INTEGRATED PRODUCTION GUIDELINES FOR EXPORT CITRUS VOL. I

CHAPTER 6: ROOTSTOCK CHOICE

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ACKNOWLEDGEMENT

The authors wish to express their thanks and sincere appreciation to the following colleagues and associates for the contributions they made in providing information and reviewing several draft manuscripts that preceded this edition of "Rootstock Choice"

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1 INTRODUCTION

A cultivated citrus tree usually consists of two joined components, the rootstock and the scion. During the planning stages of any new orchard development careful consideration must be given to the choice of rootstock. This consideration is important as the rootstock has a major bearing on tree performance and fruit characteristics. In fact, rootstocks influence every facet of tree and fruit development and can sometimes literally mean the difference between success and failure of an orchard operation. Rootstock choice should therefore be aimed at capitalising on any favourable soil or environmental factor and/or off-setting the effects of any limiting factor.

Readers should recognise that there is still much to be learnt about rootstocks. Nevertheless, the information provided herein was developed from experimental data, commercial experience locally and abroad, and is the result of observations by many individuals over many years. This current chapter on Rootstock Choice was updated from the 2007 edition. Since not all rootstocks have been or can be tested under all possible conditions, a degree of risk in rootstock choice will probably always exist. Grower experience will add to the information base on a rootstock. This Rootstock Choice guideline attempts to lead the reader through a process of familiarisation with the various rootstock options. This process will hopefully narrow the final choice to only a few options, thereby minimising the risks involved.

The commercially-used rootstocks will be discussed in some detail. Rootstock research is ongoing and a number of promising new rootstocks have become available and their characteristics will be described. A good way to find out whether these new rootstocks will be useful in a specific situation is to gain personal experience with them. Producers are therefore encouraged to plant some of the new rootstocks on a small scale within a citrus orchard where a commercially-proven rootstock is used.

2 WHY USE A ROOTSTOCK?

Citrus rootstocks are raised from seed. The seeds of most plants are the product of sexual (zygotic) union, with characteristics differentially inherited from both male (pollen) and female (egg) parents. This means that each seedling has a unique genetic component and no two rootstocks from these unique, sexually produced seedlings would behave identically in a given situation. This unpredictability in behaviour is undesirable where uniformity is so important.

Fortunately certain citrus species have an unusual genetic characteristic. While most plants produce seeds with a single sexual or zygotic embryo (monoembryonic), many citrus cultivars produce polyembryonic seeds (each seed can have multiple embryos, of which only one is the sexual or zygotic embryo). The other embryos are called nucellar embryos because they arise spontaneously from nucellar tissue in the seed. Since these nucellar embryos do not arise from sexual union, they are asexual and exclusively maternal in origin, i.e. their genetic make-up is identical to that of the mother plant. Citrus can thus be propagated true-to-type from seed; a highly advantageous situation for citrus nurserymen. In the case of rootstocks which are not highly nucellar, or even seedless as a result of triploids (cross between diploid and tetraploid), clonal rootstocks can be vegetatively propagated by means of cuttings.

Even with highly nucellar rootstocks, propagators need to visually “rogue” (cull) the seedbeds to eliminate the more variable seedlings, usually the zygotics.

To select a rootstock effectively, one must understand the purpose of roots, and therefore, of rootstocks. Roots serve multiple functions: they anchor the tree in the ground; they absorb and transport water and nutrients to the aboveground parts of the tree; they serve as synthesis or conversion sites for growth regulators; and finally, the roots also store food reserves.

To be useful, a rootstock must meet certain requirements: it must be compatible with a chosen scion cultivar, adaptable to soil and climatic environment, impart productivity in the scion and preferably have a high level of nucellar embryony. In addition, rootstocks vary in their ability to impart disease and pest resistance, cold tolerance and tree vigour. They influence the date of fruit maturity, internal and external fruit quality, yield, fruit size and the physiological characteristics of the fruit such as colour, rind characteristics (creasing, splitting and rind thickness) and sometimes even post-harvest quality.

The degree to which a specific rootstock meets these requirements and enhances any factor that influences economic return, will determine its value for a given situation. More knowledge of a rootstock's characteristics should result in the correct rootstock choice for a particular situation.

3 BACKGROUND TO ROOTSTOCK USAGE IN SOUTHERN AFRICA

Until the inception of the Citrus Improvement Scheme (CIS) in 1973, practically all commercial citrus orchards in South Africa were established on rough lemon rootstock. Since 1976, however, when the first consignment of trees certified under the CIS were planted, a relatively large number of trees on rootstocks other than rough lemon have been planted. This is illustrated by the data in Table 1, which shows the proportion of different rootstocks used for certified trees from 1976 to 2007.

The main points arising from this table are:

1. Data for the past two decades show that there has been a substantial reduction in the use of rough lemon.

2. The use of Volckameriana has decreased completely due no doubt to its poor quality inducing characteristics for oranges and its susceptibility to CTV.

3. Carrizo citrange has become the most popular rootstock over the past 10 years and has almost completely replaced Troyer citrange. The use of citrange rootstock selections now exceeds all other rootstocks.

4. The decline in the use of trifoliate orange stocks has continued and no trifoliate selections have been used for the past decade.

5. The use of Swingle citrumelo increased significantly during the 1990s, but has remained relatively constant since.

6. Over the past 10 years X639 (Cleopatra x trifoliate orange hybrid) has been used at a low, but consistent rate, no doubt due to the fact that it performs well in saline soils and soils with high pH levels.

7. Empress mandarin and Cleopatra mandarin are no longer used commercially.

8. New rootstocks emerging on the commercial scene over the past two decades include C35 citrange and Minneola x trifoliate hybrid (MxT).

4 CHOOSING THE RIGHT ROOTSTOCK

The choice of rootstock is one of the most important decisions once it has been decided to establish an orchard. This is so since, if the correct choice has been made, it will form the basis of a productive orchard for many years. Even if market demand for the chosen scion cultivar decreases, the existence of a healthy, sound root system will enable the grower to topwork such an orchard to a different scion, enabling a quicker return to economic production. In order to choose the right rootstock for a given situation, the aspects discussed below should be considered.

4.1 Building on experience

Even with all the scientific knowledge available, it would also be necessary to integrate past experience in a given situation into making the choice of rootstock. This can be based on personal experience, that of neighbouring growers and also extension specialists.

The guidelines provided in Tables 2 to 4 provide a comprehensive list of rootstock characteristics as a basis for choosing the stock best suited to a specific situation.

The reader will also need to answer the following questions before deciding on a specific rootstock:

- Is yield more important than fruit quality? High yields may negatively influence fruit size, quality and rind disorders such as

creasing.
- Will excessive tree vigour negatively influence internal and external fruit quality? What tree size and vigour are required in a given situation?

4.2 Cultivar selection

Scion selection is primarily an economic decision involving the selection of specific cultivars in anticipation of market demand. Rootstock selection serves two purposes:

- To minimise the effects of site limitations such as soil type, irrigation water quality and disease presence, to ensure economic viability.
- To enhance yield, fruit size and fruit quality.

Refer also to the chapters on citrus cultivars elsewhere in Volume I for guidelines on cultivar options.

4.3 Rootstock/Scion (in)compatibilities

During propagation, two genetically differing plants are usually combined to form the citrus tree. The relationship between scion and stock, which is commonly called affinity or compatibility, is of fundamental commercial importance.

When the union between scion and stock takes place readily and the tree continues to grow and develop without difficulty with a relatively smooth bud union, it is said to be a compatible union. However, not all citrus species are compatible with each other or with species of other genera. The degree of compatibility is related in some measure to the closeness of the genetic relationship between each component.

Experience has demonstrated that the commonly grown orange, grapefruit and mandarin cultivars are compatible with most commercially-used citrus rootstocks. These trees are generally long-lived, productive and have smooth bud unions.

The physiological implications of bud union deformities are unknown. In terms of tree life or productivity, a less than smooth bud union may not be important. Usually, rootstock overgrowth occurs with rootstocks of trifoliate orange parentage. In certain instances this may reduce tree lifespan because of compression girdling after 20 to 30 years, e.g. nucellar navels on trifoliate orange, Satsuma mandarin on Troyer citrange, Tomango midseason on rough lemon, the latter being to a lesser degree. In most instances, however, rootstock overgrowth does not seem to have a serious effect. Experience with Swingle citrumelo in South Africa also indicates a rootstock overgrowth with most scions. To date, compression girdling has not been a problem in South Africa. However, in Israel and Florida, Mandarins and Mandarin Hybrids on Swingle have been declining due to girdling problems for some time and Swingle has been discontinued as a rootstock for these cultivars. A recent decision was taken by the California Citrus Nurserymen's Society also to discontinue the use of Swingle for Mandarin types. South African growers should not be overly concerned, however, as the overgrowth and girdling are related to tree vigour and stem diameter. The more vigorous the tree and the greater the stem diameter, the sooner the girdling occurs. The higher density plantings as well as those under controlled drip irrigation and fertilisation (fertigation) now being established in South Africa, lead to better tree size control and therefore result in less vigorous trees with lesser stem diameters for many years.

