L.] Osb.), mandarins (*Citrus deliciosa* Ten., *Citrus reticulata* Blanco and *Citrus unshiu* Marc.), grapefruit (*C. paradisi* Macf.), lemons (*Citrus limon* Burn. F.) and limes (*Citrus aurantifolia* L.) (Davies & Albrigo, 1994). Within each species are various cultivated varieties (cultivars), which differ in fruit size, shape, seed content, quality, and season of maturity (Timmer & Duncan, 1999).

2.4.1 Sweet oranges

Sweet orange (*C. sinensis*) is the most widely distributed and the most produced citrus crop in the world (Ray & Walheim, 1980). Climatic adaptability and a variety of cultivars give it the ability to grow in different growing regions. Sweet oranges are divided into four groups: round, navel, blood and acid-less. Round oranges are commercially the most important group, followed by navels. Blood oranges are mainly grown in Mediterranean areas and acid-less oranges are confined to backyard use and do not have commercial importance (Davies & Albrigo, 1994).

2.4.2 Mandarins

Mandarins are primarily produced for the fresh fruit market. They include numerous species, and may be divided into several groups including the Mediterranean mandarins (*C. deliciosa*), the common mandarins (*C. reticulata*), the Satsuma group (*C. unshiu*), the naturally occurring hybrids (e.g. the Temple mandarin) and other mandarin hybrids (e.g. tangelos). The term “mandarin” is used in Japan, China, Spain and Italy. The term “tangerine” is used to refer to mandarin-type citrus in Australia and the United States of America (USA). In South Africa, mandarins are referred to as soft citrus (Davies & Albrigo, 1994).

2.4.3 Grapefruit

Grapefruit (*C. paradisi*) is probably not a true species, but a hybrid of pummelo and sweet orange (Spiegel-Roy & Goldschmidt, 1996). It is divided into two groups, white and red-fleshed grapefruit. Although these fruit are the largest of the major commercial cultivars, they are not as widely produced as mandarins or oranges. Grapefruit are mostly sold as fresh fruit (Davies & Albrigo, 1994).

2.4.4 Lemons

Excluding those used as rootstocks, lemons (*C. limon*) are divided into three groups: Femminello, Verna (Berna) and Sicilian. Distribution and production of lemons are limited to semi-arid to arid subtropical regions with minimum temperatures of greater than about 4°C (Davies & Albrigo, 1994).

2.4.5 Limes

Lime trees (*C. aurantifolia*) are the most frost sensitive of all commercial citrus species. Their distribution is limited to warm and humid tropical and subtropical regions where minimum temperatures remain above approximately 2°C. The two major groups of limes are the acid and acid-less limes, of which only acid limes are of commercial importance (Davies & Albrigo, 1994).

2.5 Climatic and geographic factors that influence cultivation

The culture of citrus requires a low frost incidence, enough moisture to sustain the trees, and suitable soils. These factors have a marked influence on the growth, development and productivity of trees (Davies & Albrigo, 1994; Timmer & Duncan, 1999). Nevertheless, citrus can be grown in a wide range of conditions.

Temperature, especially low temperatures and frost, is the main factor that governs the global range of citrus production (Davies & Albrigo, 1994; Spiegel-Roy & Goldschmidt, 1996). Limited growth occurs in all citrus tree organs at temperatures below 13°C. Extremely high temperatures of above 50°C also influence growth and development of citrus trees (Davies & Albrigo, 1994).

Significant induction of flowering requires that there is a period of drought of longer than 30 days and that temperatures stay below 25°C for several weeks. The degree of induction is proportional to the severity of and duration of stress. Flowering is not induced below 9.4°C (Davies & Albrigo, 1994).

Good quality irrigation water is a basic requirement for the successful cultivation of citrus (Srivastava & Singh, 2002). A lack of quality irrigation water limits citrus production in various regions of the world, including parts of Brazil, China and Mexico (Davies & Albrigo, 1994).

Citrus is grown in, and can adapt to, a wide range of soil conditions, but it grows best in sandy or clay loam soils. Soil properties may influence the growth habit of trees, especially root distribution. Adequate soil drainage is vital for growth as tree growth is reduced in poorly drained soils (Davies & Albrigo, 1994). Accumulation of free water in the root zone may also result in poor aeration and eventually lead to root injury (Timmer & Duncan, 1999).

2.6 Other factors that influence cultivation

The most significant limitation to profitable citrus production, other than climate and soil, is disease (Davies & Albrigo, 1994). A disease of citrus may be defined as differences from the normal appearance, form or functioning of a citrus tree or its fruit. Diseases are classified as infectious (biotic) or non-infectious (abiotic) diseases (Timmer & Duncan, 1999). Biotic diseases are caused by bacteria, fungi, mycoplasmas or viruses. They may cause the death of citrus trees or seriously limit production (Davies & Albrigo, 1994; Timmer & Duncan, 1999). Abiotic diseases are caused by nutritional and genetic defects and incorrect cultural practices, such as the inappropriate application of chemicals (Timmer & Duncan, 1999).

The occurrence and severity of a biotic disease is determined by, amongst other factors, the local climatic and environmental conditions, the virulence of the pathogen, and the susceptibility of the host plant (Timmer & Duncan, 1999). The absence of a biotic disease in a specific citrus growing region may be attributed to geographical isolation or to active exclusion of the causal agent. The local climatic conditions may also be unfavourable for infection or pathogen survival. This is often the case in arid and semi-arid areas where there is insufficient humidity for the causal agents to persist or cause infection, even if they were introduced (Timmer & Duncan, 1999).

2.7 Citrus health management

Prevention is the only truly effective means of reducing the losses caused by most citrus diseases (Timmer & Duncan, 1999). Disease control is usually specific to a particular disease, but there are some general concepts that are applicable to disease control in general. Most importantly, disease-free material should always be used in citrus cultivation (Davies & Albrigo, 1994). Pathogen-free and healthy sources of bud-wood are maintained for distribution to nurserymen and growers. A reliable source of disease-free planting material is essential to the success of any citrus industry as dissemination of diseased trees may have catastrophic effects. For this reason, citrus producing countries have stringent nursery regulations (Davies & Albrigo, 1994). In most countries where citrus is produced there are also restrictions on the import of citrus fruit and propagating material from areas where particular diseases occur.

Diseases may also be avoided by planting rootstocks and scions tolerant of or resistant to local diseases (Davies & Albrigo, 1994). However, the choice of cultivar is usually dictated by consumer demand and growers often plant disease susceptible cultivars even though more resistant cultivars are available (Timmer & Duncan, 1999).

Chemical control of diseases can be costly and labour intensive. Despite the potential adverse environmental impacts they might cause, copper and copper-based products are still widely used to prevent citrus diseases (Davies & Albrigo, 1994), but concerns about chemical residues are beginning to restrict the market access of fruit treated with chemicals. Moreover, there is an increasing public expectation that chemical inputs to the environment should be minimised. Therefore research is being focussed on alternatives to chemicals for the prevention and control of citrus diseases (Obagwu & Korsten, 2003).

2.8 The South African Citrus Industry

2.8.1 Origin and history

The arrival of citrus fruit in Southern Africa is documented in the journal of Jan van Riebeeck, the first governor of the Dutch colony in Cape Town (Reuther et al., 1967). On the 11th of June 1654, citrus plants arrived from the island of St. Helena, where citrus material had previously been established by Dutch merchants trading with the Orient (Oberholzer, 1969).

As pioneer settlers moved inland, they took citrus seed with them, but for over two centuries citrus production was only on a small scale and localised. With the discovery of diamonds and gold in the late 1800s, European immigrants flocked into the country. This created an increased demand for agricultural produce, including citrus. Initial plantings were small, as fruit was destined for local consumption (Oberholzer, 1969), but these plantings would eventually lead to the development of the South African export industry (Ray & Walheim, 1980).

2.8.2 The industry today

Citrus represents one of South Africa's most important agro-commodities. The total area under citrus cultivation is estimated at about 57 000 ha (Mabiletsa, 2003a) and citrus yields in mature orchards average about 40 to 60 tons per hectare (Mabiletsa, 2003b). Oranges are the most important citrus grown, with Valencias being the most important cultivar (Mabiletsa, 2003b). Lemons and grapefruit are also produced, but to a lesser extent (von Broembsen, 1986).

