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A progress report on citrus rootstocks studies in Sardinia (1)

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The research program on citrus rootstocks in Sardinia, with the financial support of the Italian National Research Council, was started in 1965 with the purpose of finding alternative rootstocks to substitute for sour orange in case of possible spreading of tristeza (11). The results of previous research have been published (13, 20). This paper briefly reports further results of the work in progress.

MATERIALS AND METHODS

The rootstock trials were established in 1969 at the Institute Experimental Station, near Oristano, Sardinia. Two different experiments were arranged. The first one evaluated the performance of « Hamlin » and « Frost Navel » sweet oranges (*C. sinensis* (L.) Osbeck), « Frost Eureka » lemon (*C. limon* (L.) Burm.) grafted on sour orange (*C. Aurantium* L.), and « Troyer » citrange (*Poncirus trifoliata* (L.) Raf. x *C. sinensis* (L.) Osbeck). In the second, five different rootstocks were compared with « Frost Marsh » grapefruit (*C. paradisi* Macf.): sour orange, « Troyer » citrange, « Rubidoux » trifoliolate orange (*P. trifoliata* (L.) Raf.), « Orlando » tangelo (*C. reticulata* Blanco x *C. paradisi* Macf.), and « Palestine » sweet lime (*C. limettioides* Tan.). The trees were grown at the Institute Experimental Station, and in June of 1969 were planted in the field (2). For both experiments, ten single-

(1) Ricerca collegiale coordinata del C.N.R. per il « Miglioramento genetico degli Agrumi ». Pubblicazione n. 50. Comunicazione presentata all'« International Citrus Congress », Orlando (Florida), 1-8 maggio 1977.

(2) The physical and chemical properties of the soil at the time of planting were: 50% sand, 31.5% loam, 18.5% clay, pH 6.7, 0.08% N, 0.736 mg/100 g P₂O₅, 33.6 mg/100 g K, 38.6 mg/100 g Mg, Ca n.d., 15.2 mg/100 g Na.

tree replications of each rootstock/scion combination, in a randomized-block design, were set out at 4 x 5.5 m. The bud sources were all nucellar lines originating from a single tree of each variety grafted with budwood introduced from California in 1964. Observations on growth and yielding began in 1973. Tree growth was evaluated each year, normally in December, through measurements of the trunk circumference, 10 cm under and above the bud-union, and of the canopy height and width. The canopy volume was determined by Turrell's formula (27). Yields were recorded for the last four harvests. The fruits were harvested in December for « Hamlin », in January for « Frost Navel » and « Frost Eureka », and in March for « Frost Marsh ». Fruit samples were collected on the same date of each year for fruit quality determinations. A ten fruit sample was taken from each tree. All data were subjected to statistical analysis.