Scion overgrowth can sometimes also occur. To date, no commercial combinations have been seen to decline due to this situation which usually occurs on mandarin-type rootstocks. The authors have also observed a scion overgrowth of Midknight on Volckameriana, Cleopatra, Empress and rough lemon and Miho Wase on Cleopatra without apparent problems of commercial significance.

Some incompatibilities are disease (usually virus) induced. This should not be confused with genetic incompatibility and will be discussed in the next section.

A more complete list of compatible/incompatible combinations is provided in Table 2.

4.4 Disease, virus and nematode tolerance

Rootstocks should be eliminated on the basis of their susceptibility to diseases or pests present in the scion or soil. Table 4 lists rootstock susceptibility to various fungal and viral pathogens and nematodes.

In southern Africa, the CIS has, through the nurseries, greatly reduced the possibility of scion viral infections such as severe *Citrus tristeza virus* (CTV) strains (all budwood in the scheme is pre-immunized with a mild CTV strain because of the omnipresence of CTV in the field), *Citrus psorosis virus* (CPsV) and the citrus viroid (CVd) complex [exocortis (CEVd), cachexia (CCaVd), dwarfing viroid (CVd-IIIb)]. CTV tolerance is essential for rootstocks used in southern Africa because of the abundance of aphids which transmit CTV. Therefore, sour orange and its hybrids as well as *Citrus macrophylla* cannot be used (except for certain lemon scions). CVd and CPsV are unlikely to have major problems as they are not insect transmissible, however, disease-free budwood should be used. Rootstocks, such as trifoliate orange and most of its hybrids (Troyer and Carrizo citrange and certain citrumelos) as well as Rangpur lime, are susceptible to CVd. If infected, these rootstocks will be less vigorous but probably still healthy, except for trees on *Poncirus trifoliata* which are extremely sensitive to CVd. The existence of CVd variants, which induce tree dwarfing without other negative effects, has formed the basis of tree size control research in several countries, including South Africa. (Refer to the chapter “Tree Size Control for High Density Plantings” elsewhere in Volume I.)

Observations brought to the attention of the authors indicate that trifoliate orange and its hybrids, *viz*. Troyer & Carrizo citrange, increase the susceptibility of scions to greening disease infection. It is not known why this should be the case, but it may be related to the induction of slightly different times or intensities of flushing.

Proper pre-plant assessment and preparation of the soil as well as good management practices will reduce the likelihood of harm from soil-borne pests and diseases such as *Phytophthora* and nematodes. Table 4 provides a complete list of rootstock ratings against these pathogens.

Special care should be given to rootstock selection in citrus production areas where Citrus Blight (CB), a root-graft transmissible disorder of unknown cause, occurs. Observations in rootstock trials and commercial plantings have indicated large differences in rootstock susceptibility to this malady. However, final susceptibility rankings of rootstocks are far from complete. Swingle citrumelo, X639 and Sun Chu Cha rootstocks appear to exhibit the most tolerance and growers should consider these rootstocks in CB areas. Empress mandarin, Carrizo citrange, C35 citrange and Benton citrange rootstocks appear to be the most sensitive and should be avoided in these areas.

4.5 Site selection

Rootstock selection also serves to minimise/reduce site (“Terroir”) limitations, *viz*. climate, soil type, availability and quality of irrigation water and disease presence.

4.5.1 Climate

The citrus production areas in southern Africa have been grouped into climatic regions based on the actual performance of the various cultivar selections and not on precise agro-meteorological data. Climate has a marked influence on all aspects of tree growth and fruit quality characteristics. This is discussed in detail in the sections “Current Status of Citrus Cultivars” and “Climatic Requirements for Citrus” elsewhere in Volume I. Rootstocks can be used to off-set some of these climatic limitations.

4.5.2 Soil – physical and chemical characteristics

The physical and chemical characteristics of the soil should be considered during the rootstock selection process. Physically, soils are loosely classified as sandy, sandy loam, clay loam or clay. In practice, the clay fraction of a soil can range from almost zero (e.g. most Citrusdal soils) to 50% and higher. Soils with clay levels in excess of 30 to 50% are considered marginal for citrus production, although excellent production has been achieved on soils with 50% clay. However, good management, especially irrigation management, is of paramount importance in such situations.

It is generally accepted that rough lemon and some of the other vigorous rootstocks do best on sandy soils. Trifoliate orange and its hybrids are quite well adapted to heavier soils. It must be stated again, however, that management factors can override rootstock adaptation in any given soil environment. The use of pulse drip fertigation, where the pH, EC and nutritional status of the root zone are controlled carefully with every irrigation, can have a major effect on the adaptability of most rootstocks to a wide range of soil environments.

Soils in southern Africa vary greatly in pH. Where the soil pH is alkaline due to the presence of carbonates in the soil (e.g. some soils in the Lower Letaba area), citrus production can be compromised. As the soil pH rises above 7.0, decreases in nutrient availability adversely affect trees on most rootstocks. Rootstocks which have generally performed fairly well under high pH conditions include rough lemon, Cleopatra mandarin, X639 and Rangpur (the latter not tested in South Africa). There are also some non-commercial rootstocks that merit small scale trials in southern Africa because of their tolerance to alkaline conditions, e.g. Sunki Benecke (refer to Table 7, also sections in 4.6).

Trifoliate orange, Swingle citrumelo, Carrizo and Troyer citranges and certain other trifoliate orange hybrids are the worst affected rootstocks under high pH conditions (refer to Table 4). They suffer severe lime-induced iron chlorosis as pH values approach 8.0. Growers also frequently observe incipient manganese and zinc deficiencies among trees on these rootstocks at pH values above 7.5.

Salinity levels may sometimes be a limiting factor. Citrus is generally classified as a salt sensitive plant, as relatively low levels of salinity can reduce tree performance. Refer to the sections on citrus fertilisation and irrigation in Volume II of these guidelines for more information.

Salt tolerance in a citrus tree is determined mainly by the rootstock, although the behaviour can be modified by the choice of scion. This tolerance is related to several salt effects, including the rootstock's ability to prevent the accumulation of Na^+, Cl^- and other ions in leaf tissue. Cleopatra mandarin and Rangpur have been consistently ranked as relatively NaCl tolerant. Rough lemon is semi-tolerant, while Swingle citrumelo, Carrizo and Troyer citranges are NaCl sensitive. The trifoliate oranges are very sensitive (refer to Table 4).

4.5.3 Cold tolerance

The degree of cold tolerance acquired by a tree is influenced by environmental conditions, mainly cool temperatures. During the winter months citrus trees do not normally flush and they appear to be relatively inactive. A positive correlation exists between the amount of cool weather, the degree of dormancy and cold tolerance.

Cold tolerance is also influenced by the choice of scion and rootstock. Most rootstocks can be placed into one of three general groups according to their cold tolerance ability. Trees on rough lemon, Rangpur and Volckameriana are the least cold tolerant (physiologically most active) but because of their vigour they can recover rapidly if not severely damaged. Sweet orange and Carrizo/Troyer citranges induce intermediate cold tolerance while trees on sour orange, Cleopatra mandarin, Swingle citrumelo and trifoliate orange are the most cold tolerant.

The relative performance of any rootstock in relation to cold tolerance is highly dependent on environmental conditioning. A good example is trifoliate orange which, as a seedling, is very cold hardy. Trees budded on this stock only show their superior cold hardiness in cool climates. In the warmer subtropical areas, trees on trifoliate orange are frequently less cold tolerant early in the winter than trees on other rootstocks.

In southern Africa, frost damage is relatively common in only two production areas, *viz*. the Eastern Cape Midlands (Kat River area) and Vaalharts. A relatively new, largely untested rootstock under local conditions, but with supposedly good cold tolerance, is Benton citrange. Growers in these areas should try this rootstock experimentally.

It is important to bear in mind that the cold tolerance of the rootstock does not impart cold tolerance to the fruit.

4.5.4 Drought tolerance

Drought tolerance has decreased in importance in rootstock selection under southern African conditions because of the universal use of irrigation systems which may mask rootstock differences. During heat wave conditions or where irrigation systems cannot supply the evaporative demand, especially during the critical fruit set period, rootstock tolerance to drought can mean the difference between a good or mediocre crop.

The commonly-used rootstocks are not equally tolerant to drought. Differences between rootstocks may be attributed to variations in number and distribution of fibrous roots, the horizontal and vertical extent of root system development as well as in efficiency of water uptake. Water uptake is not always directly proportional to root volume. There is a positive correlation between drought tolerance and vigour of the rootstock. Rangpur and rough lemon seem to be superior in terms of drought tolerance. In a recent observation (C. Smit and J. P. Wahl, pers. comm.) at Citrusdal, Rangpur out-performed all other commercial rootstocks where irrigation water was withheld. Refer to Table 4 for more information on rootstock adaptation to drought conditions.

4.5.5 Tolerance to flooding

A thorough understanding of rootstock tolerance to flooding is lacking. Fortunately, this is not of major concern under southern African conditions. Abroad, limited observations of seedlings under controlled conditions, and of commercial trees, indicate that rough lemon, Volckameriana and Swingle citrumelo are the most tolerant to flooding. Cleopatra and Carrizo/Troyer exhibit the least tolerance, while Sour orange and trifoliate orange are intermediate. It should be noted that tolerance to flooding and root disease tolerance are not necessarily correlated.

