crements and losses through evapotranspiration can be maintained. Tailored to the individual situation (soil type, drainage, rooting depth, etc.), this method takes much of the "guesswork" out of the irrigation system.

Conclusion

In conclusion, the irrigation operation, integrated with drainage in the total water management system, is an expedient to economic production of citrus *only* when all aspects of the operation are properly planned. The risks of high costs, with no value for the operation, are so great that the use of the limited resources of capital should be carefully budgeted. In the final analysis, however, irrigation can be a very economic and desirable production practice.

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RANGPUR LIME AS A CITRUS ROOTSTOCK IN FLORIDA

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Abstract

'Rangpur' lime (*Citrus limonia* Osbeck) is the main rootstock used in Brazil but it has had only limited acceptance as a citrus rootstock in Florida because of its susceptibility to foot rot, exocortis, and xyloporosis. Observations made in experimental plantings illustrate the productivity, high quality and good survival record of orange and grapefruit trees on this stock with and without exocortis. Exocortis often appears to induce a condition of dwarfing which could be desirable. The generally good experience of growers in 17 young commercial groves with a number of scion varieties is described. The setting-out of new, selected, small plantings on 'Rangpur' lime rootstock is justified.

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INTRODUCTION

Constantly changing conditions in the citrus industry keep the citrus grower on a never-ending quest for new rootstocks. The perfect rootstock will, perhaps, never be found but any grower can cite the deficiencies of the stocks currently in most common use in Florida. The advent of tristeza could mean calamity to groves on sour orange (*Citrus aurantium* L.) stock and a new problem, young tree decline, threatens new groves on rough lemon (*C. jambhiri* Lush.). A host of other factors make 'Cleopatra' mandarin (*Citrus reshni* Hort. ex Tan.) and sweet orange (*Citrus sinensis* (L.) Osbeck) less than perfect. Some other stocks, like trifoliate orange (*Poncirus trifoliata* (L.) Rafinesque), 'Carrizo' citrange (*Poncirus* X *C. sinensis*) and *Citrus macrophylla* Wester are well worth trying on an experimental basis in small plantings but experience with them is limited. This paper deals with another stock which is not well known to the grower but about which information is now becoming available.

'Rangpur' lime is not unknown in the world scene. It is the most important rootstock of citrus in Brazil (13) and is also used in Argentina. It apparently originated in India (18) and seedling plants can be found in almost every citrus-growing country. 'Rangpur' lime as a rootstock has been the subject of contradictory reports which often had their basis in the changes in character of this stock when infected with different strains of exocortis and xyloporosis. Results of some experiments are presented here which may help resolve some of the contradictions. Also given is a summary of grower experience with 'Rangpur' rootstock in 17 situations on more than 400 acres of grove.

It will be seen that not only is 'Rangpur' lime a promising rootstock for Florida when used under virus-free conditions but controlled and selected virus inoculation of this stock may give the grower unprecedented flexibility in control of tree size and of the solids content of the juice.

CHARACTERISTICS OF 'RANGPUR' LIME AS A ROOTSTOCK

The major difficulty involved in evaluating 'Rangpur' lime as a citrus rootstock lies in its susceptibility to exocortis disease and the fact that most of the older rootstock experiments in this country were propagated from budwood which carried this virus. The discovery that exocortis is a virus disease was made in 1949 (2). Knowledge that 'Rangpur' lime is susceptible to exocortis came in 1952 (14) and it was only in 1964 (3) that a practical and rapid means of indexing for exocortis was discovered. Even more recent are the concepts that the biggest trees are not necessarily the best and that the ability of exocortis and other viruses to induce the production of small trees was a proper subject for serious study and consideration (1, 5, 12). Very important also is an understanding of the existence of different strains of exocortis virus whose effect on trees ranges from negligible to drastic (4). Under these circumstances it is not surprising that few studies of the interaction of exocortis strain, rootstock and environment are available.

In 1960 Sinclair and Brown (19) reported on the effect of exocortis disease on 9-year old navel orange (Citrus sinensis (L) Osbeck) trees on 'Cleopatra' mandarin, sweet orange, trifoliate orange and 'Rangpur' lime. They found both yield and trunk circumference reduced for all combinations. Olson and Shull (15) studied 12-year old 'Valencia' orange scions with and without exocortis and xyloporosis virus on various rootstocks. Their data for trees on 'Rangpur' and other mandarin-limes showed that trees carrying the viruses were greatly reduced in size and yield as compared with uninfected trees. In contrast, exocortis and xyloporosis infection produced relatively little depression of growth and yield of trees on 'Cleopatra' mandarin, rough lemon and sour orange.