RESULTS

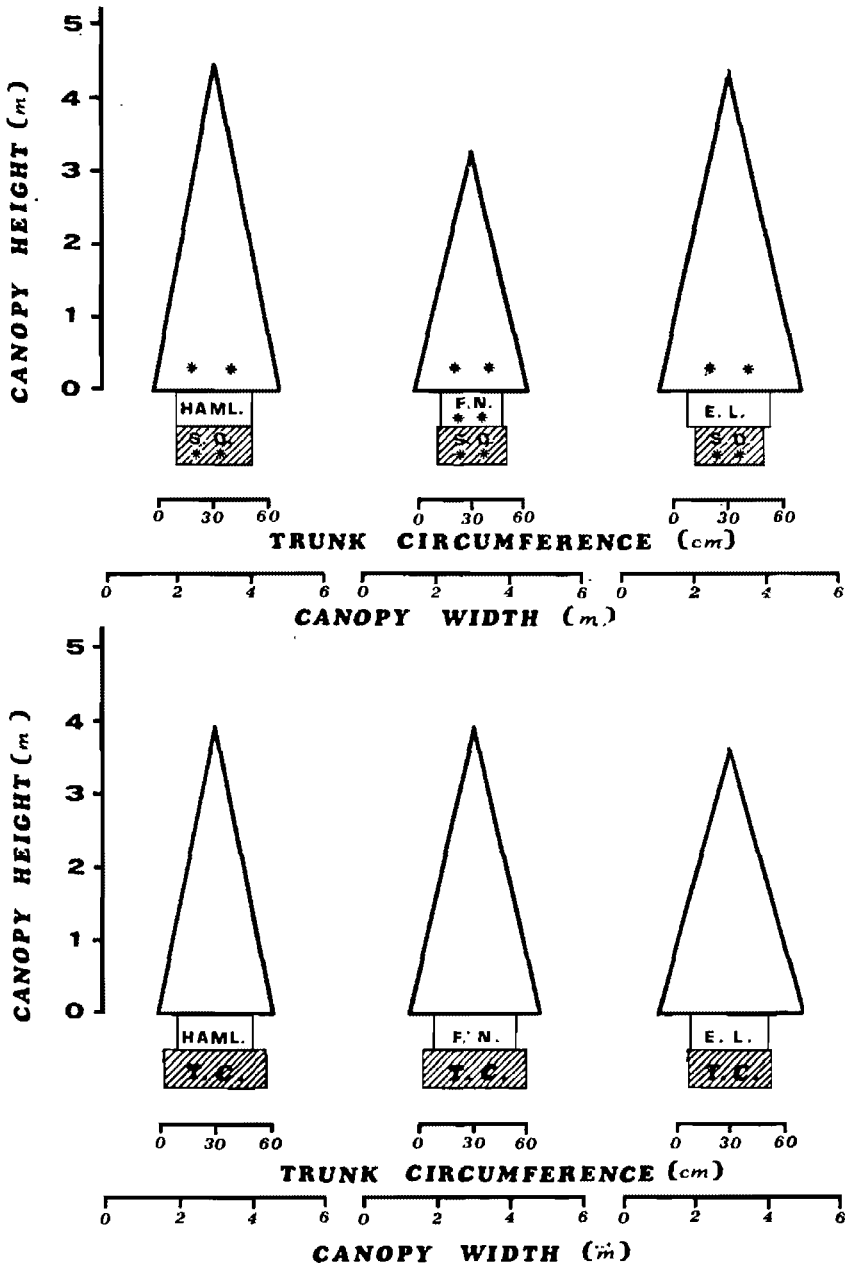
Sweet orange and lemon trial. « Hamlin » orange and « Frost Eureka » lemon trees grafted on sour orange were larger than those grafted on « Troyer » citrange, but the latter induced more growth in « Frost Navel » trees (Fig. 1). The trunk circumference below the bud-union was higher in « Hamlin » and « Frost Navel » trees grafted on « Troyer » citrange. No differences were observed in trunk circumference above the bud-union, except for « Frost Navel » trees, in which « Troyer » citrange induced a more growth.

A marked overgrowth of the rootstock was also observed in sweet orange trees grafted on « Troyer » citrange. In « Frost Eureka » lemon grafted on sour orange a little overgrowth of the scion was found.

The fruit production was improved by « Troyer » citrange in « Hamlin » and « Frost Navel » oranges, while sour orange induced greater yields in « Frost Eureka » lemon (Fig. 2).

Yield density (expressed as Kg/m³ of canopy) was increased on « Hamlin » orange by « Troyer », but no differences between the two rootstocks were found on « Frost Navel » trees. In lemon trees the yield density was increased by sour orange.