Sites without adequate drainage should not be considered for planting citrus. Trees on all rootstocks are eventually damaged under flooded conditions. Thus, when planting on poorly drained sites, proper land preparation (refer to the “Soil Preparation” section elsewhere in Volume I), including the laying of drainage pipes, should precede planting.

4.6 Horticultural characteristics of rootstocks

4.6.1 Categorising rootstocks in terms of vigour

In the absence of reliable methods to limit tree size (refer to the section in this volume on “Tree Size Control for High Density Plantings”) the rootstocks are categorised into one of three groups on the basis of growth vigour that they impart on the scions:

Group 1: Vigorous rootstocks: rough lemon, Volckameriana, Rangpur and Cleopatra mandarin (with respect to eventual tree growth vigour, Cleopatra belongs to this group, but in terms of fruit characteristics it is more similar to the group 2 rootstocks).

Group 2: Intermediate rootstocks: Carrizo and Troyer citranges, Swingle citrumelo and X639.

Group 3: Non-vigorous rootstocks: Trifoliate orange selections, e.g. Australian and Rubidoux trifoliate.

Group 1 rootstocks

By virtue of their vigorous growth, these rootstocks impart the following characteristics on the scion.

Tree growth is fast and vigorous with strong growth flushes, resulting in a large tree with a good bearing capacity. The tree’s dormancy period is shorter than in the case of trees on non-vigorous stocks, resulting in the induction of greater frost susceptibility over a longer period of the year. Root growth is rapid and deep and fibrous roots are well developed, resulting in a more drought tolerant tree, which is able to transplant easily between growth flushes.

Roots are susceptible to soil pathogens such as *Phytophthora* and to the citrus nematode.

The group 1 rootstocks are fairly tolerant of saline and high pH soils and do well in sandy soils.

Consequences of growth vigour include:

- External fruit characteristics; inclined to have coarse rinds (excepting Cleopatra mandarin), high shouldered and slower to develop colour. Rinds are thicker and less creasing-prone. Fruit size is usually good, particularly while the trees are still young.

- Internal fruit quality; fruit has low Brix and acidity levels, which count heavily against the use of these stocks for cultivars with inherently low Brix or acid levels (e.g. Satsumas in all areas and navels in warm areas). However, in cold production areas this is usually not a problem. Internal rag levels are usually higher in fruit from trees on these rootstocks.

Group 2 rootstocks

In respect of the tree and fruit characteristics listed above, the rootstocks in this group fall somewhere between those of the group 1 and group 3 rootstocks.

Group 3 rootstocks

In respect of tree growth and external and internal fruit characteristics, the slow growth rate imparted to the scion causes the opposite reaction to that described above for group 1 rootstocks. In particular, trees on trifoliate rootstocks grow slower and as a result are comparatively frost tolerant. They are also highly tolerant to *Phytophthora*, but transplant poorly and are not drought resistant. Fruit from trees on trifoliate have thin and smooth rinds and are of excellent internal quality. However, the fruit can be more creasing and splitting-prone and sometimes smaller in size than fruit produced on vigorous rootstocks.

Trifoliate rootstocks are highly sensitive to saline or alkaline soils, but perform better in replant situations and on heavy or wet soils.

4.6.2 Descriptions of individual rootstocks

The reader is referred to Tables 3 and 4 for a summary of rootstock characteristics. Table 5 provides some information on the performance of certain rootstocks in the nursery.

a) Rough lemon (*C. jambhiri* Lush)

Rough lemon is presumed to be indigenous to north-east India, where it still grows wild. Four distinct rough lemon types are recognised in India. As the best known of all rootstocks in South Africa and widely used in other citrus-producing countries of the world, there is an abundance of general information available on the performance of this rootstock.

A wide range of selections are used in southern Africa. The selection which the CIS has focused on is the Cairn. However, it should be noted that research carried out during the 1980s and 1990s has shown that various selections perform differently in different areas. It is not possible in practice to produce and maintain commercial levels of seed supplies of all the rough lemon selections. For practical reasons therefore, a selection with good overall performance was selected, i.e. Cairn.

Trees on rough lemon rank at or near the top in terms of growth vigour and tree size in comparison with trees on other rootstocks, provided that soils are disease free. Yields produced are amongst the highest for any rootstock and fruit size is generally large. However, the peel is relatively thick and juice quantity and quality is among the poorest. Fruit from trees on rough lemon do not hang as well as on certain other rootstocks, the flesh tending to dry out and become granulated. Rough lemon induces tree sensitivity to cold. However, young trees damaged by cold recover more rapidly than trees on less vigorous rootstocks which were severely damaged.

Trees on rough lemon are tolerant to CTV and CVd. They are susceptible to citrus nematodes and are severely affected by *Phytophthora* root rot/gummosis but are not as susceptible as sweet orange. High susceptibility to blight is one of the major weaknesses and will undoubtedly affect the extent of future usage in South Africa. Rough lemon can be used on a wide range of soils, but it is particularly well adapted to deep, coarse sands on which many other rootstocks do not perform well. It is not sufficiently tolerant to root rot and should not to be used on wet, poorly-drained soils, even though it is more tolerant of flooding than most rootstocks. It tolerates calcareous soils with pHs above 7.5 but is sensitive to very saline soil conditions. It is regarded as a poor replant stock, but with the currently available chemicals can possibly perform adequately in a replant situation where irrigation is carefully controlled.

In general, rough lemon is not a good rootstock for mandarins as fruit tend to dry out (granulate) early, reducing the already naturally short picking season of most mandarin cultivars. Also, the alternate bearing tendency of mandarin cultivars may be enhanced by the use of rough lemon. However, rough lemon is an excellent rootstock for round oranges, particularly when they are grown for processing, as high yields lead to a good per hectare production of kg soluble solids, unsurpassed by trees on most other rootstocks. Also, some cultivars such as the Valencia have an inherently high juice quality and propagating them on rough lemon does not greatly reduce their quality. These cultivars usually yield best on rough lemon, though Brix will be lower. However, for a quality sensitive selection, such as the Delta Seedless, which has to comply with higher internal export standards, rough lemon is not recommended. Rough lemon is usually a poor choice for navel oranges because of the large, coarse, low quality fruit produced. Grapefruit quality is markedly reduced on rough lemon, therefore rootstocks producing higher quality, such as Carrizo/Troyer citrange and Swingle citrumelo, are commonly used (where soils permit).

b) Volckameriana (*C. volckameriana*)

This rootstock resembles rough lemon in many respects, such as general tree growth habit, tree vigour as well as foliar and other anatomical features. In southern Africa its performance as a rootstock for lemons has been excellent. Relatively young plantings (less than 10 years old) of grapefruit, Valencia and navel on Volckameriana are generally performing well, but its use in combination with these cultivars is no longer recommended due to sensitivity to Tristeza. Its effect on scion growth and fruit quality is very similar to that of rough lemon.

Trees on Volckameriana appear to be less affected by cold than those on rough lemon. It is slightly less susceptible to *Phytophthora* root rot compared with rough lemon and is adapted to a fairly wide range of soil conditions. It is not susceptible to CVd, but is damaged by citrus nematodes and sensitive to CTV. Trees on this rootstock have been affected by CB and appear to be as susceptible as those on rough lemon.

In areas where extensive use has been made of Volckameriana it is not seen as an improvement on rough lemon. The opposite is rather true in some cases.

c) Cleopatra mandarin (*C. reticulata* Blanco)

Like sour orange and rough lemon, the performance of Cleopatra mandarin as a rootstock has been observed over many years. The growth of trees on Cleopatra is good, producing a standard to very large-sized tree.
Cleopatra is considered a “lazy” rootstock, i.e. trees on Cleopatra grow well but fruit relatively poorly until they are approximately eight to ten years of age or older. Similar reports of yield problems with Cleopatra have been received from many citrus areas outside southern Africa. Fruit is of high quality, equal to that on the citranges, but tends to be on the small side, especially in the case of Valencias. It has been used with success for navels (where smaller fruit size is not a disadvantage). Performance of grapefruit on Cleopatra is also, by all accounts, excellent.

Cleopatra induces good cold tolerance in the scion and trees on this rootstock are unaffected by CTV and CVd. It is also fairly tolerant to *Phytophthora* root rot/gummosis. It is susceptible to citrus nematode. Blight may affect trees on Cleopatra, but this rootstock ranks with sour and sweet oranges as one of the most tolerant. The general tolerance of this rootstock, combined with the observation that trees only become

affected by blight at a relatively advanced age, suggests that Cleopatra should be considered for interplanting in blight-affected orchards.
Cleopatra mandarin has a relatively deep root system, is quite well adapted to dry conditions and is thus somewhat drought tolerant. Cleopatra has the highest salinity tolerance of all the commercial rootstocks through having the ability to exclude sodium and chloride from being taken up by the root system. This rootstock does well on deep, loamy, well-drained soils but is adversely affected by soils with high water tables.

In trials conducted in Florida to compare various rootstocks for blight tolerance Cleopatra mandarin only began to show decline symptoms after about 12 years.