Citrus is grown in almost every province in South Africa. Main areas of production are found in Limpopo Province in the areas surrounding Tzaneen, Letsitele and Letaba; in Mpumalanga around Nelspruit, Hectorspruit, Groblersdal and Marble Hall; in North Western Province around Rustenburg; in Kwazulu-Natal around Muden; in the Western Cape Province around Clanwilliam (Kotzé, 2004, Personal Communication), Citrusdal, Somerset West and Grabouw (Kelly, 1995); and in the Eastern Cape Province around Uitenhage, the Kat River and the Sundays River Valley (Mabiletsa, 2003b; Oberholzer, 1969; Reuther et al., 1967; Urquhart, 1999). Smaller areas of citrus cultivation can be found in the Vaalharts and Warrenton areas (Mabiletsa, 2003a) and other parts of the Northern Cape (le Roux, 2004; Urquhart, 1999).

Citrus is cultivated in a variety of different climatic regions which allows a range of cultivars and varieties of fruit to be produced across South Africa (Mather, 1999). The Western Cape and Eastern Cape are considered to be cooler citrus growing areas and production is focussed on lemons (Veldman & Barry, 1996), Navel oranges and soft citrus (mandarins). In these two regions farm sizes are smaller than in Mpumalanga, Limpopo and KwaZulu-Natal, where the climate is better suited to the cultivation of grapefruit and Valencia oranges. In terms of volume, Mpumalanga and Limpopo provinces produce the greatest amounts of citrus (Mather, 2003).

Citrus cultivation requires access to water and the majority of farms operate with capital-intensive irrigation equipment. Fruit farming is labour intensive, particularly during harvesting

season. More than 100,000 farm workers are permanently employed with an additional unknown number of seasonal workers also employed (Mather, 1999). The other main cost associated with citrus production is agrochemicals (London & Myers, 1995).

2.8.3 Export of citrus from South Africa

The introduction of refrigerated shipping facilities led to the first ever successful export of 3000 standard cases of citrus fruit to the U.K. in 1906. This was a great stimulus for citrus production in South Africa (Oberholzer, 1969). Since then export of citrus fruit has increased steadily. By the 1960s, South Africa was exporting over half of all southern hemisphere fresh citrus and was ranked amongst the top five fresh citrus exporters in the world (Mather, 2003). Currently, South Africa is the world's third largest exporter of fresh citrus fruit after Spain and the USA (Citrus Growers Association, 2004; FAO, 2002a), and up to 70% of the citrus produced is exported annually, with more than 50 million cartons sold world-wide. This earns South Africa around R2 billion in foreign exchange (Mabiletsa, 2003b).

South African citrus exports provide overseas markets with a steady supply of citrus as fruit from different geographical areas in this country matures at different times. In Limpopo Province and Mpumalanga, fruit ripens earlier than the citrus varieties in the relatively cooler Western and Eastern Cape regions (Mather & Greenberg, 2003). The combination and assortment of fruit available and South Africa's counter-season advantage in being able to supply fruit to countries in the northern hemisphere during its summer is central to the South African Citrus Industry's marketing strategy (Mather, 1999).

The export period is from April to October. South Africa's most important competitors are Argentina, Chile and Australia during the main season; and Israel, Spain, Egypt and the USA towards the end of the marketing season. The biggest export market is Europe, followed by the Middle East, Japan, the Far East and the USA (Mabiletsa, 2003b).

Global citrus consumption is increasing very slowly, but competition for citrus markets is strong. Markets in the northern hemisphere are regularly oversupplied. Longer seasons in northern hemisphere citrus production have also exacerbated problems of oversupply (Mather, 2003).

Citrus which cannot be exported because of quality and excessive chemical residues is sent to the domestic market (Urquhart, 1999).

2.9 Citrus production around the world

Citrus trees are sensitive to below freezing temperatures and outdoor growing areas are limited to the tropics and subtropics. Production is mostly limited to latitudes of between 40°N and 40°S, where minimum temperatures are greater than approximately 7°C (Davies & Albrigo, 1994).

The three major citrus producing countries; Brazil, USA and China dominate global production, producing around 40% of the world's citrus. Other major citrus producing countries include Mexico, Spain and India, but these together produce only 8% (FAO, 2004).

The citrus industry of the world is vast and constantly changing as millions of trees are uprooted or planted every year. Production areas may shift as a result of diseases or market forces. However, there is no recent overview of global citrus cultivation. In the following section citrus production areas of the world are reviewed and mapped. The aim is to collate information on geographical areas of citrus cultivation, to document the major types of citrus grown, and to produce maps that broadly indicate areas of citrus cultivation. A review of global citrus production areas is a daunting task as information of citrus growing areas are not generally published and if it is available, the information is often presented in the countries' native language. Therefore the database presented is incomplete and will need regular updating, but still it has several important applications. For example it may enable the collation of more detailed distribution of citrus within these broad areas and also the collation of citrus pathogen distribution data for future use in citrus disease management.

World-wide, citrus production regions can be divided into 6 major regions, (with approximate percentage of world production in 2002 indicated): Asia (31%), South America (25%), North and Central America (22%), Africa (11%), Southern Europe and Asia Minor (10%) and Oceania (0.6%) (FAO, 2002b). Citrus producing counties in these six regions are reviewed in descending order of the volume of total citrus fruits produced in 2002.

2.9.1 Asia

In Asia, citrus has been cultivated for thousands of years (Iwagaki, 1991; Reuther et al., 1967; Zhaoling, 1986). Many types of citrus originated in South East Asia and today it is one of the most important agricultural crops produced. Much of Asian production occurs on small farms. These farms have higher production costs and lower yields than Western citrus producing countries (Bové, 1995), as diseases, especially virus-like diseases, impair production. Additionally, there is a lack of suitable improved varieties and of disease-free planting material (Anonymous, 1996; Bové, 1995).

Citrus industries in the Far East mainly produce mandarins (Anonymous, 1990; Bean et al., 2003; Hardy, 1997; Iwagaki, 1991; Mahajan, 2002; Singh, 1969). Citrus industries of Near East Asia are far smaller and less developed and grow different kinds of citrus, such as oranges, mandarins, limes, lemons and grapefruit (Bové, 1995; Catara et al., 1988; Reuther et al., 1967). The industries of the Near East are particularly affected by high temperatures and water scarcity (Bové, 1995; Singh, 1969).

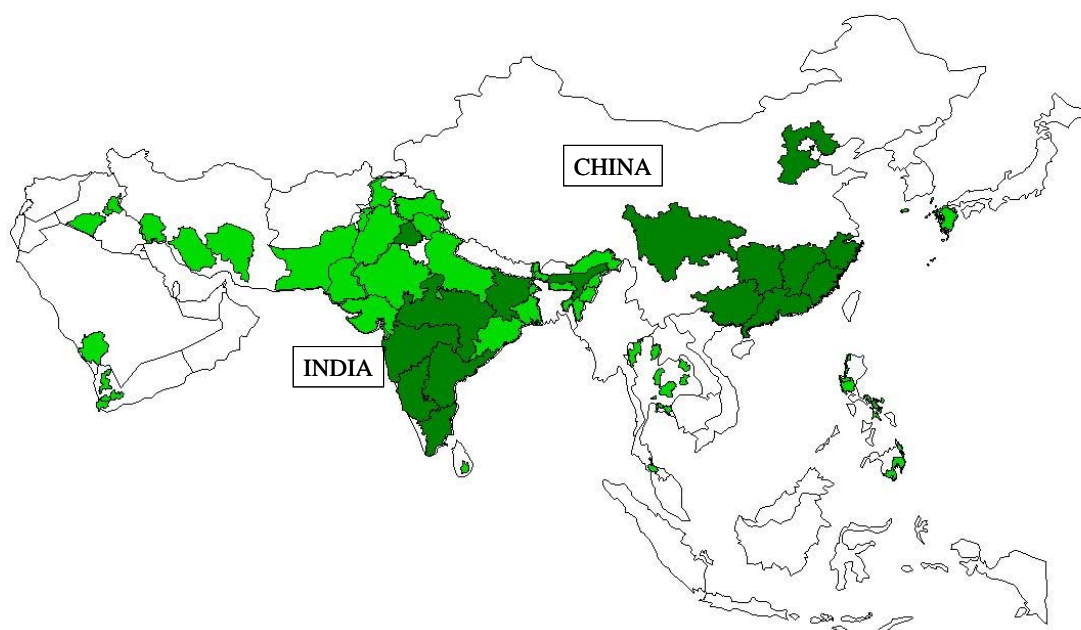


Figure 2.1 — Some of the administrative regions where citrus is produced in Asia. The two countries which produce the most citrus are indicated. Major areas of production are indicated in a darker colour.