In a study of the ability of citrus roots to survive flooding, Ford (9) had one test involving 'Rangpur' lime. He found that 'Rangpur' and 'Carrizo' were somewhat less damaged than 'Milam' lemon and rough lemon and distinctly better than Poncirus trifoliata, sweet orange, sour orange and 'Cleopatra' mandarin.

In some reports 'Rangpur' was found to induce as much cold susceptibility as rough lemon (7, 11) while in others trees on 'Rangpur' were observed to be somewhat more resistant to cold than those on rough lemon (8, 10). Despite the differences reported it is evident that trees on 'Rangpur' must be considered relatively susceptible to cold injury.

Mixed reports are also found with respect to the susceptibility of 'Rangpur' lime to foot rot disease. Moreira (13) describes 'Rangpur' as being "fairly resistant to *Phytophthora* foot rot" and Cooper et al (7) describes foot rot as a problem of other stocks but do not mention it in connection with 'Rangpur' lime. Nevertheless growers' observations listed in Table 4 indicate that foot rot has been a serious problem of 'Rangpur' in young plantings in Florida.

Method

To document the performance of trees on 'Rangpur' lime rootstock, tabulated summaries are given in Tables 1 and 2 of observations of trees on 'Rangpur' and, for comparison, on rough lemon and sour orange. Data for these tables has been selected from 7 rootstock experiments. Four experiments, which are now 20 years old, have been described previously (6, 17). Results from three other experiments which are 10 years old have not been published before. The effects of introducing different strains of exocortis virus into 'Marsh' grapefruit trees on various rootstocks are being studied in a 5-year old experiment. The experimental unit consists of 6 single-tree replications. Results from this experiment for 3 rootstocks are extracted in Table 3. All rootstock experiments described are in St. Lucie County, Florida.

Growers on the east coast of Florida, known to have used 'Rangpur' lime as a rootstock were questioned about their plantings. Table 4 is a summary of their reports.

Results

Four rootstock experiments, all with sweet orange scions, are summarized in Table 1. Trees in Experiment 1 are free of exocortis (and psorosis and xyloporosis), but trees in the other 3 experiments listed in Table 1 carry a mild strain of exocortis. Despite this difference in exocortis status the average yield per tree of trees on 'Rangpur' was close to or better than the yield of trees on rough lemon and distinctly better than yield of trees on sour orange. Current yield data show no indication of change in this situation. A similar trend in tree size is shown by average canopy diameter. With respect to Brix of juice (total soluble solids), trees on rough lemon and sour orange are at opposite ends of the scale, as expected. Fruit from trees on 'Rangpur' lime are distinctly higher in Brix than those from trees on rough lemon but are closer to the rough lemon rating than the rating for sour orange. In Experiment 2 one tree on 'Rangpur' lime is missing, probably due to foot rot. The missing tree on 'Rangpur' in Experi-

Table 1. Site, size, productivity, quality, and survival of orange trees carrying no exocortis or a mild strain of the virus.

Expt. no.	Variety	Age	Soil type	Virus strain	Rootstock	Average[1] yield tree (boxes)	Average canopy diameter (feet)	Brix[1]	Tree survival[4]
1.	Pineapple	10	Felda	None[2]	Rangpur	2.7	12.3	10.16	10/0/0
				"	Rough lemon	3.1	13.5	10.00	10/0/0
				"	Sour orange	1.9	11.5	10.89	10/0/0
2.	Valencia	10	Felda	Mild	Rangpur	1.6	12.2	11.94	10/1/0
				"	Rough lemon	1.3	13.7	11.61	10/0/0
				"	Sour orange	0.8	12.4	12.77	10/0/0
3.	Valencia	20	Wabasso[5]	Mild	Rangpur	2.0	14.8	11.60	14/1/1
				? (3)	Rough lemon	2.0	15.2	11.56	14/0/4
				? (3)	Sour orange	1.2	14.1	12.43	14/0/0
4.	Valencia	20	Park-wood	Mild	Rangpur	2.7	18.0	11.68	5/0/0
				? (3)	Rough lemon	3.0	20.5	11.16	8/0/1
				? (3)	Sour orange	2.1	17.2	12.46	6/0/0

(1) Average of at least 5 years of data for 10 year old trees and 14 years of data for 20 year old trees.
(2) Old-line bud source; negative for exocortis by citron tests.
(3) Two sources of budwood used, one with a mild and one with a strong strain of exocortis. On exocortis tolerant stocks like rough lemon it is impossible, without indexing, to determine the strain carried. Such indexing has not yet been done.
(4) Tree survival: Number of trees planted/number dead or missing/number in decline.
(5) Formerly classified as "Leon".

ment 3 was killed by lightning. All trees in decline, 4 on rough lemon and one on 'Rangpur', show symptoms of citrus blight.