In southern Africa experience with mandarins on Cleopatra is very limited, but many years of experience in Florida has shown it to be an excellent rootstock for all mandarin cultivars that are sufficiently large-fruited to tolerate the reduction in fruit size associated with Cleopatra. Preliminary indications are that Cleopatra is also a suitable stock for Owari Satsuma, especially in the Sundays River Valley area. Some scion overgrowth of Miho wase, Kuno and Imamura Satsumas on Cleopatra has been reported in six-year-old plantings in a cold production area, *viz*. the Eastern Cape.

Cleopatra mandarin has had limited use as a rootstock. However, considering the importance of Tristeza, blight and salinity tolerance, Cleopatra is one of the best rootstock choices among current commercial rootstocks for many cultivars. Its attributes may outweigh the yield and fruit size disadvantages and thus enhance the future value of this rootstock.

d) Trifoliate orange (*Poncirus trifoliata* Raf.)

Trifoliate orange is a rootstock of world-wide significance that has been used commercially for many years on a limited basis. It is now widely used in Japan, China, Uruguay, Argentina, to some extent in Florida and California and in the colder areas of Australia. Many selections of *Poncirus trifoliata* have been made and named. They have been classified on the basis of differences in flower size and growth habit. Large-flowered types (e.g. Pomeroy) grow upright with little branching, while the small-flowered types (e.g. Rubidoux, Australian) are less vigorous and have a bushy growth pattern. Research has shown that trees on the large-flowered types are usually slightly more vigorous and bear less fruit per unit of canopy volume than those on the small-flowered selections. The most commonly used trifoliate selections in the RSA are Rubidoux and Australian trifoliate.

Trees on trifoliate orange bear well for their size, although on sandy soils, the yield per tree will be less than for trees on rootstocks better adapted to such soils. Fruit quality is excellent, generally with high soluble solids and acid content and a smooth, thin peel. Fruit size may be smaller than for other rootstocks. Fruit can hang well on the tree.

Trifoliate orange is very valuable in breeding programmes as a source of resistance to the citrus nematode, some species of *Phytophthora*, and to CTV, but this rootstock is notably susceptible to CVd. Trees on this rootstock may be very stunted when infected with CVd. Most selections of trifoliate orange are tolerant and/or resistant to the citrus nematode. In Florida, CB has become a serious concern affecting the continued or expanded use of trifoliate orange. The incidence of this disorder has been relatively high, but is not as severe as on rough lemon. There is evidence that trees on trifoliate impart a greater sensitivity to greening disease in the scion than rough lemon or the mandarin rootstocks.

Trifoliate orange grows well on fertile, clay to loamy type soils. It does not develop a very deep or wide ranging root system. It is poorly adapted to saline or calcareous conditions, but its excellent tolerance to gummosis/root rot (best of all rootstocks) makes it useful for wet conditions.

Trifoliate orange is generally a satisfactory rootstock for most sweet orange cultivars, especially those in the navel group. In California an incompatibility problem of certain navel selections has led to severe tree decline after 15 to 20 years. This problem has not been experienced to the same extent in the RSA, probably due to higher budding heights used. In California, experience has shown that Rubidoux trifoliate and Rich 16-6, another trifoliate selection, are more compatible with navel scions. Valencias on trifoliate do very well, especially in the hot, lowveld areas where fruit size is not such a limiting factor. However, the fruit tend to have thin rinds and are prone to splitting. In the cooler areas, Valencias and navels on *P. trifoliata* also tend to be more prone to creasing than on most other rootstocks. Grapefruit cultivars on *P. trifoliata* perform quite satisfactorily. Fruit size of red grapefruit may be compromised. Commercial experience in Florida has indicated that some risk is involved when using trifoliate orange as a rootstock for some mandarin and mandarin hybrid scions. These combinations occasionally decline from a bud union incompatibility.

In South Africa, trifoliate orange rootstocks are recommended for heavy or replant soils and for use with low quality cultivars such as Satsumas (with high budding, i.e. 20 to 30 cm, to delay or overcome possible incompatibilities). Trifoliate rootstocks are useful in situations where land is scarce and high tree densities are required to give early financial returns.

e) Troyer and Carrizo citranges (*C. sinensis x P. trifoliata*)

Hybrids of Sweet orange and trifoliate orange are known as citranges. Carrizo and Troyer are hybrids of Washington navel orange and *P. trifoliata.* These two citranges are visually indistinguishable and are of considerable interest throughout the world as rootstocks because of their tolerance to Tristeza virus and root rot. Carrizo has been a leading rootstock in Florida while Troyer was widely used in California until C35 citrange became popular. The main difference between Troyer and Carrizo is that the latter is also burrowing nematode resistant, a nematode not present in southern Africa.

In the past, Troyer was widely used in the RSA, but the popularity of Carrizo has increased at the expense of Troyer (Table 1). As with Troyer, Carrizo has performed well in replant orchards in the Sundays River Valley, where its performance has been far better than rough lemon.

An advantage of Troyer and Carrizo is the excellent performance of young trees on these rootstocks. They are vigorous and produce excellent crops of high quality fruit in their early years. Fruit size is usually medium to large and internal fruit quality is excellent. Their major disadvantage is the tendency to induce a high incidence of creasing. This is a serious problem in the Sundays River Valley and some other areas. Troyer also induces higher acid levels than rough lemon, but while this has occasionally created problems with Valencias, Minneola tangelos and grapefruit in the cooler production areas, it can be advantageous in the warm/hot areas. Colour development of fruit on trees budded to Troyer and Carrizo is usually 8 to 10 days ahead of that on rough lemon.

Troyer and Carrizo inherited their susceptibility to CVd from the trifoliate orange parentage. Severe CVd variants will cause infected trees on these rootstocks to decline and be unproductive. Milder variants are less injurious and are being studied as possible dwarfing agents. CCaVd and CTV are not harmful to trees on these rootstocks. Troyer and Carrizo have been ranked as tolerant to *Phytophthora* gummosis/root rot in screening tests. Commercially, growers experience only occasional problems. Trees on Troyer and Carrizo appear somewhat susceptible to *Fusarium* dry rot decline, which is prevalent in certain Eastern Cape orchards. These rootstocks are tolerant to citrus nematodes. There is some evidence that the citranges may impart a higher degree of greening susceptibility to the scions than rough lemon and the mandarin rootstocks.

CB affects trees on Troyer and Carrizo. Since the 1960s Carrizo has gradually replaced rough lemon in Florida because of severe losses from blight occurring in plantings on the latter rootstock. Trees on Carrizo were heavily planted and some of these orchards are now also experiencing considerable tree loss from CB. The incidence of CB, nevertheless, is highly variable.

Troyer and Carrizo are sensitive to alkaline-induced chlorosis and in some cases trees have severely declined as a result of iron and other trace element deficiencies on saline, calcareous and especially high pH soils. Troyer and Carrizo have a less developed feeder root system than rough lemon. They are therefore not as tolerant to low soil moisture levels compared with rough lemon. Irrigation regimes which are suitable for good tree performance where rough lemon is the rootstock may prove inadequate for trees on Troyer and Carrizo. This may be one of the reasons why, in certain cases, these rootstocks perform less satisfactorily.

Troyer and Carrizo are excellent rootstocks for sweet orange and grapefruit cultivars and most mandarin hybrids. However, there has occasionally been some tree decline accompanied by a bud union crease with certain mandarin cultivars on Troyer, e.g. Owari Satsuma as seen in California after 15 to 20 years. This phenomenon has not been a problem in the RSA most probably due to higher budding practices.

f) Swingle citrumelo (*C. paradisi x P. trifoliata*)

Hybrids of grapefruit and trifoliate orange are known as citrumelos. There are many named and unnamed citrumelos (Table 6) but Swingle has been the most widely and thoroughly tested. It is a hybrid of Duncan grapefruit and trifoliate orange produced in 1907 in Eustis, Florida. Swingle attracted little attention until the 1940s when it began to be tested in Florida, Texas and California under its code name CPB 4475.

From experience gained in South Africa, Swingle became popular during the 1990s, but its popularity has decreased since then for no apparent reason. It has proved to be a superior grapefruit and Minneola tangelo rootstock, although problems with high fruit acidity levels do occur in the cooler areas. This also happens with Troyer and Carrizo for similar scions. No obvious disadvantages have been encountered in combination with Valencia and navel scions. Limited information is available on this rootstock in combination with mandarins, although young Ellendale tangors and Clementines on Swingle have performed very well to date. Swingle exhibits incompatibility with Eureka lemons, as well as with Tomango and Shamouti midseason cultivars and Murcotts.

Observations made in the Gamtoos River Valley region of the Eastern Cape have shown that Midknight on Swingle tends to bear smaller fruit after 10 to 12 years. In addition, fruit rinds are also coarser than even trees on rough lemon. Trials at Letaba Estates, however, have not shown these trends up to 12 years and Midknights on Swingle are in good condition in a replant situation.