2.9.2 South America

Citrus is cultivated in all South American countries, although there is significant variation in the quality and quantity of production. Mainly oranges and lemons are produced, with Brazil being the world's biggest producer of oranges (Barros, 2003; Donadio et al., 1996; Passos et al., 1999) and Argentina being third in the production of lemons and limes (FAO, 2002a). Lemons and limes also dominate citrus cultivation in Peru, as they are used in local beverages. In Brazil, citrus canker and Sudden Death of Citrus disease are the greatest threats to the industry. Unofficial estimates of 2002 suggest that between one and three million plants could be affected by the Sudden Death of Citrus disease in this country (Barros, 2003).



Figure 2.2 — Some of the administrative regions where citrus is produced in South America. The two countries which produce the most citrus are indicated. Major areas of production are indicated in a darker colour.

2.9.3 North & Central America

The USA is the second largest producer of citrus globally, and, as a result, citrus ranks as the fruit crop of greatest economic value in this country. Production is concentrated in the states of Florida, California, Arizona and Texas. The differences in climate between these states result in different patterns of production. Frost is the main concern of the industry (Hearn, 1986; Jacobs, 1994). The USA mainly grows oranges and grapefruit, of which 75% of oranges and 50% of grapefruit are processed (Jacobs, 1994). Fresh citrus exports are small in comparison to other citrus industries (Jacobs, 1994), but the USA is the world's biggest supplier of fresh grapefruit.

Citrus is produced throughout the countries of Central America. Mexico is the fourth largest producer of citrus in the world, and the largest producer of lemons and limes (FAO, 2002b).

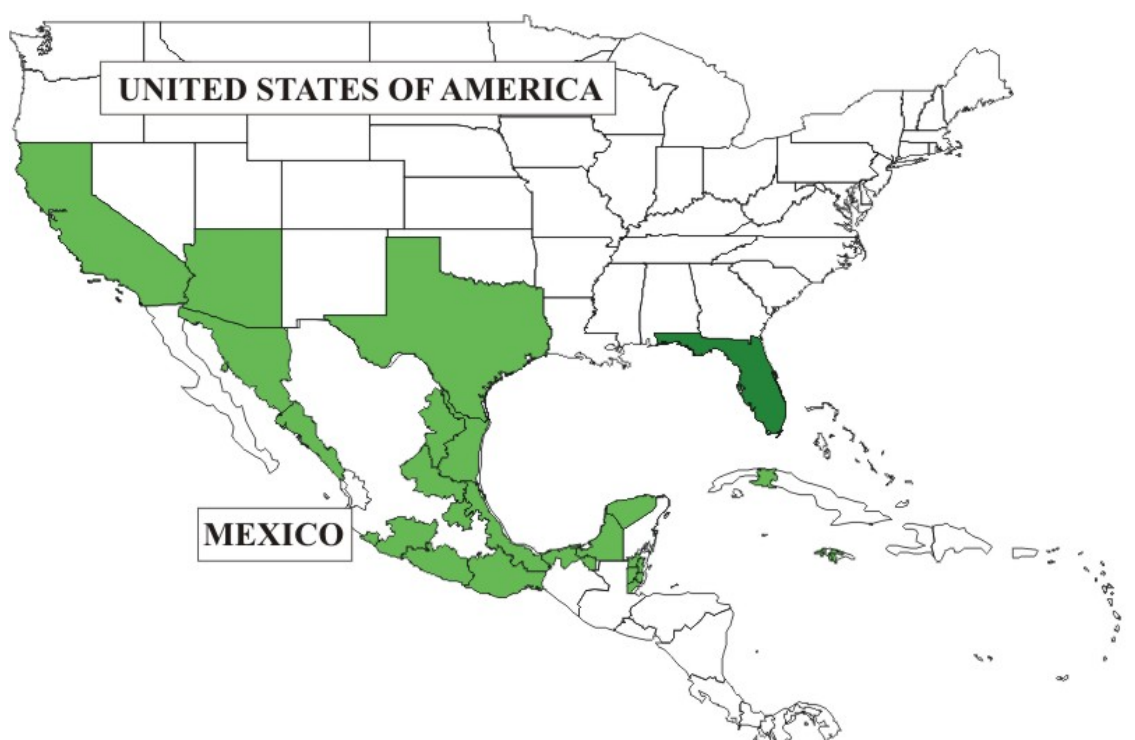


Figure 2.3 — Some of the administrative regions where citrus is produced in North and Central America. The two countries which produce the most citrus are indicated. Major areas of production are indicated in a darker colour.

2.9.4 Africa

In Africa, citrus is cultivated over a wide range of geographical and climatic zones (Rey, 1997; Stanbury, 1996). Rootstocks and varieties have been specially developed to suit the varying climatic conditions.

In Central and Western Africa, citrus is the second largest fruit crop after bananas. The main constraints to production are disease, including African leaf and fruit spot disease, tristeza and Huanglongbing (Citrus Greening). In rainforest areas citrus is grown with cocoa trees and other small cash crops as part of mixed cropping systems. In Western and Central Africa the entire citrus crop is sold on local markets as fresh fruits. Fruits tend to stay green as a result of inadequate periods of low temperatures and are thus not suitable for the export market (Rey, 1997).

In Southern Africa the industry is dependent on export. Most citrus production areas are situated in rural areas. These industries are of major importance to the economies and provide employment for hundreds of thousands of people (Stanbury, 1996).

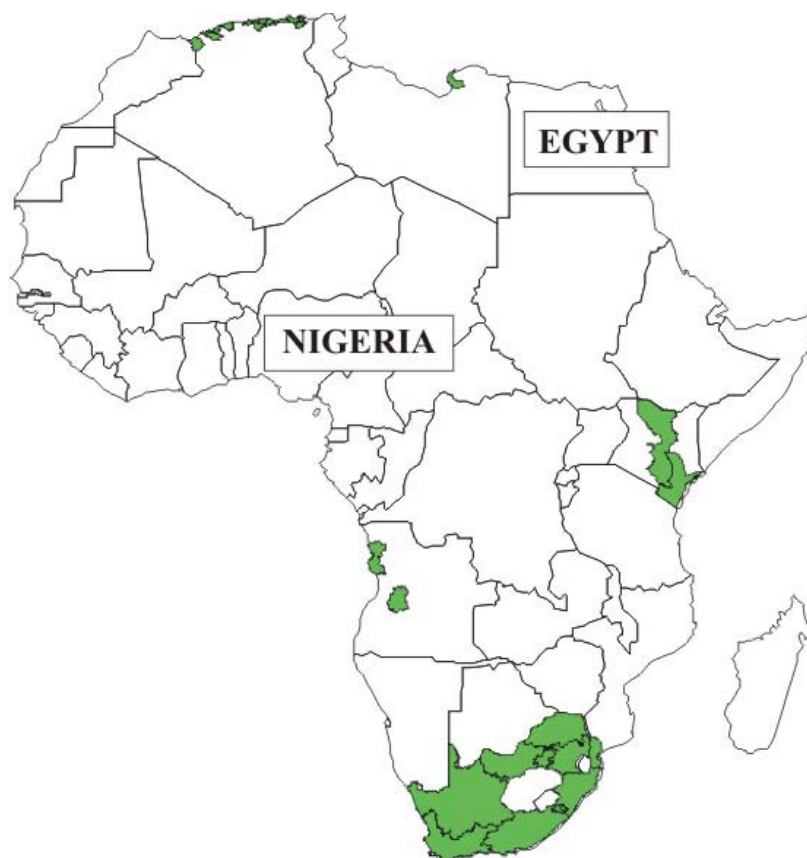


Figure 2.4 — Some of the administrative regions where citrus is produced in Africa. The two countries which produce the most citrus are indicated.