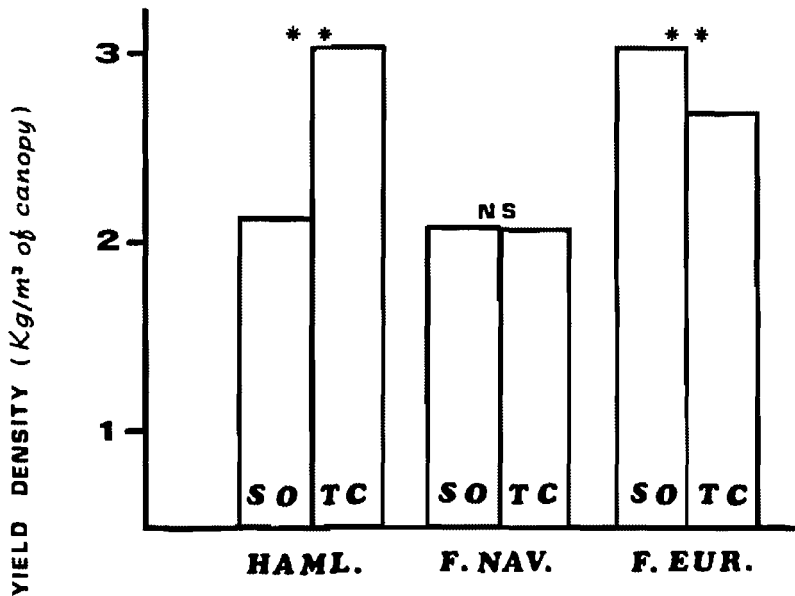
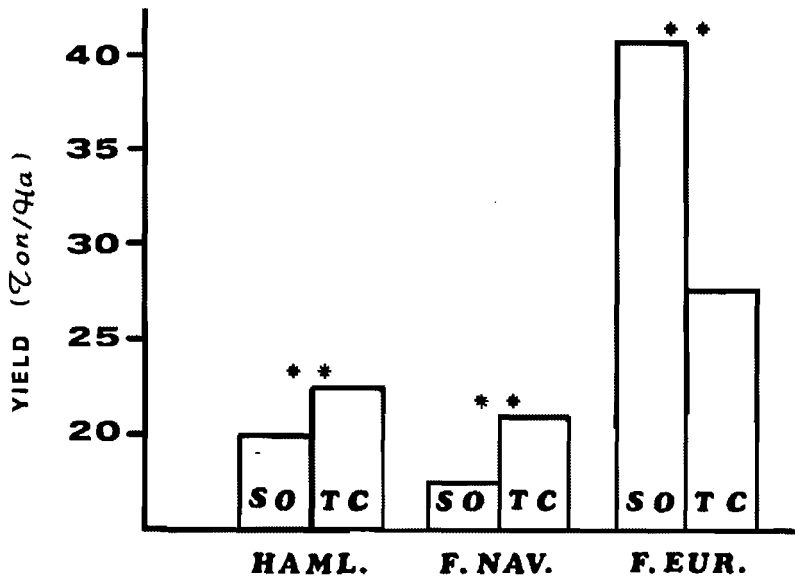
Rootstock also affected the fruit quality. In « Hamlin » orange (Table 1) « Troyer » citrange improved the rind and flesh texture, reduced the fruit weight and the rind thickness, increased the juice content (expressed as



** SIGNIFICANT DIFFERENCE BETWEEN SO AND TC. 1% LEVEL.

Fig. 1 - Growth habit of « Hamlin » and « Frost Navel » sweet oranges, and of « Frost Eureka » lemon grafted on sour orange and « Troyer » citrange.

Fig. 1 - Habitus vegetativo degli aranci « Hamlin » e « Frost Navel », e del limone « Frost Eureka » innestati su arancio amaro e citrange « Troyer ».



* * SIGNIFICANT DIFFERENCE BETWEEN SO AND TC, 1% LEVEL

Fig. 2 - Yield/Ha and yield efficiency of « Hamlin » and « Frost Navel » sweet oranges, and of « Frost Eureka » lemon grafted on sour orange and « Troyer » citrange. (Average of the last four years).

Fig. 2 - Produzione ad ettaro ed efficienza produttiva degli aranci « Hamlin » e « Frost Navel », e del limone « Frost Eureka » innestati su arancio amaro e citrange « Troyer ». (Medie degli ultimi quattro anni).

Table 1 - Fruit quality of « Hamlin » nucellar sweet orange on sour orange and « Troyer » citrange rootstocks (Four-year average: fruit samples collected in December 5, 1973, 1974, 1975, 1976).

Tabella 1 - Caratteristiche qualitative dei frutti di arancio dolce « Hamlin » innestato su arancio amaro e citrange « Troyer » (valori medi di un quadriennio: campioni raccolti il 5 dicembre del 1973, 1974, 1975 e 1976).

Fruit characteristics	Sour orange	Troyer citrange	Significance level (1)
LENGTH (cm)	6.6	6.5	NS
WIDTH (cm)	7.1	6.9	NS
L/W RATIO	0.93	0.94	NS
AVE. WEIGHT (g)	162	150	*
RIND TEXT. IND. (2)	7.1	7.3	*
RIND COL. IND. (3)	9.7	9.8	NS
FLESH COL. IND. (3)	10.1	10.1	NS
FLESH TEXT. IND. (4)	2.6	2.9	*
AVE. NO. SEED	0.8	0.9	NS
RIND THICK. (mm)	5.8	5.3	**
JUICE (%)	46.0	48.0	**
TSS (%)	9.0	10.1	**
TA (%)	0.87	1.02	**
TSS/TA RATIO	10.3	9.9	NS

(1) NS: no significant difference.