There has been a marked overgrowth of mandarin type scions by Swingle rootstock in Israel causing compression girdling and tree decline; this has resulted in a loss in popularity of Swingle for these cultivars. Observations in Florida and California have also noted this phenomenon, but to a lesser degree. Swingle is presently the most popular rootstock for mandarin types in Florida, while growers in California are still investigating this issue. To date Swingle has not displayed this problem in South Africa. It appears to be linked to tree vigour and stem diameter so the slower growing, higher density plantings under tree size management are less likely to develop the marked overgrowth necessary to create compression girdling. As with Troyer and Carrizo citrange, budding height may also play a role in the severity of this problem.

The growth of trees on Swingle in their first five years, regardless of scion, is similar to that of trees on Troyer. Grapefruit cultivars grow vigorously on Swingle and produce large trees. Sweet orange trees, particularly Valencias, are similar to trees on Troyer citrange in size.

Trees on Swingle citrumelo produce high yields of large-sized fruit with an internal quality equal to Troyer/Carrizo citrange. Swingle overgrows most orange cultivars (benching) and indications are that it is just as prone to cause creasing in scion fruit as Troyer citrange.

The Swingle tree itself is very cold tolerant. Limited observations in Florida with field trees less than ten years old indicate that trees on Swingle would rank as similar to trees on sour orange and Cleopatra mandarin, but superior to those on Carrizo citrange or rough lemon in this respect.

Although blight has affected trees on Swingle in the few older commercial plantings, the incidence has been low.

When screened for *Phytophthora parasitica* resistance in Florida, Swingle exhibited better resistance than Carrizo and was classified as resistant. Swingle also exhibited tolerance to the citrus nematode and CTV as well as CVd. In Florida, certain old line budwood sources have resulted in severe stunting with a diagnostic crease at the bud union of trees on Swingle. An unknown virus, possibly citrange stunt, may be the cause. In the USA, CEVd usually causes no obvious symptoms. For example grapefruit trees on Swingle in Texas are essentially unaffected by CEVd. However, orange trees in Florida with CEVd and CCaVd are somewhat dwarfed. Swingle is sensitive to Armillaria, a fungus disease which occurs in isolated cases and affects the rootstock just beneath the soil surface.

Swingle citrumelo is a suitable rootstock for most soils except heavy clay or highly calcareous conditions. Soils with a clay content greater than 25 to 30% may restrict root growth. Trees on Swingle are more salt tolerant than other trifoliate hybrids, but are more sensitive to calcareous conditions and subject to lime-induced chlorosis. Despite these characteristics, it is reported that trees on Swingle are doing well in the Sundays River Valley area. Also, the addition of Fe-chelates to the soil can overcome the chlorosis, as has been seen in Florida. pH adjustment to between 5.8 and 6.2 through regular fertigation applications, overcame Fe chlorosis in California on heavy, calcareous soils.

Trees on Swingle are moderately drought tolerant and greenhouse tests with small potted plants in Florida have indicated good tolerance to flooding, but this has not been confirmed under field conditions.

Swingle citrumelo has been widely exploited in South Africa.

The main advantages of Swingle citrumelo are as follows: It is *Phytophthora* root rot/gummosis resistant, drought tolerant, nematode resistant, cold tolerant and Tristeza tolerant.

g) X639 hybrid (*P. trifoliata* x *C. reticulata,* cv. Cleopatra mandarin)

This rootstock cultivar arose from a cross between Cleopatra mandarin and *P. trifoliata* made at the CSFRI by Dr Hojby in the early 1950s. It has subsequently been tested in several small plantings conducted by individual growers mainly in the Sundays River Valley, where its subsequent exploitation has been limited. Results obtained from these plantings and a commercial grapefruit orchard at Tambankulu in Swaziland, have indicated that X639 is capable of inducing good internal fruit quality and of producing fair yields of good sized fruit. High levels of creasing of fruit on this rootstock are reported. Its overall characteristics appear similar to Troyer citrange, but may be slightly more sensitive to *Phytophthora* root rot.

In tests conducted in Australia on seedlings derived from South African X639 seed, it was found comparable to Swingle citrumelo, but slightly less susceptible in terms of saline/calcareous conditions.

In trials conducted in Florida, X639 behaved similarly to Cleopatra mandarin with regard to CB tolerance, i.e. trees were susceptible, but took about 12 years to show decline. It is tolerant to CTV but highly susceptible to CVd.

It is a rootstock with promise, seemingly well-suited to grapefruit, with no apparent problems in combination with Valencias, navels and mandarins, and deserves to be used to a greater extent in commercial plantings, particularly on loamy soils and where fruit with a high internal quality is required. It is doing well in the higher pH soils of the Lower Orange River area. Eureka lemons on X639 are doing very well in the Eastern Cape.

h) Sour orange (syn. Bitter Seville, *C. aurantium L.*)

This rootstock, being the closest to the ideal rootstock in most citricultural respects, cannot be used due to its susceptibility to CTV and the endemic nature of this disease in southern Africa.

Sour orange was once the most important rootstock in almost every citrus growing region of the world and it still ranks as one of the world's great and most widely used rootstocks. Its popularity has been due to adequate yields, superb fruit quality and tolerance to root rot, cold and blight. Few, if any, trees of sweet orange, grapefruit or mandarin have survived on sour orange in regions such as South America, Central America, the Caribbean, Florida and South Africa where extremely virulent and damaging forms of CTV exist. It is these highly virulent forms of the virus and aphid vector populations that have doomed sour orange as a rootstock. In scions that are a poor host to CTV, e.g. lemons, it can be used commercially without any problems.

i) Sweet orange [*C. sinensis* (L.) Osbeck]

The use of sweet orange as rootstock was popular in the RSA at one stage. There are still some existing orchards on this rootstock. The trees on this rootstock are vigorous and productive. Sweet orange induces good fruit size as well as excellent internal quality and exhibits tolerance to CTV and CVd. Trees on this rootstock appear to be largely unaffected by CB. The factor which largely precludes this rootstock from extensive commercial utilization is its high susceptibility to *Phytophthora* gummosis/root rot. However, the availability of effective fungicides makes the use of the stock possible, but probably not economically viable.

j) Macrophylla or **Alemow** (*C. macrophylla*)

Macrophylla or Alemow has never been used in the RSA as a rootstock. It has been extensively used as a lemon rootstock in California and, in recent years, has become extremely popular in Spain where water with high salinity levels is used for irrigation. Lemon trees on this rootstock are extremely precocious. Trees grow vigorously for a few years, with growth thereafter being considerably less vigorous due to heavy fruit loads.

Fruit size is large, but the fruit on young trees generally have a low juice and Brix content and tend to dry out early. In rootstock trials trees on Macrophylla have consistently produced fruit with the lowest juice quality. The insensitivity of lemons as a scion to CTV makes this a rootstock option for lemons under RSA conditions.

Trees on Macrophylla are very susceptible to cold damage in addition to CTV (not with lemon as scion), CCaVd and CB. It is resistant to root rot and is salt and boron tolerant. Magnesium deficiency has been a persistent problem on calcareous soils. Delayed sieve tube necrosis may reduce tree lifespan.

k) Rangpur; Rangpur lime (*C. reticulata var. austera*)

The Rangpur fruit is an acid mandarin type, often called Rangpur lime. Rangpur is similar in many respects to rough lemon. It induces high vigour, large trees, minimal cold tolerance, high yields, large fruit size and soluble solids similar to that produced on rough lemon. Trees have no tolerance to citrus nematodes. Like rough lemon, it is highly tolerant to CTV but unlike rough lemon, it is sensitive to CVd. It is very susceptible to *Phytophthora* damage but is one of the best rootstocks for salt tolerance.

Rangpur was extensively used in Brazil's huge citrus industry in the past where its susceptibility to root rot was not a limiting factor. Furthermore, trees on Rangpur in Brazil produce better quality fruit than those on rough lemon. Rangpur can be grouped with rough lemon regarding CB susceptibility, i.e. very susceptible, which is one of the factors that have led to its decline in use in Brazil.

There may be an interest in Rangpur in the RSA despite it not being superior to rough lemon in many respects. The salt tolerance of this stock may result in more plantings, while it has been observed, under conditions of restricted irrigation, that Rangpur showed the best drought tolerance when compared to rootstocks such as rough lemon and the citranges. It has been suggested that, in areas where heat waves can be expected in the early summer fruit set period (e.g. Citrusdal), this rootstock may be better able to cope with such adverse conditions of short term high evaporative demand, allowing the tree to hold on to the fruit better than the other rootstocks.

l) Other rootstocks

The following rootstocks hold promise for the future, either as potential dwarfing rootstocks or those which have a good tolerance to adverse soil, disease or climatic conditions.

- **Flying Dragon trifoliate**

Flying Dragon was introduced to the United States in 1915 by Swingle. In 1972 it was included in the University of California CTV tolerance trials at the South Coast Field Station, near Los Angeles. At five years the trees were just over one metre high and slightly under one metre wide. At nine years of age their height ranged from 1.5 to 2 metres and they averaged 1.5 metres in width. There has been no apparent effect from inoculation with CTV.