2.9.5 Southern Europe and Asia Minor

This region mostly produces oranges and mandarins, but also a wide range of other citrus. Most of the industries sell fruit in the EU, with the industries in Turkey and Spain largely depending on this market. Italy produces blood orange varieties (Tarocco), which have a good market share in Europe (Regini, 2002). Italy, Spain and Greece also produce large quantities of organic citrus for sale in the EU, with Italy being the largest producer of organic citrus in the world (Liu, 2003).



Figure 2.5 — Some of the administrative regions where citrus is produced in Southern Europe and Asia Minor. The two countries which produce the most citrus are indicated.

2.9.6 Oceania

Most of Australia's citrus production is consumed locally, although some fresh citrus is exported, particularly to the USA and Asia. Citrus is the largest overall horticultural export and significant amounts of research are aimed at overcoming market access barriers (Horticulture Australia, 2002). In New Zealand the industry is small, but it is also of economic importance (Reuther et al., 1967).

Citrus is also produced in many South Pacific Islands, and is an important part of the food crops grown for domestic use (Clarke & Thaman, 1993). However, citrus production suffers from diseases, insect pests, and damage from tropical cyclones and high winds. Consequently, citrus crops are uneconomic and further development will require aid.

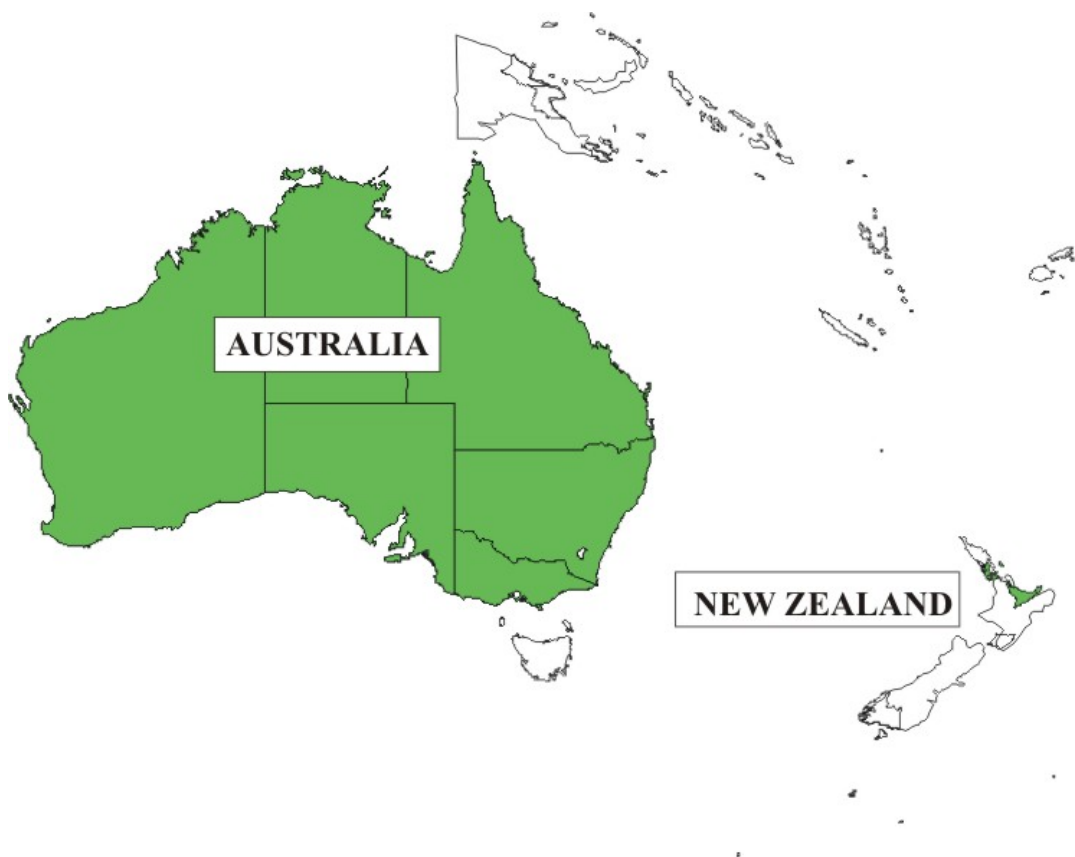


Figure 2.6 — Some of the administrative regions where citrus is produced in Oceania. The two countries which produce the most citrus are indicated.

2.10 Tables of the citrus producing countries of the world

Seven tables are presented here, one for each citrus producing area of the world, and one for the citrus producing states of the USA. Countries are presented in descending order of volume produced in 2002 (FAO, 2002b) with production expressed as metric tonnes. Only countries where detailed information could be obtained are presented in the tables, but after each table is a list of countries that also produces citrus in that region. A list of references for the specific countries is presented in Table 2.8. For most countries, information was obtained from FAO 2002b, but for brevity this reference is not repeatedly included.

Table 2.1 — Citrus producing countries of Asia.

Country (Asia)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
China	12 469 639	Mandarin Orange	Pummelo Kumquat Ornamental citrus	Commercial citrus is grown in 19 provinces. The provinces where most citrus is produced are Sichuan, Guangdong, Zhejiang, Guangxi, Hunan, Fujian, Hebei Chongqing and Jiangxi.	Third largest producer of citrus world-wide. Greatest producer mandarins.	17 36
India	4 580 000	Mandarin Sweet orange Acid lime	Grapefruit Pummelo Lime	Citrus is grown in the states of Maharashtra, Andhra Pradesh, Punjab, Karnataka, Bihar, Tamil Nadu, Madhya Pradesh Gujarat, Uttaranchal, Haryana, Himachal Pradesh, Punjab, Rajasthan, Jammu, Kashmir, Orissa, Uttar Pradesh, West Bengal, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura.	Sixth largest producer of citrus world-wide, but does not play important part in citrus trade. Citrus productivity is low and post-harvest losses occur due to a lack of cold storage and modern processing facilities.	53 75 78
Iran	3 723 000	Orange Mandarin	Acid lime	There are three major citrus regions - the Caspian Sea belt; the southern coastal belt (including the Persian Gulf and the Gulf of Oman) and the southern inland belt. The southern inland belt is scattered through the low valleys of the southern Zagros mountain range and is part of the provinces of Khuzestan, Fars and Kerman (including areas around Dezful and Ahwaz, Kazerun, Jahrom, Darab, Minab, Jiroft, Bam and Shadad).	The seventh biggest producer of citrus in the world in 2002.	21

Country (Asia)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Pakistan	1 995 000	Mandarin (Kinnow, Feutrell) Orange (Bloodred, Musambi)	Grapefruit Lemon Palestine lime	Punjab (including the cities of Islamabad-Rawalpindi, Sargodha, Faisalabad, Lahore, Sahiwal, Multan and Bahawalpur), Peshawar, North-West Frontier Province (NWFP) and the province of Sind (in Hyderabad).		21 23 75
Japan	1 438 000	Mandarin (Satsuma)		The citrus-growing area extends from Tokyo to the island of Kyushu . The principle areas are confined mainly to the south-western coastal prefectures of Shizuoka, Wakayama and Ehime. Other areas include Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Kachoshima, Kochi, Tokushima, Yamaguchi, Hiroshima, Aichi, Mie, Kagawa, Shime, Osaka and Kanagawa.	Fourth largest producer of mandarins in 2002, but these are consumed locally and not exported. Despite large production, great quantities of citrus are imported. Phytosanitary barriers preventing the import of citrus from Argentina to Japan (due to Mediterranean fruit fly) were lifted in April 2003	42 44 45 48 49 53 60 72 78
Thailand	1 114 800	Mandarin	Orange	The two main areas of production in Thailand are the central coastal region and the mid-north inland region. Important areas of cultivation include the Ping river valley, Lamchi valley, Donburi and Haadyai. Citrus is also produced in Chiengmai, Chonburi, Chandhaburi, Pathom, Nakhon, Nan valley, Petchboon, Roiet, Sonkla-Pattoni, Sakon Nakhon .	Trees are harvested three to four times a year, but insect pests severely restrict production	6 78
Indonesia	986 132	Orange	Mandarin		Citrus fruits are a significant part of mixed village gardens (which constitute up to 20% of the agricultural land in Java)	7 72
Syrian Arab Republic	756 150	Orange	Mandarin Lemon	Main citrus growing areas are along the Mediterranean coast.	Citrus cultivation is economically important, but because fruits are consumed locally and not exported, there is price recession.	9 21 72