*: significant difference at 5%.

** : significant difference at 1%.

(2) Visually determined on a scale ranking 1 to 8.

(3) Visually determined with the aid of a color table on a scale ranking 3 (dark green) to 13 (deep orange).

(4) Visually determined on a scale ranking 1 to 3.

Table 2 - Fruit quality of «Frost Navel» nucellar sweet orange on sour orange and «Troyer» citrange rootstocks (Four-year average; fruit samples collected in January 10, 1974, 1975, 1976, 1977) (1).

Tabella 2 - Caratteristiche qualitative dei frutti di arancio dolce «Washington navel» sel. Frost innestato su arancio amaro e citrange «Troyer» (valori medi di un quadriennio: campioni raccolti il 10 gennaio 1974, 1975, 1976 e 1977).

Fruit characteristics	Sour orange	Troyer citrange	Significance level
LENGTH (cm)	7.7	7.5	**
WIDTH (cm)	8.2	8.0	**
L/W RATIO	0.94	0.94	NS
AVE. WEIGHT (g)	247	223	**
RIND TEXT. IND.	7.1	6.9	NS
RIND COL. IND.	10.3	10.2	NS
FLESH COL. IND.	10.5	10.4	NS
FLESH TEXT. IND.	2.7	2.8	NS
RIND THICK. (mm)	6.0	5.4	**
JUICE (%)	47.1	49.3	**
TSS (%)	10.3	10.3	NS
TA (%)	0.84	0.81	NS
TSS/TA RATIO	12.3	12.7	NS

(1) See table 1, footnotes (1), (2), (3), (4).

Table 3 - Fruit quality of «Frost Eureka» nucellar lemon on sour orange and «Troyer» citrange rootstocks (Four-year average: fruit samples collected in January 25, 1974, 1975, 1976, 1977) ⁽¹⁾.

Tabella 3 - Caratteristiche qualitative dei frutti di limone «Eureka» sel. Frost innestato su arancio amaro e citrange «Troyer» (valori medi di un quadriennio: campioni raccolti il 25 gennaio 1974, 1975, 1976 e 1977).

Fruit characteristics	Sour orange	Troyer citrange	Significance level
LENGTH (cm)	8.3	8.3	NS
WIDTH (cm)	6.1	6.0	NS
L/W RATIO	1.36	1.38	NS
AVE. WEIGHT (g)	167	168	NS
RIND TEXT. IND.	6.7	6.9	*
RIND COL. IND.	6.8	7.0	*
FLESH COL. IND.	6.6	6.6	NS
FLESH TEXT. IND.	2.6	2.6	NS
AVE. NO. SEED	7.3	8.8	NS
RIND THICK. (mm)	6.4	5.9	**
JUICE (%)	33.1	34.8	**
TSS (%)	8.4	8.6	NS
TA (%)	5.54	5.56	NS

⁽¹⁾ See table 1, footnotes (1), (2), (3), (4).

percent (W/W)), and increased total soluble solids and acids percentage, while no differences were observed on the other characteristics of the fruit.

In « Frost Navel » orange (Table 2) the fruits from trees on sour orange were larger and heavier than those from « Troyer » citrange, but « Troyer » reduced the fruit rind thickness, and increased the juice content.