Available information indicates that Flying Dragon reacts similarly to other strains of trifoliate orange in respect of its tolerance to certain soil pathogens, i.e. highly tolerant of *Phytophthora* and citrus nematode, and its ability to induce high fruit quality in the scion. Trial plantings on this rootstock were established in South Africa in the late 1980s, but to date commercial use of this rootstock has not become a reality. This rootstock limits tree size quite substantially. High initial planting densities will have to be considered, i.e. in excess of 1 000 trees/ha and more. As with the normal trifoliate orange, Flying Dragon does not seem to be well suited to sandy soils; it also does not do well in high pH and saline soils. In a recently established trial at Lindcove Field Station in California, various scions on Flying Dragon were tested for compatibility. No serious problems have been encountered thus far with any scion except, of course, Eureka lemon.

- **Yuma citrange (also known as Sacaton citrumelo)**

In a trial block on an estate in the Eastern Cape, this rootstock has had a remarkably uniform and very pronounced dwarfing effect in combination with Valencias and navels. Per-tree yields have been excellent, with good fruit size and quality. This dwarfing effect has subsequently been noticed in another rootstock trial block in Swaziland in combination with Valencias and Tambors (Ortanique). However, with grapefruit as scion the trees equal Troyer in size, yield and all other respects. This dwarfing effect is not evident on Yuma in the USA, regardless of scion. Indications are, however, that in combination with Superplant Scheme scion material, i.e. mild CTV pre-immunized material, the dwarfing effect is less obvious. When using budwood of the "Amanzi" budwood source, the dwarfing effect is more obvious.

Preliminary research data, obtained during the early 1990s with Palmer navel and Delta Valencia scions, indicated that, when using Amanzi material as a budwood source or Amanzi bark for inoculation purposes, tree volumes are between 30 and 50% of the corresponding virus-free controls and 30 to 60% of the Nartia CTV mild strain inoculated trees. This seems to indicate that CTV is not the reason for the dwarfing effect, unless a very severe strain is present in the Amanzi source. If not, however, it is difficult to explain why some unidentified CVd would differentially affect grapefruit scions compared to other scions.

Limited experience in the RSA with this rootstock makes assumptions risky. However, it seems safe to assume that in respect of disease and nematode susceptibility, fruit quality induction, adaptation to soil types, etc. the Yuma citrange closely resembles Troyer/Carrizo citrange. It certainly is an excellent standard rootstock for grapefruit.

This promising rootstock should be tested under a wide variety of conditions. It has potential to become a rootstock of importance. Using the Amanzi dwarfing strain for non-grapefruit cultivars at planting densities of 600 to 1 000 trees/ha (expected canopy volumes of 15 to 25 cubic metres compared to 40 to 60 cubic metres on Troyer/rough lemon), should be considered. Yuma, however, produces a high percentage of zygotic seedlings and selection in the nursery must be very strict.

- **Minneola x trifoliate hybrid [(*C. paradisi* x *C. reticulata)* x *P. trifoliata*]**

Minneola x Trifoliate (MXT) is a very vigorous stock in the nursery but, once budded, induces some size controlling effect in the scion. In two trials, one in the Eastern Cape and one in Limpopo Province, in combination with Palmer navel scion, tree volumes were about 55% of trees budded to rough lemon/Troyer citrange. Excellent per tree yields and tree productivity (expressed as yield/unit tree size) were obtained, significantly higher than that obtained for the standard rootstocks. In combination with

Clementines, in the Eastern Cape, quality and production have been similar to Swingle and Carrizo, whilst tree size has been slightly smaller. Several scion cultivars budded to rootstocks of this hybrid have performed outstandingly in a planting at Malelane. No incompatibility with Eureka lemon appears to exist, but severe incompatibility with Kumquat is evident.

The adaptation of this rootstock to various soil types is not well known. Early indications are that it does not adapt well to soils with a high pH. MxT is sensitive to CVd, but tolerant to CTV. Trials done to date indicate good tolerance to *Phytophthora* and nematodes, which makes it suitable for use on replant soils. Based on the promising results obtained so far, this hybrid should be seriously considered when choosing a rootstock, for limited acreages initially to gain further information for larger commercial ventures in future.

- **Terra Bella citrumelo**

Terra Bella citrumelo originated from the same source as Yuma citrange which was from a rootstock sucker on a tree discovered in Yuma, Arizona. This material was found by Dr. John Carpenter of the USDA Date and Citrus station located at Indio, California when he was sourcing seed for inclusion in his rootstock trials. Seed from the same source was supplied to a Frank Mc Master in California where he established this new rootstock for evaluation purposes. At John Carpenter's insistence the name Yuma citrange was not used and Dr. Henry Schneider of UCR as well as other local experts were of the opinion that the new rootstock was a citrumelo and not a citrange.

The name Terra Bella citrumelo was given to the new rootstock and it has been extensively planted by Frank Mc Master using navels, Valencias, Minneolas, lemons, Satsumas, Pummelos and Star Ruby Grapefruit as scion material. Most mandarins have done well on this rootstock as well.

In South Africa, plantings are limited to date, but early indications are that it is slightly dwarfing under local conditions. Trees in the Malelane area are healthy and only slightly less dwarfing than C35, which reduces tree size by 25 to 30% in mature trees (10 years plus).

This rootstock shows promise and should be included on a small scale in new plantings.

- **Benton Citrange**

This rootstock was bred in NSW, Australia in an attempt to produce rootstocks compatible with Eureka lemon. A hybrid of Ruby Blood orange and trifoliate, Benton performed well in trials and has been used for commercial Eureka plantings in Australia since 1990 where it proved to be both CTV and *Phytophthora* tolerant. It was, however, found to be sensitive to salinity and calcareous soils.

In South Africa under replant conditions it performed best in a range of 10 rootstocks including commercial and experimental rootstock selections. Trees on Benton are more compact than trees on rough lemon, Swingle and Carrizo resulting in more manageable trees, closer spacing and superior production per hectare. In the Letaba trial both Deltas and Midknights on Benton tested negative for *Phytophthora.*

Further trials are being established with Benton as one of the rootstocks in order to expand the knowledge over a wider range of scion cultivars. This rootstock shows promise and should be included on a small scale in new plantings.

- **Rangpur x Troyer citrange hybrid**

This hybrid has undergone evaluation in Florida since 1968. It induces a slight dwarfing of the orange scion, but is precocious and stimulates good yields of large fruit. It is extremely sensitive to CEVd. It is tolerant to CTV, moderately tolerant to *Phytophthora* and nematodes, but susceptible to blight.

In eight year old trials (Eastern Cape, Palmer navel as scion) the trees on this hybrid were relatively small (30% of tree size on standard rootstocks) but healthy-looking, inducing good yields and fruit size. This is a rootstock worth testing on a small scale and is of tremendous potential benefit as a size-controlling rootstock for high density planting.

- **Citrange 35 (C35)**

(*C. sinensis x P. trifoliata*)

C35 was developed in California and is a cross between Ruby sweet orange and trifoliate orange. It has performed well in trials in combination with grapefruit, navels, Valencias and mandarin types. According to data from California the growth of trees on C35 compares well with that on Troyer and Carrizo citranges up to about six years of age, at which stage growth is slower with the eventual mature tree size being 25 to 30% smaller. Productivity, internal quality, and fruit size are good. As a result, C35 has become very popular amongst Californian growers and is now one of their leading rootstocks. There have been reports of tree dieback with Clemenules on C35 and Fukumoto on C35 appears to have more incompatibility problems than other rootstocks.

C35 became extremely popular in the 1990s in California and demand for seed still exceeded supply into 2000. C35 has a lower percentage of polyembryonic seedlings than other citranges. Coupled with the shortage of seed it is possible that seedling culling in the nurseries was insufficient, resulting in off-type or zygotic seedlings being included in new plantings, resulting in incompatibilities and dieback.

Note: This occurred with Swingle citrumelo in South Africa in the early 1990s when seed demand exceeded supply with similar dieback being found in commercial orchards.

C35 performs in soils similar to Troyer and Carrizo, i.e. it does not adapt well to saline and high pH soils. It is fairly tolerant to *Phytophthora,* nematodes and CTV, but sensitive to CEVd. In Florida, C35 has performed well with 8 to 10-year-old grapefruit and orange trees not showing susceptibility to CB. In South Africa, however, this rootstock has been shown to be sensitive to CB in trials conducted in the Letsitele region.

This is one of the most promising new rootstocks, which can be used on a semi-commercial scale in combination with grapefruit, Valencias, navels and mandarins.

- **Sunki Benecke**

This rootstock is a hybrid of Sunki mandarin and Benecke trifoliate orange. Sweet orange trees on this rootstock are large in field trials at Fort Pierce and in the Foundation planting in Winter Haven, Florida. Initial tests indicate this rootstock to be resistant to Phytophthora, burrowing nematode and CTV and tolerant of high pH and calcareous soils, Trials are still young, but early yields have been excellent.

This is another extremely promising new rootstock, which can be used on a semi-commercial scale in combination with grapefruit, Valencias, navels and mandarins.

- **Own-rooted citrus as rootstocks**

The term own-rooted refers to seedling citrus trees, rooted stem cuttings and propagation by air layering. The techniques to root cuttings are quite practical and economically feasible.

When should rooted cuttings be considered? In cases where a rootstock has many desired characteristics but either:

- the fruit of such a rootstock bears few seeds (some new rootstocks are even seedless), or

- the seed of such a rootstock is low in polyembryony, i.e. few nucellar or true-to-type seedlings are obtained.