Country (Asia)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Republic of Korea	643 525	Mandarin (Mikans)		The citrus industry is centred in the Cheju Province (an island of the southern tip of the Korean Peninsula).	Yields are improving and planting areas expanding as governmental support programs boosts the industry. The majority of fruit is consumed locally. Considerable amounts of citrus exports to the USA were refused due to citrus canker in 2002. This phytosanitary barrier remains.	10 66
Israel	510 487	Orange	Grapefruit Lemon Mandarin	Main areas extend along the coastal plain from Kfar Rosh Hanikra in the extreme north-western Gaza to Beer Sheba in the South. Citrus production is concentrated in the central area, within about 20 kilometres from the Mediterranean coast. A belt of citrus stretches inland along the Yesreel valley from Haifa to the Jordan River area below the Sea of Galilee. Newer plantings of mandarins can be found in the Northern Negev and internal valleys.	Water shortage, low profitability, aging orchards and competition from Spain and Morocco contribute to the steady decline of the industry. As an indication of its decline in importance, the Israeli Citrus Marketing Board closed at the end of 2003.	7 15 18 24 40
Lebanon	289 300	Orange (mainly Valencia)	Lemon Lime Grapefruit Sour orange	All areas are located on the coastal plain. Growing areas include Tripoli and Akkar in the north, and Sidon and Tyre in the south.		40 72
Yemen	198 182	Sweet orange	Lemon Sour orange Mandarin Small-fruited acid lime	Major area is the Lawdar-Mudia region, with production concentrated in Tihama. Other areas include: Say'un-Tarim (in Wadi Hadramawt), Mukayras, Zinjibar-Gaar areas and the Jawl-Madrum district (near Al Musaymir, Al Baida), Ta'izz , in the Barakani area, Mauza, Hammam Ali and San'a (Wadi Dahr), Ibb and Warazan (Al Rahida region).	There has been a decrease in citrus acreage in the last decade. This may be due to a decrease in rainfall as most irrigation water comes from wells and the Lawdar-Mudia area is running short of irrigation water.	21
Philippines	179 000	Mandarin	Orange	Mandarins were extensively grown in the Batangas region of Luzon but many orchards there have been destroyed by huanglongbing (Citrus Greening) and production has shifted to Mindanao , Bicol , Ilocos and the Southern Tagalog region in Luzon. Valencia oranges are grown in the Davao region of Southern Mindanao .		6 72

Country (Asia)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Saudi Arabia	140 000	Orange (Navel, Valencia)	Lemon Lime Small amounts of grapefruit	Citrus is primarily produced in the highland oases of the Asir , from Taif to Najran, and in the Fayfa, Abha and Buraidah-Unaizah regions of which the Najran area is the most important area.	Phytophthora gummosis is a major disease of citrus in Saudi Arabia	21 90
Jordan	124 207	Mandarin	Orange Lemon Lime Small amounts of grapefruit	Citrus is primarily cultivated in the Jordan Valley, with mild wet winters and extremely hot dry summers.	Some citrus is exported, but, out of season, importation is necessary to meet local demand	21
Nepal	80 644	Mandarin	Junar orange Kagzi lime Pummelo Sweet lime Citron Bitter orange	The citrus zone in Nepal is between 900 and 1,500m above sea level. Kagzi lime is grown in the Hills and in the Tarai. Areas include: Baglung, Baitadi, Bhojpur, Dailekh, Dadeldhura, Dhankuta, Gulmi, Gorkha, Ilam, Jararkot, Kavre, Kaski, Lamjung, Palpa, Ramechap, Sankhuwasabha, Sindhuli, Sindhupalchok, Syangja, Tanahu and Tehrathum.		67 78
Palestine	74 589	Orange	Lemons Limes Mandarins Grapefruit		Citrus producing areas have been declining during the past 15 years, due to water-scarcity, poor institutional support and the poor quality of fruit produced.	12
Malaysia	30 391	Mandarin Orange	Lime Lemon Pummelo Grapefruit	The Cameron highlands are one of the major citrus growing areas in Malaysia.	Citrus are usually grown in home gardens	57 72
Sri Lanka	26 920	Mandarin Orange	Lime	The largest citrus area centres around Bibile-Moneragla in lower Uva Province. Small citrus areas exist north and west of this in the Lagalla district and the upper Gal Oya Valley. Other plantings may be found on the northern part of the island in the Vavuniya-Omantai district.	Citrus plantings are found throughout the island and are mainly home garden plantings, ranging from a few trees to half an acre.	72

Country (Asia)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
United Arab Emirates	21 255	Lemon Lime			Citrus comprises about 5% of the total fruit production with 80% of production being dates and about 10% being mangoes.	21
Iraq	data not available	Sweet orange (Mahali)	Mandarin Lemon	Citrus is grown mainly in central Iraq, north and south of Baghdad , along the banks of the River Tigris and its tributary, the River Diyala , as well as along the River Euphrates, north and south of Kerbala .	Citrus is mostly grown in the shade of date-palms to protect the citrus trees against high temperatures and solar radiation. This practice also protects against frost in the winter.	21 75
Oman	8385	Small-fruited acid lime	Palestine lime		Limes are an important export commodity and are grown in the northern coastal plain (Al Batinah).	21

Other citrus producing countries in Asia include Vietnam, producing 456,800 metric tons of citrus. Several other countries produce less than 100 000 metric tons a year and these include: Laos, Cambodia, Republic of Azerbaijan, Bangladesh, Georgia, Bhutan. Countries that produce less than 1000 metric tons yearly are Uzbekistan, Tajikistan, Bahrain, Qatar, Brunei Darussalam, Timor-Leste, Kuwait and the West Bank (FAO, 2002b).

Table 2.2 — Citrus producing countries of South America.

Country (South America)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Brazil	20 844 915	Orange	Mandarin Lemon Lime Grapefruit	Oranges are produced in 22 of the 27 states of Brazil. Citrus is predominantly produced in the state São Paulo with 80% of production coming from this state (main citrus growing areas within the state include Campinas, Ribeirão Preto, São Jose do Rio Preto and Sorocaba). A further 15% comes from Bahia, Sergipe, Minas Gerais and Rio Grande do Sul . Other citrus areas include Espirito Santo and Rio de Janeiro in the Southeast; Alagoas, Ceará, Maranhão, Paraíba, Pernambuco and Piauí in the Northeast; Paraná and Santa Catarina in the South; Amazonas, Pará and Rondonia in the North; and Distrito Federal, Goiás, Mato Grosso do Sul and Mato Grosso in the Central West.	The number one orange producer in the world produced almost 20% of the total world citrus production in 2002. It is the greatest exporter of frozen concentrated orange juice, but fresh orange exports are relatively small. Citrus canker, Citrus Black Spot, Greening and Sudden Death of Citrus disease are the greatest threats to the industry. Unofficial estimates in 2002 reports 1 to 3 million plants could be affected by the Sudden Death of Citrus disease.	16 27 29 46 56 64 69 79
Argentina	2 566 000	Lemon	Orange Mandarin Grapefruit	Large orange plantings can be found in Corrientes, Misiones and Entre Rios and lemons are grown in the Tucuman, Salta and Jujuy provinces.	Phytosanitary barriers to trade preventing the import of citrus from Argentina (due to Mediterranean fruit fly) to Japan was lifted in April 2003	25 36 48 72
Peru	727 614	Orange (mainly Valencia) Lemon Lime	Mandarin Grapefruit	Production areas are found along the Northern and central coastal areas and on the East Andean Slope. Orange production is concentrated within 90 miles of Lima , and limes are grown in the northern coastal area of Piura , adjacent to Ecuador. Mandarin, grapefruit and sweet lemon are produced in the areas of Lima, Ica and Piura.	Great amounts of citrus trees were devastated in the 1970s and early 1980s as a result of a then unknown pathogen, now thought to be Tristeza virus.	86
Bolivian Republic of Venezuela	630 883	Orange Mandarin	Lemon Lime Grapefruit	Main production areas are found in the states of Aragua, Carabobo, Falcon, Miranda, Monogas, Sucre, Yaracuy and Zulia .		54 72