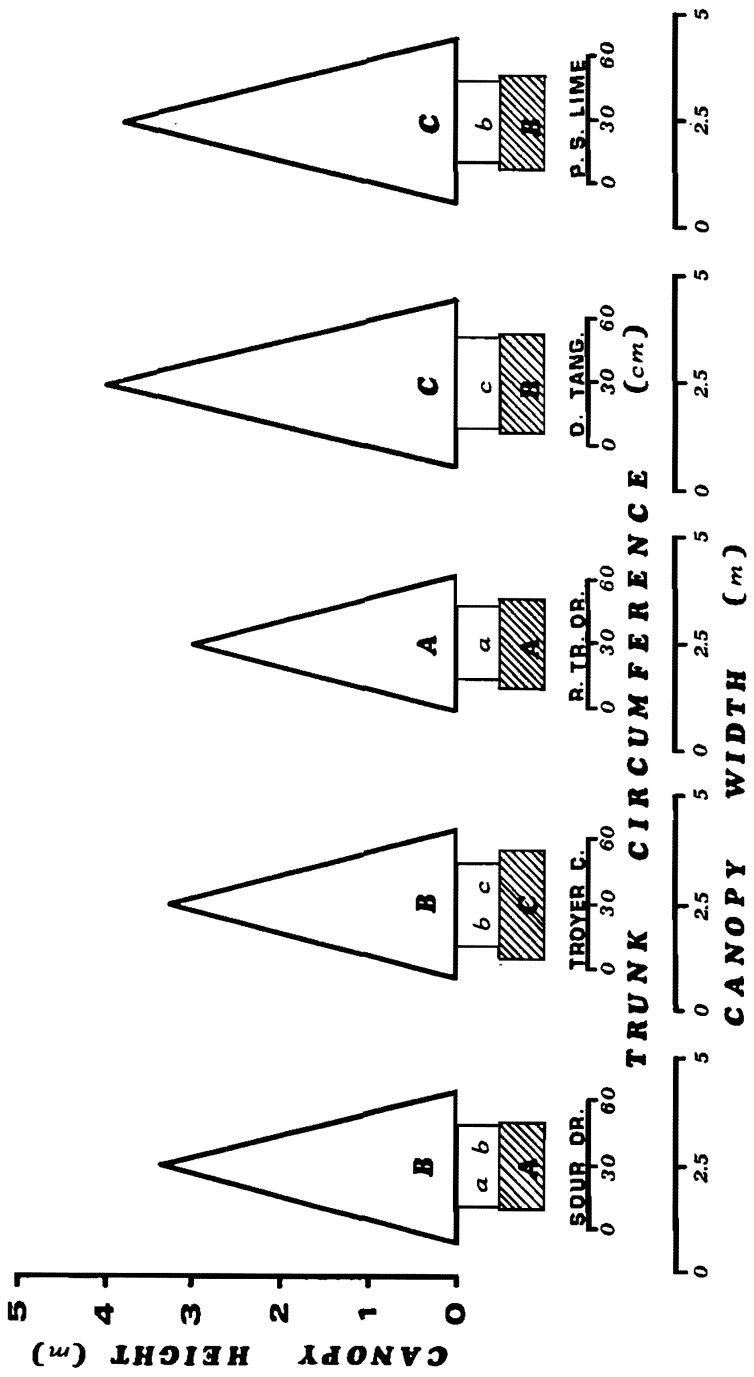
With « Frost Eureka » lemon the fruit quality determinations (Table 3) have shown that « Troyer » citrange improved the rind texture and color, reduced the rind thickness, and increased the juice percentage. No further differences on fruit quality were observed.

Grapefruit trial. The largest trees were found on « Orlando » tangelo and « Palestine » sweet lime, with the smallest ones on « Rubidoux » trifoliolate orange (Fig. 3). Trees on sour orange and « Troyer » citrange had an intermediate growth. The trunk circumference above the bud-union was larger in trees grafted on « Orlando » tangelo, and less in trees on « Troyer » citrange, « Palestine » sweet lime, sour orange, and « Rubidoux » trifoliolate orange.

The largest trunk circumference below the bud-union was on « Troyer » citrange, the smallest on sour orange and « Rubidoux » trifoliolate orange, and intermediate on « Palestine » sweet lime and « Orlando » tangelo. Overgrowth of the rootstock was found in trees grafted on « Troyer » citrange, and on « Rubidoux » trifoliolate orange.