Potential new rootstocks where clonal propagation may have to be considered include the Yuma citrange, Flying Dragon trifoliate orange, F80 - citrumelos and Benton citrange.

5 OTHER CONSIDERATIONS

Some other considerations when choosing a rootstock:

1. Tree spacing: refer to the section on “Tree Spacing” elsewhere in this volume.

2. What is the relative value of the principal performance criteria, *viz*. yield, fruit quality and CTV or CB tolerance?

3. Should only one rootstock be selected or is it better to hedge your bets by selecting several? In this regard several estates follow the practice of using two rootstocks

per orchard and either plant alternate rows to a rootstock or, more commonly, alternate the two stocks within a row. However, using two rootstocks in one orchard may sometimes lead to management problems where slightly different cultural practices are required for the specific rootstocks or if fruit maturity dates differ.

Sometimes multiple rootstocks should be used in problem sites, i.e. where soil types vary widely in a small piece of land. Each rootstock should then be matched to the soil type best suited to that rootstock.

6 ROOTSTOCK RESEARCH

The development of a new rootstock is inherently a long and involved process. It is unlikely that any new rootstock will have all the desirable attributes. However, one of the prime future objectives is to find reliable size-controlling rootstocks coupled with characteristics such as good yields, fruit size, internal fruit quality, disease resistance and adaptability to a wide range of scions and soils. (Refer to the section "Tree Size Control for High Density Plantings" elsewhere in this volume.).

New rootstocks are the result of selection and breeding procedures. Classical breeding involves hand-pollination of flowers of selected trees. New techniques which are utilised in other parts of the world, such as cell fusion, and tissue culture to regenerate whole plants, are faster and may circumvent some of the obstacles encountered with the classical approach. The goal in both approaches is to produce new rootstocks that have a pest and disease resistant root system compatible with a scion producing an abundance of high quality fruit. Such rootstocks should also possess certain other characteristics including:

- Adaptability to a multitude of soil and climatic conditions.
- Seediness, with a high degree of nucellar embryony and ease of propagation.
- Correct degree of vigour to induce fruit set and maturation on a given scion cultivar.
- Practical immunity or high levels of resistance to pathological and entomological organisms.
- Freedom of or tolerance to destructive viruses and decline disorders.

Such rootstocks do not presently exist nor are they likely to be found through natural selection.

To produce such rootstocks through breeding programmes, if possible, will probably require considerable time. Therefore, it is quite apparent that rootstock development and testing is inevitably a continuous activity. It should be equally apparent that on-site evaluation has many potential benefits for the local grower. Rootstocks that have not been fully evaluated but are suitable for small scale grower trials are described in Table 7.

7 SUMMARY: CHOOSING A ROOTSTOCK

Step 1: Gather the facts about your site

A. Soil - texture, depth, restrictive layers, pH, salts, drainage and any other factors that influence tree growth. Should you and how deep should you loosen/prepare the soil. Establish what soil amelioration is required, e.g. ridging and/or liming, and carry out soil preparation accordingly.

B. Water - supply, quality and disease levels. Type of irrigation system.

C. Macroclimate and microclimate - minimum plus maximum temperatures.

D. Disease status - *Phytophthora* and nematodes.

E. History - past experience is valuable.

Step 2: What is your objective?

A. Scion cultivar - a choice which can only be changed by topworking or replanting.

B. Market - fresh or processing; export or local, i.e. do you want to go for fruit quality or yield?

C. Time of maturity.

Step 3: Know the rootstocks

Draw on:

A. Your own experience or that of others in your area.

B. Research data of field trials under similar conditions.

Step 4: Identify suitable rootstocks

Review a list of possible choices, eliminate those least acceptable.

Table 1. Percentage of the different rootstocks used for certified trees in South Africa: 1976 – 2007

Year	Carrizo citrange	Swingle citrumelo	Rough Lemon	X639 hybrid	Troyer citrange	C35 citrange	MxT	Volcka-meriana	Yuma citrange	Poncirus trifoliate	Empress mandarin	Cleopatra mandarin	TOTAL TREES
1976	-	4	41	-	24	-	-	8	-	1	-	-	79 403
1978	1	1	52	-	33	-	-	5	-	6	1	1	316 585
1980	2	-	48	-	32	-	-	14	-	4	-	-	330 808
1982	-	-	63	1	18	-	-	10	-	5	-	3	572 424
1984	1	1	70	1	10	-	-	15	-	-	-	2	450 977
1986	3	6	52	1	7	-	-	25	1	4	-	1	527 230
1987	5	4	44	2	11	-	-	30	-	2	-	2	820 504
1988	14	1	13	1	36	-	1	11	2	5	2	3	621 496
1989	14	6	46	3	9	-	-	19	-	1	-	2	501 089
1990	16	9	30	2	13	-	-	23	1	5	-	1	540 174
1991	19	8	15	4	24	-	1	17	-	2	-	-	513 278
1992	16	6	21	3	28	-	-	13	-	2	-	1	506 965
1993	22	27	13	3	24	-	1	8	-	3	-	1	1 175 345
1994	18	36	13	7	14	-	4	6	1	2	-	-	653 950
1995	26	30	23	4	7	-	1	6	1	1	-	-	1188131
1996	20	43	19	7	5	-	2	2	-	-	-	-	1174832
1997	24	31	28	8	4	-	2	2	-	-	-	-	333771
1998	29	29	29	8	2	-	-	2	1	-	-	-	995574
1999	33	31	25	8	-	-	2	-	1	-	-	-	407683

Year	Carrizo citrange	Swingle citrumelo	Rough Lemon	X639 hybrid	Troyer citrange	C35 citrange	MxT	Volcka-meriana	Yuma citrange	Poncirus trifoliate	Empress mandarin	Cleopatra mandarin	TOTAL TREES
2000	54	16	25	4	1	-	-	-	-	-	-	-	705533
2001	38	31	19	4	3	-	1	3	1	-	-	-	780888
2002	42	27	15	7	3	3	2	-	-	-	-	-	614845
2003	51	22	10	8	4	3	2	-	-	-	-	-	1454996
2004	51	20	19	3	1	3	1	1	1	-	-	-	1206528
2005	38	27	17	4	2	7	4	-	1	-	-	-	1866176
2006	47	21	14	6	1	7	4	-	-	-	-	-	1613914
2007	36	31	18	3	2	6	3	-	-	-	-	-	1343312

Table 2. General suitability of rootstock cultivars for use with various scion cultivars in southern Africa

Scion cultivar	Rough lemon	Volcka-meriana *7	Troyer/ Carrizo citrange	Trifoliate	X639 hybrid	Swingle citrumelo	Cleopatra Mandarin	C35
Navels	X	X	1	2	1	1	2	2
Valencias	1	X	1	1	1	1	2	2
Marsh/Rosé G/F	2	X	1	1	1	1	1	2
Star Ruby G/F	3	X	1	1	1	2	2	2
Eureka lemon	1	1	X NC	X NC	2	X NC	1	X NC
Lisbon lemon	1	1	1	1	1	?	1	1
Clementine	X	X	1	2	?	?	2	1
Minneola tangelo	3	X	1	1	2	1	1	2
Mandarin Hybrids**	X	X	1	1	1	1	1	1
Navels	1	X	1	2	1	1	1	1
Valencias	1	X	1	1	1	1	1	1
Eureka lemon	1	1	X NC	x NC	2	X NC	1	X NC
Lisbon lemon	1	1	1	1	1	?	1	?
Clementines	3	X	1	1	?	?	2	1
Satsumas	X	X	1 NC *4	1*4	?	?	2*6	1
Minneola tangelo	1	X	2 *5	3 *5	?	1*5	1	1
Mandarin Hybrids**	X	X	1	2	?	2	1	1

Remarks: 1 = suitable; 2 = acceptable; 3 = marginal; X = not suitable; NC = not compatible; ? = insufficient information available.
*1 Hot/warm areas : Tshipise, Letsitele, Lower Letaba, Hoedspruit, Malelane, Lower Malelane, Swaziland Lowveld, Pongola, Nkwalini.
*1 Semi-desert areas: Kakamas
*1 Intermediate areas: Marble Hall, Nelspruit, Ngonini, Karino, Barberton, White River, Letaba, Levubu.
*2 Cool areas: Rustenburg, Potgietersrus, Lydenburg, Zebediela.
*2 Cold areas: Eastern Cape Midlands, Gamtoos River Valley, Sundays River Valley, Amanzi, Western Cape, Central KZN Midlands.
*3 Reportedly incompatible in Australia; no problems evident in RSA.
*4 Delayed incompatibility reported in California after 15 to 20 years; due to higher budding in RSA not expected to be a severe problem.
*5 Acid levels may be too high in certain areas.
*6 Some scion overgrowth seen in cool areas with Miho Wase, Kuno and Imamura Satsumas.
*7 Volckameriana is only recommended in combination with lemons due to its sensitivity to Tristeza.
** There are numerous mandarin hybrids so it is wise to obtain more detailed advice than can be included in this table
The above ratings are generalisations and therefore cannot hold true for all circumstances or conditions.