The 3 grapefruit (*C. grandis* (L.) Osbeck) rootstock experiments covered in Table 2 carry strong strains of exocortis. Average yield per tree is approximately the same for trees on all 3 rootstocks in Experiment 1. It should be noted that trees on rough lemon and sour orange have a larger canopy diameter than those on 'Rangpur' lime. Experiment 2 consists of the same types of trees as Experiment 1 but is located on a hammock-type soil (Parkwood) instead of the flatwoods type (Wabasso, formerly classified as "Leon") used in Experiment 1. Yield of trees on rough lemon is almost twice as great as trees on 'Rangpur' in Experiment 2 but the grove area occupied by trees on rough lemon is more than twice as large as that occupied by trees on 'Rangpur'. The situation in Experiment 3, Table 2 with respect to yield and tree area is similar to Experiment 2. Brix of fruit juice of the 3 experiments involving strong strains of exocortis is highest for trees on sour orange but fruit from 'Rangpur' lime is closer in Brix to the high standard of sour orange than the low level registered for fruit from trees on rough lemon. Within the past year there has been some deterioration in the health of the trees in Experiment 1, Table 2. The cause of the condition is not known but 3 times as many trees on rough lemon were affected as on 'Rangpur' (Table 2). Trees on sour orange are unaffected. Table 2 shows additional trees on rough lemon in decline in Experiments 2 and 3. The 2 dead trees in Experiment 3 on 'Rangpur' succumbed early in the life of the planting. Cause of death was foot rot in one case and was not clear in the other.

The first results from an experiment which has not been described previously are presented in Table 3. The full experiment involves 16 rootstocks for a nucellar source of 'Marsh' Grapefruit. Trees on many stocks are divided, like the 3 shown, into 4 groups. Trees in 3 of the groups were inoculated as shown when one year old. The fourth group was uninoculated. The 3 inoculum sources were individual trees in

Table 3. Productivity, size and quality of 5-year old '*Marsh*' grapefruit trees inoculated when one year old with specified strains of exocortis.

Rootstock	Virus strain inoculated	Average(1) yield / tree (boxes)	Average canopy diameter (feet)	Average(2) weight per fruit	Brix(2)	Acid(2)	Ratio(2)
Rangpur	strong	3.4	13.4	376.9	8.43	0.95	8.98
	none	3.2	14.4	388.2	8.05	0.95	8.57
	none(3)	2.8	13.8	388.2	8.38	0.98	8.72
	mild	2.9	13.0	363.0	8.78	0.98	9.09
Rough lemon	strong	2.7	12.6	401.8	7.95	0.98	8.20
	none	2.5	13.8	415.4	7.90	1.01	7.94
	none(3)	2.0	13.1	407.4	7.88	1.00	7.98
	mild	2.8	13.0	338.3	7.90	0.98	8.21
Sour orange	strong	1.7	14.5	390.4	8.98	1.02	8.92
	none	1.6	14.0	388.2	8.90	1.03	8.71
	none(3)	1.3	15.0	358.7	9.05	1.08	8.57
	mild	1.9	13.8	395.0	8.95	1.05	8.68

(1) Two-year average. (2) Two-year average for fruit sampled about December 1. (3) Non-exocortis old-line tissue inoculated.

Table 2. Site, size, productivity, quality and survival of grapefruit trees carrying a strong strain of exocortis.

Expt. no.	Variety	Age	Soil type	Rootstock	Average(1) yield tree (boxes)	Average canopy diameter (feet)	Brix(1)	Tree survival(2)
1.	Ruby Red	20	Wabasso(3)	Rangpur	3.0	14.3	9.35	14/0/2
				Rough lemon	3.4	17.6	8.73	14/0/6
				Sour orange	2.9	15.7	9.94	14/0/0
2.	Ruby Red	20	Park-wood	Rangpur	2.7	15.3	9.62	6/0/0
				Rough lemon	5.2	23.2	8.51	6/0/1
				Sour orange	4.0	19.7	9.69	6/0/0
3.	Marsh	10	Felda	Rangpur	3.0	11.8	8.80	10/2/0
				Rough lemon	5.8	15.8	7.86	10/0/1
				Sour orange	3.3	13.8	9.21	10/0/0