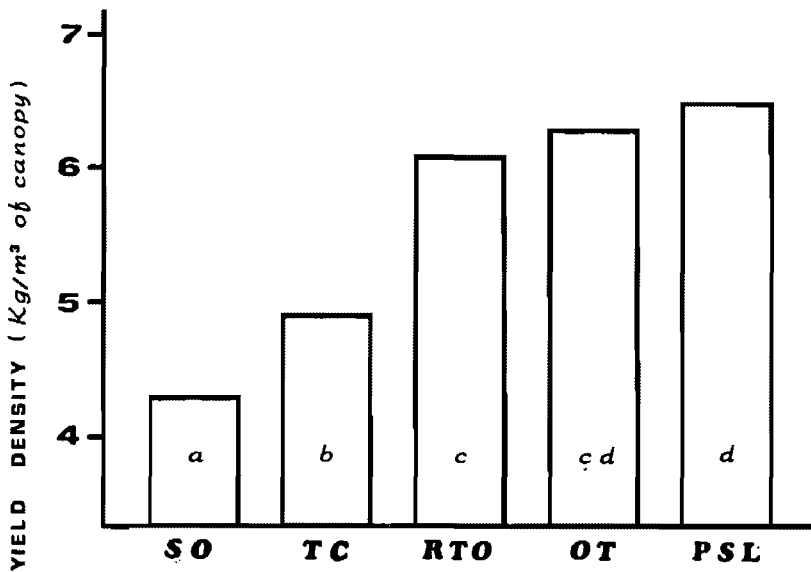
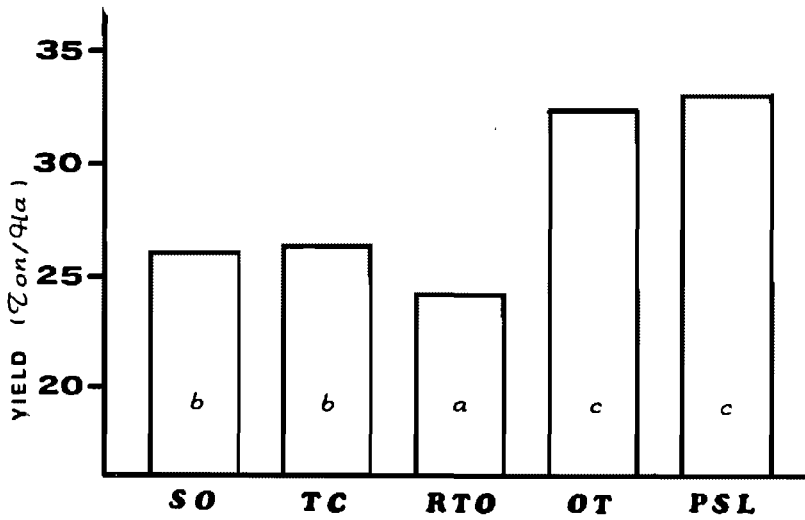
The highest average yield for the last four seasons was obtained from trees grafted on « Orlando » tangelo and « Palestine » sweet lime; the lowest on trees on « Rubidoux » trifoliolate orange, and intermediate in trees grafted on sour orange and « Troyer » citrange (Fig. 4). The yield density was greatest in trees grafted on « Palestine » sweet lime and « Orlando » tangelo. Trees on sour orange had the smallest yield density, followed by trees on « Troyer » citrange. The yield density recorded in trees on « Rubidoux » trifoliolate orange did not differ significantly from the trees grafted on « Orlando » tangelo.

The 4-year average of fruit quality determinations (Table 4) showed that trees on « Palestine » sweet lime, « Orlando » tangelo, and sour orange produced fruits with the largest size, while those on « Rubidoux » trifoliolate orange produced the smallest fruits. The fruit shape was also affected by rootstocks: in fact more flattened fruits were produced by trees on « Palestine » sweet lime and « Orlando » tangelo. The average fruit weight was highest in trees on « Palestine » sweet lime and « Orlando » tangelo, and lowest in trees on « Rubidoux » trifoliolate orange. « Troyer » citrange and



DIFFERENT LETTER OR LETTERS WITHIN THE SAME ROW INDICATE SIGNIFICANT DIFFERENCE (P = 0,05)

Fig. 3 - Growth habit of « Marsh seedless » grapefruit grafted on five rootstocks.
 Fig. 3 - Habitus vegetativo del pompelmo « Marsh seedless » innestato su cinque portinesti.



DIFFERENT LETTER OR LETTERS WITHIN THE SAME ROW
INDICATE SIGNIFICANT DIFFERENCE ($P = 0,05$)

Fig. 4 - Yield/Ha and yield efficiency of « Frost Marsh » grapefruit grafted on five rootstocks (Average of the last four years).

Fig. 4 - Produzione ad ettaro ed efficienza produttiva del pompelmo « Marsh seedless » innestato su cinque portinnesti (Medie degli ultimi quattro anni).