Country (South America)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Paraguay	291307	Orange	Grapefruit Mandarin Lemon Lime	The country is divided into two major citrus producing areas. The eastern areas including: Central, Cordillera, Caaguazu, Alto Parana, San Pedro, Concepcion, Amambay , and Itapua and the western areas including: Presidente Hayes (area of Colorado and Teniente Irala Fernandes) and Boqueron .	Paraguay has a small domestic citrus industry and citrus groves are widely scattered throughout the country.	39 72
Chile	254 000	Orange Lemon	Mandarin Grapefruit	Citrus production falls within the provinces of Coquimbo, Valparaiso, the Metropolitan Region, Libertador General Bernardo and Maule . Citrus production areas include: Copiapó, Vallenar, Ovalle, La Ligua, Quilloc, Santiago, Santa Cruz and the valleys of La Serena, Elqui, Azapa, Petorca (near La Ligua), lower Aconcagua (near Quillota), Limarí and Huasco, Cachapoal (near Peumo Santiago) and Tinguiririca (near Nancagua).	Production areas lie within a hundred miles north and south of the capital Santiago. The Peumo-San Vicente Valley is the most important lemon and orange producing area, followed by scattered plantings on the Pacific Coast south and west of Santiago. Limes are grown at Pica near the Peruvian border.	35 63
Uruguay	235 516	Orange Mandarin	Lemon Grapefruit	Salto is the major area and, with exception of plantings in Melo, nearly all citrus is grown near the Uruguay River, including Paysandú, Rivera, Cerro Largo, Maldonado, Montevideo, Canelones, San Jose and Florida .	Mandarins are mainly grown in the north, while oranges are mainly grown in the south.	7 8 19 72

Other citrus producing countries in South America include Colombia, producing 297,962 metric tons, Bolivia, producing 255,355 metric tons, and Ecuador, producing 264,033 metric tons (FAO, 2002b).

Table 2.3 — Citrus producing countries of North and Central America

Country (North and Central America)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
United States of America	14 690 951	Orange (Valencia) Grapefruit	Lemon Mandarin	Almost all citrus fruit is produced in four states- Florida, California, Arizona, and Texas . Florida is the largest producer, with over 70% of total production. Hawaii and Louisiana also produce some citrus (Table 2.7).	Second largest producer of citrus after Brazil. Citrus is mainly processed. Fresh citrus exports are relatively small, but the USA is the largest supplier of grapefruit.	7 43 46 68 72
Mexico	6 260 119	Orange	Lime Grapefruit	Citrus is produced in the states of Colima, Michoacan, Guerrero, Oaxaca, Tamaulipas, Veracruz, San Luis Potosi, Hidalgo, Yucatan, Tabasco, Nuevo Leon, Sonora, Sinaloa Campeche , states in the southern part of Mexico. Each of these states specialises in certain types of citrus with the production of Persian Limes, Mexican Key limes and Oranges being concentrated in different areas. All of Mexico's citrus is grown in the hot and temperate zones.	The area planted with Persian and Key Limes has increased in response to an increase in domestic demand, good prices on the international market, little competition from other countries and few phytosanitary concerns. Mexico is now the world's largest producer of Persian limes. Frosts and drought are the major problems faced by the Mexican citrus industry.	2 20 30 37 76 72
Cuba	480 501	Orange (Valencia)	Grapefruit Persian lime Lemon (Eureka) Mandarin (Dancy)	The biggest citrus growing area in Cuba is Jaguey Grande (in the province of Matanzas). Other citrus areas include Isle of Youth (located southwest of the coast) Guane, Ceiba, Sola, Ciego de Avila, Troncoso, Contramaestre, Arimao, Cap Thomas, Vilorio and Moron.	Citrus is widely grown throughout Cuba and citrus plantings can be found in every province. Persian lime is the most widely cultivated citrus. One of the industry's major concerns is the Tristeza virus.	2 29 41 38 56
Jamaica	221 000	Orange Grapefruit		Citrus production in Jamaica is concentrated in Manchester, Clarendon, Westmoreland, St. Ann, St. James and St. Mary .		2 72
Belize	213 414	Orange (Valencia)	Grapefruit	Historically citrus in Belize were grown mainly in the Stann Creek Valley , but now there are plantings in the Belize, Cayo, Toledo and Orange Walk districts as well.	Fires and hurricane damage threatens the industry. The export of citrus production is the Belize's an important source of income for the country.	8 10 72

Country (North and Central America)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Honduras	195 936	Orange	Grapefruit	Production areas include Bajo Aguan, Valle de Lean, the Sula Valley, Guinope, Valle de Angeles and Signatepeque.	Oranges are grown at low altitudes and are not of a high quality.	2

The Caribbean Community and Common Market (CARICOM) is made up of The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent, The Grenadines, Suriname, and Trinidad and Tobago. In these countries, citrus is sold on the fresh fruit market predominantly for domestic consumption. Belize, Jamaica, and Trinidad and Tobago account for almost 90% of the regional citrus production. In these three countries, the citrus industry makes a significant contribution to economic development and rural livelihoods and contributes to foreign exchange earnings. Moreover, the industry represents an important source of income for thousands of small-scale rural agricultural producers. Oranges are the main citrus produced (approximately 65% of total production), followed by grapefruit (comprising 26% of production) (Donovan, 2002).

Other citrus producing countries are Costa Rica, producing 394,920 metric tons, and Guatemala, producing 252,877 metric tons. Countries producing less than 100,000 tonnes a year include Nicaragua, El Salvador, Haiti, Panama, Puerto Rico and the Bahamas. Countries that produce less than 1000 metric tonnes include: Guadeloupe, French Guiana and Martinique.

Table 2.4 — Citrus producing countries of Africa

Country (Africa)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Nigeria	3 250 000			Citrus is mainly produced in western Nigeria. Two major processing plants are established in Ibadan (Oyo state) and Abeokuta (Ogun state)	Nigeria is the biggest producer of citrus in Africa, although citrus is mainly for domestic consumption.	61
Egypt	2 527 276	Orange	Lemon Sweet and sour lime Mandarin Small amounts of grapefruit	Most commercial production is within the Nile River delta provinces of Kalioubiya, Charkieh, Menoufieh, Gharbieh and Behera. Major citrus production, however, is concentrated in Lower Egypt. More recently planted orchards can be found in the newly reclaimed lands.	Egypt has recently seen large increases in production. The climate is well-suited for orange production, and this accounts for over half total production.	1 7 72
South Africa	1 712 149	Orange (mainly Valencia)	Grapefruit Lemon	Main areas are in Limpopo Province (in the areas surrounding Tzaneen, Letsitele, Letaba), Mpumalanga (areas surrounding Crocodile River Valley, Hectorspruit, Groblersdal, Marble Hall and Nelspruit), North Western Province (areas surrounding Rustenburg), Kwazulu-Natal (areas around Muden), Western Cape Province (areas surrounding Citrusdal, Somerset West, Grabouw) and the Eastern Cape Province (areas surrounding Uitenhage, the Kat River and the Sundays River Valley). Smaller areas of citrus cultivation can be found in the Vaalharts and Warrenton areas and other parts of the Northern Cape .	Lemons are predominantly produced in the Eastern and Western Cape Provinces.	47 51 52 61 72 81 82 83
Morocco	1 152 200	Orange	Mandarin Small amounts of grapefruit	The coastal areas of the Mediterranean Sea and Atlantic Ocean. The Souss Valley is one of the main production regions and about half of all citrus and half of all mandarins in Morocco are produced in this area. Other regions include the interior district of Tadla (at Beni-Mellal) the northern inland citrus areas of Meknes, Fes, the small coastal areas of Rabat and Casablanca, the greater inland areas of Marrakech and Gharb, and the northern coastal Oriental area.	Moroccan citrus orchards are old and more than 55% of the trees are older than 30 years. Citrus production areas are localized due to climate, topography, and water availability. Morocco has the capacity to increase its citrus output and the mandarin industry continues to grow.	7 21 28 87