(1) Average of 5 years of data for 10 year old trees and at least 14 years of data for 20-year old trees.
(2) Tree survival: Number of trees planted/number dead or missing/number in decline.
(3) Formerly classified as "Leon".

the 3 ten-year old experiments mentioned in Tables 1 and 2. Table 3 demonstrates the precocity of yield of trees on 'Rangpur' lime despite the fact that by 1970 the trees had been carrying their inoculated viruses for 4 years. Tree growth has shown only minor differences to date for the various categories, with surprisingly strong growth for trees on sour orange. Although most figures seem to show little response to inoculation thus far, a definite response is seen in the levels of Brix of the 4 groups on 'Rangpur' lime. The uninoculated trees show a low Brix rating only slightly higher than the general level for trees on rough lemon while the 3 inoculated groups are approximately midway in degrees Brix between the averages of rough lemon and sour orange. The fact that inoculation of tissue from the non-exocortis old-*line source also* raised the Brix of grapefruit suggests that influences other than exocortis may also produce this effect.

Rootstock trials involve a relatively small number of trees in a special situation. When rootstock experiments have indicated that a certain rootstock may have some commercial value the logical next step is the use of this stock in small scale grower plantings. Table 4 is a capsule summary of grower experience with 17 plantings on 'Rangpur' lime. Six scion varieties were used. In all more than 400 acres of plantings are involved, most of which are 5 to 7 years old. All plantings tabulated are located in 4 counties on the lower east coast of Florida, mainly in St. Lucie and Indian River counties. More plantings with 'Marsh' grapefruit tops were found than with any other scion variety. This was a result of the belief of some growers that grapefruit on 'Rangpur' comes into bearing earlier and matures earlier in the season than on any other stock. A number of the growers said they had been able to meet maturity standards very early in the season with plantings on 'Rangpur' lime. Yield figures show impressive production for young groves.

Most of the groves listed in Table 4 were propagated from exocortis-free budwood. Trees in groves 13 and 14 were propagated from budwood obtained from trees on 'Rangpur' lime in Experiment 3, Table 1 with the knowledge that the budwood carried a mild strain of exocortis virus. The growers indicated that they would be satisfied if they could duplicate in their own groves the performance exhibited by trees on 'Rangpur' in this experiment. The only grove grown from budwood carrying a strong strain was no. 10, propagated inadvertently from exocortis-infected budwood. All trees in this planting show exocortis bark scaling below the bud union but trees are thrifty, though stunted, and are productive for their size.

Table 4 reveals the high susceptibility of 'Rangpur' to foot rot. Nevertheless it is the judment of the writer, and of most growers who have used Rangpur', that foot rot is probably no more of a problem with 'Rangpur' rootstock than with rough lemon.

Indications are that virus-free trees on 'Rangpur' are likely to be as low in soluble solids as are comparable trees on rough lemon. Scion varieties which are naturally low in solids may fail to reach maturity standards. The growers covered in Table 4 were not in agreement on the cold resistance of their plantings. Limited damage from cold was mentioned for 2 groves but others were impressed with the lack of damage in comparison with trees on rough lemon stock. In a few cases trees on 'Rangpur' produced numerous root-sprouts, like trees on rough lemon, but this was not mentioned by most growers.

Few plantings utilizing 'Rangpur' lime rootstock are located on Florida's central ridge. It has been used successfully in the grove of Florida's Division of Plant Industry north of Davenport as a rootstock for exocortis-free scions.*

Discussion

The advantages of dwarf trees are still not generally recognized in Florida. Small trees, planted in large numbers on a given area, make that area attain substantial production early. Small trees are easier to pick and spray. The advantages of planting smaller trees have been discussed by a number of writers (5, 12, 16). Workers in Australia are investigating the value of delayed inoculations of exocortis introduced into trees on *Poncirus trifoliata* (1).

Evidence presented in this paper should not be taken to mean that exocortis infection of citrus trees on 'Rangpur' lime stock is never harmful. Undoubtedly strains of exocortis exist whose presence in citrus trees on 'Rangpur' can pro-

*Personal communications from Mr. Don Bridges, Chief Bureau of Budwood Registration.

Table 4. Scion, size, productivity, disease status and comments on some commercial plantings of citrus trees on 'Rangpur' lime rootstock on the east coast of Florida.