Table 4 - Fruit quality of « Frost Marsh » nucellar grapefruit on five rootstocks. (Four-year average: fruit samples collected in March 27, 1973, 1974, 1975, 1976) (1) (2).

Tabella 4 - Caratteristiche qualitative dei frutti di pompelmo « Marsh seedless » sel. Frost innestato su cinque portinnesti (valori medi di un quadriennio: campioni raccolti il 27 marzo del 1973, 1974, 1975 e 1976).

ROOTSTOCKS	LENGTH (cm)	WIDTH (cm)	L/W RATIO	AVE WEIGHT (g)	RIND TEXT.IND.	RIND COL. IND.	FLESH COL. IND.	FLESH TEXT. IND.	AVE. NO SEED	RIND THICK. (mm)	JUICE (%)	TSS (%)	TA (%)	TSS/TA RATIO
SOUR ORANGE	9.4 c	10.7 c	0.88 b	394 c	7.4	7.0 a	6.9 a	1.9 a	2.1	8.4 c	40.0 b	9.7 b	1.69	5.7 ab
TROYER CITRANGE	8.9 b	10.3 b	0.86 b	383 b	7.5	7.2 ab	7.1 ab	2.2 b	2.0	7.8 b	42.4 c	10.0 b	1.59	6.3 c
RUBIDOUX TRIF. OR.	8.5 a	9.8 a	0.87 b	339 a	7.6	7.4 b	7.4 b	2.3 b	2.0	7.0 a	43.5 d	10.7 c	1.66	6.4 c
ORLANDO TANGELO	8.9 b	10.8 c	0.82 a	418 d	7.4	7.0 a	7.0 a	2.0 a	1.6	9.0 d	38.9 a	9.8 b	1.66	5.9 b
PAL. SWEET LIME	9.0 b	10.9 c	0.82 a	417 d	7.5	7.0 a	6.9 a	2.0 a	2.2	9.3 d	40.2 b	9.1 a	1.65	5.5 a
SIGNIF. LEVEL	**	**	**	**	NS	*	*	**	NS	**	**	**	NS	**

(1) See table 1, footnotes (1), (2), (3), (4).

(2) Means followed by the same letter or letters in each column do not differ significantly at 5%.

« Rubidoux » trifoliolate orange improved the fruit rind color, and the flesh color and texture.

The fruits from trees on « Palestine » sweet lime and « Orlando » tangelo had thick rind, and those from trees on « Rubidoux » trifoliolate orange had relatively thin rind. The juice percentage was highest in fruits coming from trees on « Rubidoux » trifoliolate orange, followed by « Troyer » citrange, « Palestine » sweet lime and sour orange, and « Orlando » tangelo, respectively. « Rubidoux » trifoliolate orange also improved the total soluble solids percentage, and the solids/acids ratio. The lowest total soluble solids content was found in fruits from « Palestine » sweet lime, which also induced the lowest solids/acids ratio. No rootstock effects on rind texture, average seed number per fruit, and total acids were ever observed in this experiment.

DISCUSSION

These experiments show that the yield of « Hamlin » and « Frost Navel » sweet oranges can be significantly increased by the use of « Troyer » citrange rootstock in place of sour orange, as previous results by other authors have demonstrated (2, 3, 4, 22).

Fruit quality was also improved by « Troyer » citrange, according to the other authors (2, 7, 8), although fruit size was slightly reduced (5). On the other hand tree growth was reduced by « Troyer » citrange in « Hamlin » orange (6), but was increased in « Frost Navel » trees (15).

Similar results are reported by Russo (25, 26) for « Moro », « Sanguinello moscato », and « Tarocco » oranges further confirming that « Troyer » citrange can be considered as an alternative rootstock for some Italian sweet orange varieties. A different performance of « Troyer » citrange was observed in « Frost Eureka » lemon. In this case the best growth and productivity was obtained on sour orange which confirms earlier experiments conducted abroad (17, 21, 22), and those reported in Italy by Russo (25) for « Femminello Santa Teresa » lemon. « Troyer » citrange, on the other hand, improved some fruit characteristics like rind texture and color, rind thickness, and juice content.

Even if no definite symptoms of graft-incompatibility, as usually found (1, 12, 19, 21), have been until now observed in our experiment on « Frost Eureka » / « Troyer » combination, low productivity induced by « Troyer » do not encourage its use as a rootstock for « Eureka » lemons. Moreover

this production decline could be a precocious symptom of graft-incompatibility.