Country (Africa)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Algeria	520 019	Orange	Mandarin Small amounts of lemon, grapefruit and other mixed varieties	Citrus is produced along the coastal area at altitudes below 400m, where frosts are rare. Orchards are concentrated in five main areas namely Blida (in the Valley of Mitidja), Mascara , Chlef , Mostaganem and Annaba . Smaller plantings are found in the areas of Skikda , Algiers , Tlemcen , Bejaia , Tizi Ouzou , Oran , Jijel , Guelma and Bouira .	Generally, production per tree is low because of age, availability of irrigation water and cultural practices. Recently the government initiated a programme to reinvigorate the industry. About 130 000 nursery trees were introduced in order to meet future domestic demand and to develop the export market.	21 40 72
Tunisia	312 000	Orange	Grapefruit Mandarin Lemon Lime	The Cape Bon peninsula near Soliman, Menzel Bou Zelfa, Grombalia and Beni Khaled. Other citrus areas are on the southern side of Cape Bon near Hammamet, Nabeul and Ben Kriar as well as adjacent to the city Tunis.		72 78
Guinea- Conakry	210 000	Orange		Oranges are mainly grown in the area of the Foutah Djallon mountains.		71
The Sudan	148 460	Lemon Lime Grapefruit	Orange Mandarin		The first report on citrus trees in the Sudan dates back to 1896.	21
Zimbabwe	122 680	Orange	Lemon Lime Mandarin Grapefruit	The Mazoe Valley, Umtali, Sinoia and Beit Bridge. Major new plantings can be found in the Shama Valley district.	Citrus Black Spot is one of the more serious diseases affecting the citrus industry in Zimbabwe.	61
Angola	78 000	Orange Mandarin		Citrus is produced in the provinces of Bengo , Kuito , Huambo and Sumbre	The industry is not significant.	61
Swaziland	73 500	Grapefruit Orange		The Theumani, Tambuti, Ngonini and Big Bend areas.	Plantings are mainly concentrated in large estates.	61 72
Libyan Arab Jamahiriya	67500	Orange Lemon Lime	Mandarin	Citrus production is concentrated mainly around coastal areas extending from Surma to Gharabulli and into the interior (40 km south to Azizia). Some orchards are also planted in the Benghazi area and around Fueihat (15 km south of Benghazi).	All citrus produced is consumed locally, imports and exports of citrus are negligible.	21

Country (Africa)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Other types			
Côte d'Ivoire	61 250	Orange Lemon Lime	Small amounts of grapefruit		One of the primary producers of citrus oils including lemon, lime, bitter orange oils and Bergamot.	11 61
Kenya	40 390	Orange Grapefruit	Small amounts of lemon and mandarin	Production areas are confined to the Eastern and Coastal parts.	The industry is not significant.	61
Senegal	31 000	Orange	Lime	Lime trees are established in Casamance.		71
Mozambique	30 500	Grapefruit Orange	Lemon Lime Small amounts of mandarin	Production areas are found in Maputu and Beira.	Citrus production is affected by Citrus Black Spot.	61
Somalia	data not available	Grapefruit Small fruited acid lime		Citrus is mainly produced in the Mogadishu region.		21

Citrus is also produced in the Democratic Republic of the Congo (92,816 metric tons produced in 2002).

Countries that produced less than 100 000 metric tonnes include: Madagascar, Sierra Leone, Tanzania, Ethiopia, Central African Republic, Togo, Benin, Republic of Congo, Guinea-Bissau, Liberia, Réunion, Malawi, Djibouti, Burkina Faso, Gabon and countries producing less than 1000 metric tons are: Botswana, Mauritius, Cameroon, Seychelles (FAO, 2002b) and Uganda (citrus production data not available) (Oberholzer, 1969).

Table 2.5 — Citrus producing countries of Southern Europe and Asia Minor.

Country (S. Europe, Asia Minor)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Spain	5 778 396	Orange (Navel, Valencia) Mandarin	Lemon Grapefruit	Citrus is grown in three autonomous communities, Valencia , Murcia and Andalucia . The majority of plantings (more than 80%) are situated in the east coast region of Levante, in the provinces of Valencia, Castellón de la Plana, Alicante and Tarragona. Minor plantings can be found in the southern coastal Andalusian provinces of Sevilla, Málaga, Almería, Córdoba, Huelva, Cadiz and Granada. Newer plantings can be found in the provinces of Sevilla and Huelva. Oranges are mainly grown in Valencia and Castellón de la Plana, lemons in Alicante and Murcia, and sour oranges in Sevilla.	Spain is the sixth largest producer of lemons. The industry is reliant on export and plays an important role in the Spanish economy. Spain is the largest exporter of fresh citrus fruits, with about 65% going to other countries of the EU. About 40% of new citrus plantings are mandarin. Based on the past ten years' growth, the industry will most likely continue to expand.	3 34 40 53 62 65 87 88 89
Italy	2 789 185	Orange Lemon Mandarin	Small quantities of bergamot, grapefruit and citron	Seventy percent of all citrus grown in Italy is grown in Sicily , with the greatest density of citrus plantings on the East Coast. Other citrus growing areas are Calabria , Basilicata , Campania , Lazio and Puglia .	Blood orange varieties such as Tarocco have a good market share in Europe, but the majority of production is for local consumption. The industry suffers structural problems such as old varieties, lack of water, and fragmentation (the average size of farms in Sicily is less than one hectare).	5 40 70
Turkey	2 493 000	Orange Red grapefruit Mandarin (Satsuma)	Lemon	Areas are fragmented and widely separated, but mainly coastal. Over 90% of production comes from the Mediterranean Sea Coast, especially Antalya and Izmir . Almost all oranges are produced in the provinces of Icel , Hatay , Adana and Antalya . Lemon production is centred on the Icel and Antalya provinces. The rest of production occurs along the Aegean and Black Sea Coasts.		7 21

Country (S. Europe, Asia Minor)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Greece	1446 795	Orange (Navel, some Valencia)	Lemon Mandarin	Citrus plantings are scattered throughout Greece. Main areas are the Arta-Préveza district of Ipiros ; Vólos district of Thessalia , Mesolóngion district of Central Greece , Corinth, Amalias, Pírgos, Pátrai, Návpليون, Sparta and Kalámai districts of the Peloponnesus and the Khanía district of Crete as well as Argolis, Messinia and Achaia.	Fresh fruits are exported. Competition from other Mediterranean citrus producing countries is a major concern. Lemon production is declining due to older trees being uprooted and replaced by apricot trees or grapes.	40 72 74
Portugal	351152	Orange	Mandarin Small amounts of lemon and grapefruit	Major citrus production areas are in the districts of Ribatejo, Braga , Oeste, Sotavento, Algarve, Baixo-Douro, Outra-Banda, Coimbra , Beja-Vidigaeira , Barlavento Algarvio and Alto Douro.		40 72
France	30492	Mandarin Grapefruit	Small amounts of orange and lemon	Most citrus plantings are located on Corsica . Other plantings of lemon and orange trees can be found in the Alpes-Maritimes province centred around Nice.		40 72
Cyprus	15100	Sweet orange	Mandarin Grapefruit Lemon	Plantations are concentrated in the warm littoral regions of the island including the areas of Nicosia , Famagusta , Limassol and Paphos .	The export industry is economically important and a major employer. Most orchards are small plantations.	21 72

Table 2.6 — Citrus producing countries of Oceania

Country (Oceania)	2002 production (tonnes)	Types cultivated		Citrus cultivation areas (areas in bold are indicated on the map)	Notes	Refs
		Major types	Minor types			
Australia	575 000	Orange (Valencia, Navel)	Mandarin Lemon Grapefruit (mainly white-fleshed Marsh) Lime	About 80% of total citrus production is irrigated areas in the south-east around the Murrumbidgee and Murray Rivers, with about 90% of orchards in the Riverina, Sunraysia and Riverland irrigation areas of New South Wales (NSW), Victoria and South Australia . These areas include Renmark, Loxton, Berri and Waikerie, with small plantings in Mypolonga and Lyrup. Most of the remaining 20% is from Queensland , including Central Burnett (Mundubbera / Gayndah), Central Highlands (Emerald), Wide Bay / Burnett Coastal, Sunshine Coast, Mareeba and Charters Towers. Queensland produces about 70% of the total mandarins. Limes are produced on small mixed farms in the coastal areas of Queensland. Other citrus areas are the south west of Western Australia , the central coastal region and northwestern parts of NSW and the Northern Territory .	Although the Australian citrus industry is relatively small by world standards, it is an economically important horticultural crop. However, recently, about one million Valencia trees were removed due to low market prices. Citrus is grown in all states except Tasmania. New trees (15 000) were planted fairly recently in Katherine (Northern Territory). The availability of water remains a constraint. Citrus Black Spot is one of the major citrus pathogens in Australia.	7 13 26 31 33 34 80
New Zealand	31 211	Mandarin Sweet orange	Lemon Grapefruit	There are four main citrus growing areas on the north island, namely Kerikeri (Bay of Islands), Auckland , Bay of Plenty and Gisborne.	Climatically, New Zealand is at the southern limit for citrus production. Only frost-free eastern areas of the north island are suitable for commercial production. The citrus industry is not large, but is economically important.	72 77

Most Pacific Islands produce relatively small quantities of citrus, the largest producer being Tonga (3,500 metric tonnes) (FAO, 2002b).