Grove #	Scion	Age	Acres	County	Exocortis strain	Foot rot approx. %	Approx. yield boxes/tree	Remarks
1	Red Gft.	1	6	Ind. Riv.	none	1	-	Good growth
2	Marsh Gft.	6	0.5	Ind. Riv.	none	1	-	Good growth; medium quality
3	"	6	80.	" "	none	33	good	Large fruit; early maturity; low solids
4	"	7	10.	St. Lucie	none	10	7.5	
5	"	7(3)	6.	" "	none	1	3.0	Hamlin topworked with GF in 1967
6	"	6	25.	" "	none	15	4.5	Frost damage; good size
7	"	3	30.	" "	none	5	-	
8	"	5.5	45.	Palm Beach	none	-	good	Early maturity; good growth in poor soil; solids O.K.
9	"	3.5	20.	Ind. Riv.	none	10	-	Good growth; low solids
10	"	5.5	7.	Martin	strong	none	1.6	Bark scaling below bud union; good quality
11	Valencia	6.	10.	Ind. Riv.	?	5	2.5	
12	"	1.	10.	" "	none	5	-	Good growth
13	"	5.	15..	St. Lucie	mild	5	1.0	Frost damage
14	"	3.	3.	" "	mild	1	-	Good growth
15	Hamlin	5.	100.	" "	none	8	1.5	Low solids; cold not a problem
16	Orlando	5.	20.	" "	?	25	2.5	
17	Robinson	5.	20.	" "	none	10	2.0	Good performance

duce very harmful effects. This paper provides data showing that infected trees on 'Rangpur' are nevertheless often productive for their size, and that trees with exocortis may produce fruit of higher quality than virus-free trees. Trees in experimental plantings also established a record of consistent bearing and good survival.

At present the indiscriminate use of exocortis-inoculation of trees on 'Rangpur' would not be justified. Much remains to be learned regarding the proper utilization of the exocortis-inoculation technique. It is not yet clear whether it is the exocortis *per se* or some accompanying constituent which produces the effects observed. The use of mechanically-transmitted strains of exocortis will help answer these questions. It is not known whether the inoculum which is effective for one variety will be successful when used with other varieties. The effect of soil types and environmental influences on the kind of trees produced must also be investigated. For all these reasons it is best that new plantings on 'Rangpur' be small ones. Enough success has been attained, however, to justify more trials in the immediate future.

Field trials of 'Rangpur' lime rootstock in commercial plantings on limited acreage can be of 3 types: (1). Plantings with exocortis- and xyloporosis-free scions as a replacement for trees on rough lemon. Such trees can be expected to grow rapidly into large trees, to come into production early and to produce fruit with a low level of total soluble solids in the juice. The apparent resistance of trees on 'Rangpur' to citrus blight suggests that it might be more resistant also to young tree decline. It could be used as a rootstock of value in a portion of the areas affected by young tree decline. 'Rangpur' should not be used with virus-free scions of varieties which have difficulty meeting maturity standards, since it is no better than rough lemon under these conditions. (2). Plantings with scions carrying exocortis and/or xyloporosis. These should be plantings designed to reproduce desirable existing virus-infected blocks like some described in this article. They should be propagated from trees on 'Rangpur' lime in plantings of this kind and should be set out on land of a soil type similar to the original planting. (3). Plantings which are originally virus-free but are later inoculated with a strain of exocortis to slow down growth. Plantings of this sort would show initial rapid growth but the growth rate would slow down within a few years after inoculation. Brix of the juice would increase following inoculation. This is similar to the plan used for trees on *P. trifoliata* in Australia (1) and for the experiment which provided the information or Table 3. Results with this type of field trial will, at first, be the least predictable of the 3 mentioned here but experiments of this kind will eventually provide trees most closely designed to fit a given situation.

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PROBLEMS IN USING 'MILAM' ROOTSTOCK AS A BIOLOGICAL BARRIER

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ABSTRACT

'Milam' rootstock has not been supporting populations of burrowing nematodes in biological barrier tests in the field. However, the growth of rough lemon roots into the barrier area can harbor and enhance the migration of burrowing nematodes and other pathogenic nematodes such as citrus nematodes to which 'Milam' may be susceptible.

'Milam' as a biological barrier must be used in conjunction with a narrow root-killing chemical barrier. This is necessary to minimize the spread of burrowing nematodes on susceptible roots growing into the biological barrier area. The chemical barrier should be renewed when there is evidence (by digging into the chemical barrier area with a shovel) that roots of 'Milam' and susceptible hosts are intermingling. This period may be as long as 2 years.

'Milam' should not be planted in nonfumigated soil because of the added danger of infestations of citrus nematodes and meadow nematodes.

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GREENHOUSE STUDIES

'Milam' in 2 separate tests has been evaluated for 6 and 7 years respectively as a biological barrier, utilizing large soil tanks 25 feet in