The grapefruit experiment confirms only partially the results of some other experiments reported in the literature (9, 10, 14, 16, 23, 24, 28, 29, 30). Those results are not comparable with ours, because of the different environmental conditions, or because not all our rootstocks were compared together in the research reported in the literature. In conclusion this experiment points out that the trees grafted on « Orlando » tangelo and « Palestine » sweet lime gave a greater growth and a greater production than those on sour orange and « Troyer » citrange, while the poorest growth and yield were observed in trees on « Rubidoux » trifoliolate orange. This last rootstock, however, improved fruit quality, since it reduced rind thickness, increased the juice content, the total soluble solids percentage, and the solids/acids ratio. Moreover, because of its dwarfing effect it could be used in high-density plantings.

Acceptable fruit quality was also observed on trees grafted on « Troyer » citrange, while sour orange, « Palestine » sweet lime, and « Orlando » tangelo negatively affected some fruit characteristics, mostly the rind thickness, the juice content and the solids/acids ratio.

Therefore the evaluation of a given rootstock may depend on several factors, and increasing yield may not result in the equal improvement of fruit quality.

SUMMARY

This paper reports further results of long-term research on citrus rootstocks in Sardinia started in 1969. Two rootstocks (sour orange and « Troyer » citrange) have been compared for « Hamlin » and « Frost Navel » sweet oranges, and « Frost Eureka » lemon. Five rootstocks (sour orange, « Troyer » citrange, « Rubidoux » trifoliolate orange, « Orlando » tangelo, and « Palestine » sweet lime) were also compared for « Frost Marsh » grapefruit. The growth and productivity for all of the stock/scion combinations were evaluated from 1973 to 1977. The results showed that both growth and productivity of « Frost Navel » orange were better on « Troyer » citrange than on sour orange. « Hamlin » orange productivity was also improved by « Troyer » citrange, while sour orange increased the tree-growth. In « Frost Eureka » lemon both growth and productivity were increased by sour orange. The fruit quality was normally improved by « Troyer » citrange in comparison with sour orange. The growth and fruit production of « Frost Marsh » grapefruit were mainly increased by « Orlando » tangelo and « Palestine »

sweet lime. Intermediate growth and productivity were found on sour orange and « Troyer » citrange. The lowest growth and yield were recorded on « Rubidoux » trifoliate orange, but it and « Troyer » citrange improved fruit quality.

RIASSUNTO

Vengono riferiti ulteriori risultati di una ricerca a lungo termine sui portinnesti degli agrumi condotta in Sardegna a partire dal 1969.

Sono stati messi a confronto due portinnesti (arancio amaro e citrange « Troyer ») per l'arancio dolce « Washington navel » sel. Frost e « Hamlin », e per il limone « Eureka » sel. Frost; e cinque portinnesti (arancio amaro, citrange « Troyer », arancio trifoliato « Rubidoux », tangelo « Orlando » e limetta dolce di Palestina) per il pompelmo « Marsh seedless » sel. Frost. Su queste combinazioni d'innesto sono state valutate l'attività vegetativa e produttiva dal 1973 al 1977. I risultati hanno messo in evidenza che nel « Washington navel » sel. Frost sia l'accrescimento che la produttività sono stati migliorati dal citrange « Troyer » rispetto all'arancio amaro.

Anche nella cv « Hamlin » la produzione è stata incrementata dal citrange « Troyer » che, a sua volta, ne ha ridotto la vigoria.

Nel limone « Eureka » sel. Frost sia la vigoria che la produttività sono state incrementate dall'arancio amaro. Le caratteristiche qualitative dei frutti sono state generalmente migliorate dal citrange « Troyer » nei confronti dell'arancio amaro.

Nel pompelmo « Marsh seedless » sel. Frost sia l'attività vegetativa che produttiva sono state maggiormente incrementate dal tangelo « Orlando » e dalla limetta dolce di Palestina, seguiti dall'arancio amaro e dal citrange « Troyer ». La minore vigoria e produttività è stata rilevata negli alberi innestati su arancio trifogliato « Rubidoux », ma quest'ultimo, assieme al citrange « Troyer », ha notevolmente migliorato le caratteristiche qualitative dei frutti.

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