Table 2.7 — Citrus producing states of the United States of America

State	Types cultivated		Citrus cultivation areas	Notes	Refs
	Major types	Minor types			
Florida	Orange (Valencia) Grapefruit Mandarin Lime	Lemon	The Lake, Polk, Orange and Highlands and the coastal Indian River section of Brevard, St. Lucie, Martin, Palm Beach and Indian River counties. Almost every county in the state has some small citrus groves. Dade is the major lime-producing county.	Produces 40% of the world's grapefruit and More than 80% of the total mandarins and lemons produced in the USA	22 46 72
California	Orange (Navel)	Lemon Grapefruit Mandarin Other citrus	Commercial areas are limited and include coastal valley and desert sections with different climatic conditions. The coastal sections extend from the Mexican border to Santa Barbara, and inland for forty kilometres. The coastal valley splits into three distinct districts, Santa Ana River Valley, San Joaquin Valley, and Sacramento Valley. These areas include San Diego and Riverside, which is a major grapefruit production area. In coastal areas, citrus is grown in gardens as far north as Butte and Tehama counties.	Oranges are mainly produced for the fresh fruit market.	7 46 55 59 84 85
Arizona	Grapefruit	Lemon Orange Mandarin	The lower Colorado River Valley, desert plateaus around Yuma, the Wellton-Mohawk area and the Salt River Valley centring around Phoenix. In the Phoenix area there is considerable orange production.	Citrus produced are mainly for the fresh citrus market.	46 55 72
Texas	Grapefruit	Mandarin Orange	Citrus are grown in the three southern-most counties of Texas-Cameron, Willacy and Hidalgo and in the Lower Rio Grande Valley.		32 46 58 73
Louisiana	Orange(Navel) Mandarin (Satsuma)		On the edge of the Gulf of Mexico citrus is grown in a part of the Louisiana Delta known as Plaquemines Parrish.	All fruits are sold on the fresh market.	55
Hawaii	Mandarin Orange	Mexican lime Pummelo Grapefruit	The industry is confined to the most southern island.		72

Table 2.8 — List of references used in the tables of citrus production.

Ref.	Citation	Countries used for
1	Abdi & Ibrahim, 2003	Egypt
2	Albrigo & Menini, 1984	Honduras, Jamaica, Cuba, Mexico
3	Anonymous, 1988	Spain
4	Anonymous, 1990	Democratic Republic of Korea
5	Anonymous, 1992	Italy
6	Anonymous, 1996	Philippines, Thailand
7	Anonymous, 1997	Australia, Egypt, Indonesia, Israel, Morocco, Turkey, USA California
8	Anonymous, 1999a	Belize
9	Anonymous, 1999b	Syria
10	Anonymous, 2000a	Belize
11	Anonymous, 2000b	Côte d'Ivoire
12	Anonymous, 2000c	The Palestine
13	Anonymous, 2001	Australia
14	Anonymous, 2004	Angola
15	Barak, 2003	Israel
16	Barros, 2003	Brazil
17	Bean et al., 2003	P. R. China
18	Bedford, 1971	Israel
19	Betancur et al., 1984	Uruguay
20	Bocardo et al., 2001	Mexico
21	Bové, 1995	Algeria, Cyprus, Iran, Iraq, Jordan, Libya, Morocco, Oman, Pakistan, Saudi Arabia, The Sudan, Somalia, Syria, Turkey, United Arab Emirates, Yemen
22	Brown & Brown, 2001	USA Florida
23	Catara et al., 1988	Pakistan
24	Chalutz & Roessler, 1986	Israel
25	Contreras de Alcain & Marmelicz, 1984	Argentina
26	Darby, 2003	Australia
27	Donadio et al., 1996	Brazil
28	Et-Otmani et al., 1990	Morocco
29	Fairchild & Gunter, 1986	Brazil, Cuba
30	Flores, 2003	Mexico
31	Forsyth & Cope, 1986	Australia
32	French, 1984	USA Texas
33	Gallasch et al., 1984	Australia
34	Gallasch et al., 1998	Australia, Spain
35	Gallasch et al., 2000	Chile
36	Garran, 1996	Argentina

Ref.	Citation	Countries used for
37	Garza-López & Medina-Urrutia, 1984	Mexico
38	González et al., 2000	Cuba
39	González et al., 1997	Argentina, Paraguay
40	González-Sicilia, 1969	Algeria, France, Greece, Israel, Italy, Lebanon, Portugal, Spain
41	Hardy, 1991	Cuba
42	Hardy, 1997	Japan
43	Hearn, 1986	U.S.A
44	Iwagaki, 1991	Japan
45	Iwamasa, 1988	Japan
46	Jacobs, 1994	Brazil, USA Arizona, California, Florida
47	Kelly, 1995	South Africa
48	Kenzo, 2003	Japan, Argentina
49	Kitagawa & Kawada, 1986	Japan
50	Korf, 1998	Japan
51	Mabiletsa, 2003a	South Africa
52	Mabiletsa, 2003b	South Africa
53	Mahajan, 2002	India, Japan, Spain
54	Mendt, 1988	Bolivia
55	Melnick, 2001	USA Arizona, California, Louisiana, Texas
56	Muraro & Spreen, 1996	Brazil, Cuba
57	Murthi & Speldewinde, 1991	Malaysia
58	Neff, 1999	USA Texas
59	Newcomb, 1977	USA California
60	Nishiura, 1977	Japan
61	Oberholzer, 1969	Angola, Côte d'Ivoire, Kenya, Moçambique, Nigeria, South Africa, Swaziland, Zimbabwe
62	Oritz et al., 1988	Spain
63	Ortúzar et al., 1996	Chile
64	Passos et al., 1999	Brazil
65	Pazos, 2003	Spain
66	Phillips & Seung, 2003	D. R. Korea
67	Pokhrel, 1997	Nepal
68	Powell & Huang, 1977	USA
69	Prates et al., 1984	Brazil
70	Regini, 2002	Italy
71	Rey, 1997	Guinea-Conakry, Senegal
72	Reuther et al., 1967	Algeria, Argentina, Belize, Bolivia, Cyprus, Egypt, France, Greece, Jamaica, Japan, Indonesia, Lebanon, Malaysia, Mexico, New Zealand, Paraguay, Philippines, Portugal, Sri Lanka, South Africa, Swaziland, Syria, Tunisia, Uruguay, USA Arizona, Florida, Hawaii
73	Sauls, 1998	USA Texas

Ref.	Citation	Countries used for
74	Sekliziotis, 2003	Greece
75	Singh, 1969	India, Iraq, Pakistan
76	Spreen et al., 1996	Mexico
77	Spurling, 1969	New Zealand
78	Srivastava & Singh, 2002	India, Japan, Nepal, Thailand, Tunisia
79	Timmer, 2005	Brazil
80	Tugwell & Gallasch, 1998	Australia
81	Urquhart, 1999	South Africa
82	Veldman & Barry, 1996	South Africa
83	von Broembsen, 1986	South Africa
84	Warner, 1997	USA California
85	Warner, 1998	USA California
86	Wahl, 2000	Peru
87	Witney & Chao, 2000	Morocco, Spain
88	Zaragoza & Agustí, 2001	Spain
89	Zaragoza & Hensz, 1986	Spain
90	Zekri & Al-Jaleel, 2000	Saudi Arabia
91	Zhaoling, 1986	P. R. China

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