Table 3. Characteristics of rootstock cultivars suitable for use in southern Africa - influence of rootstock on tree growth, production and fruit quality

Factor	Rough lemon	Volcka-meriana	Cleopatra mandarin	C35	Troyer/ Carrizo citrange	Trifoliate	X639 hybrid	Swingle citrumelo
Tree Performance								
Tree growth rate	Vigorous	Vigorous	Moderate *1	Moderate +	Moderate	Slow	Moderate -	Moderate +
Final tree size	Large	Large	Large	Medium	Medium +	Medium -	Medium	Medium +
Cold hardiness	Poor	Poor	Fair	Good	Good	Excellent *2	Good	Good
Longevity	Fair	?	Good	Good	Good	Good	?	Good
Productivity and quality								
Yield per tree	Good	Good	Satisfactory	Satisfactory	Good	Good	Good	Good
Fruit size	Good	Good	Fair	Satisfactory	Good	Satisfactory	Good	Good
Fruit maturity	Early	Early	Mid	Good	Mid	Mid-late	Mid	Mid
TSS %	Low	Low	Good	Good	Good	Excellent	Good	Good
Acid %	Low	Low	Moderate	Good	Moderate +	High	Moderate	Moderate
Rind thickness	Fair +	Fair +	Fair	Good	Thin	Very thin	Thin	Thin -
Creasing	Light	Light	Light	Light	Moderate +	Severe	Moderate +	Moderate +
Rind texture	Coarse	Coarse	Intermediate	Good	Smooth	Smooth	Smooth	Smooth
Rind colour development	Intermediate	Intermediate	Intermediate	Good	Early	Early	Early -	Late

Note:

i) Variance above or below the category given is indicated where necessary by + or -.
i.e. **+ means more than; - means less than.**

ii) The above ratings are generalisations and therefore cannot hold true for all circumstances or conditions.

iii) A question mark (?) indicates that insufficient information is available at present to provide a response rating.

*1 Very vigorous in subtropical climates.
*2 Not good in subtropical climates.

Table 4. Characteristics of rootstock cultivars for use in southern Africa - response to various disease and soil factors

Factor	Rough lemon	Volcka-meriana	Cleopatra mandarin	C35	Troyer/ Carrizo citrange	Trifoliate	X639 hybrid	Swingle citrumelo
Factor								
Citrus viroids	Tolerant	Tolerant	Tolerant	Sensitive	Sensitive	Sensitive +	Sensitive	Intermediate
Citrus tristeza virus	Tolerant	Poor	Tolerant	Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Citrus Blight	Poor	Poor	Good	Susceptible	Interm/poor	Poor	Intermediate	Intermediate
Phytophthora	Susceptible	Susceptible	Intermediate	Intermediate	Tolerant +	Tolerant +	Tolerant	Tolerant +
Citrus nematode	Susceptible	Susceptible	Susceptible	Tolerant(?)	Tolerant	Tolerant +	Tolerant ?	Tolerant +
Soil Condition								
Poor drainage	Sensitive +	Sensitive	Sensitive	Intermediate	Intermediate	Tolerant	?	Tolerant
High clay	Sensitive	Sensitive	Intermediate	Intermediate	Intermediate	Tolerant	Intermediate	Intermediate
High sand	Tolerant	Tolerant	Intermediate +	Intermediate +	Sensitive	Sensitive +	?	Intermediate +
Replant	Sensitive	Sensitive -	Sensitive -	?	Intermediate	Tolerant	Intermediate	Tolerant
High chloride / salt	Intermediate	Intermediate	Tolerant +	Intermediate	Sensitive	Sensitive +	Intermediate ?	Intermediate
High calcium / pH	Tolerant	Tolerant	Tolerant	?	Sensitive	Sensitive +	?	Intermediate ?
Drought	Tolerant	Tolerant	Tolerant	Tolerant	Intermediate	Sensitive	?	Tolerant -

Note:

i) Variance above or below the category given is indicated where necessary by + or -, i.e. **+ means more; - means less.**

ii) The above ratings are generalisations and therefore cannot hold true for all circumstances or conditions.

iii) A question mark (?) indicates that insufficient information is available at present to provide a response rating.

Table 5. Nursery characteristics of citrus rootstocks

Rootstock	Remarks
Lemon types	
Rough lemon	Seeds are highly nucellar and germinate well. Seedlings have good vigour, scion buds force easily and grow rapidly, especially in warm and hot climates.
Volckameriana	Similar to rough lemon except seedlings are more variable and culling should be stricter.
Macrophylla (Alemow)	Seeds are polyembryonic but seedlings are variable, moderately vigorous, and bud and force easily.
Mandarin types	
Cleopatra mandarin	Seeds are highly nucellar and germinate well. Seedlings are problematic in the nursery, not always growing vigorously. They are not easy to bud, and buds difficult to force. Sometimes nurserymen have to cut seedlings back and wait for new growth on which to bud.
Rangpur	Seeds are highly nucellar and germinate readily. Seedlings are vigorous, easy to handle, bud readily and force easily.
Orange types	
Sweet orange	Seeds are 70 to 85% nucellar but this varies with the cultivar. Seedlings are thorny, bushy and vigorous and generally easy to bud and force.
Trifoliate orange	Seeds are about 90% nucellar and may require chilling for best germination. Seedlings have low to moderate vigour, are very thorny, and small-flowered cultivars are bushy, making them difficult to bud. Seedlings respond to prolonged day length, but generally go dormant outdoors in the autumn. Flying Dragon seedlings must be culled carefully because of the large number of off-types.
Trifoliate hybrids	
Carrizo and Troyer citrange	Both citranges are excellent nursery plants with highly nucellar seed, and both produce uniform, vigorous, single stem seedlings that are easy to bud and force.
Swingle citrumelo	Seeds are about 90% nucellar with an excellent germination percentage. Seedlings are very vigorous, uniform, upright and easy to bud, but forcing may be erratic with some buds not breaking.
C35	Seedling populations are less polyembryonic than other trifoliate hybrids such as Carrizo citrange so careful selection is necessary to obtain nucellar seedlings which are uniform.

Table 6. Approximate number of seeds/litre

Rootstock	Approx. number of seeds/litre
Swingle citrumelo	3 100
Carrizo citrange	2 600
Troyer citrange	2 600
Rough lemon	5 600
Volckameriana	6 800
X639	4 800
Australian trifoliate	3 800
Minneola x trifoliate	3 100
C35 citrange	2 600
Benton citrange	2 600
Rangpur lime	5 600
C32 citrange	2 600
Sour orange	4 000
Pomeroy trifoliate	3 800
Rubidoux trifoliate	3 800
Flying Dragon	4 000
Cleopatra mandarin	5 000
Yuma citrange	4 000
Empress mandarin	5 500

Table 7. Rootstocks suitable for small-scale grower trials

Rootstock	Seed source availability	Remarks
Citranges		
Citrange 35 (C35)	CIS*	Developed in California. A hybrid of trifoliate orange and Ruby sweet orange. Early performance with most scions quite good. Tolerant to *Phytophthora*, citrus nematode and CTV. California using a high % of this rootstock now. Being evaluated in RSA.
Benton citrange	CIS	Developed in Australia and selected for root rot tolerance. Very promising in Australia and early trial results in Florida and South Africa are encouraging. Apparently trees on Benton are quite cold tolerant. CTV tolerant; CB unknown. Is being included in new trials in RSA. Has performed well in trials at Letaba Estates.
Koethen citrange (Koethen Sweet orange x Rubidoux trifoliate orange)	CIS	Under trial in Florida since 1968. Moderate cold tolerance; not affected by CTV; very good yield, and no tree loss due to root rot. In RSA, KSW x TR on Palmer navel scion (8 years old in Eastern Cape) had a marked size controlling effect but with very good yields and productivity. Has performed well in trials at Letaba Estates.
Trifoliate oranges		
Flying Dragon	CIS	Refer to text, par. 4.6.2.l.
Citrumelos		
Terra Bella		Evaluated on small commercial scale in California where it has performed well. Showing 20 to 25% dwarfing in comparison with Carrizo citrange.
F80-3		Evaluated in Florida. Tree sizes similar to Swingle in combination with valencia and pineapple. Also suitable for grapefruit. Tolerance to cold, CTV and root rot appears good. In RSA with Palmer navel scion (E. Cape; 8 years) trees are small but healthy with good yields and size. Has performed well in trials at Letaba Estates trees being slightly smaller canopy volume than C35.
F80-8		Very similar to R80-3 in Florida. In RSA, trees with Palmer navel slightly larger than F80-3.
F80-9		Induces smallest trees of the three F80-hybrids tested in Palmer navel trial in Eastern Cape. Otherwise similar

Rootstock	Seed source availability	Remarks
		to F80-3 and F80-8. Performed better than Carrizo and Swingle in Letaba replant trials
Hybrids		
Minneola x trifoliate		Refer to text, par. 4.6.2.l.
X639		Refer to text, par. 4.6.2.g.
Sunki Benecke		Refer to text, par. 4.6.2.l.
Rangpur x Troyer		Refer to text, par. 4.6.2.l.

*Citrus Improvement Scheme. If not available in the RSA, the CIS can import from the USA.