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Effects of Forcing Method and Root Pruning on the Growth of Budded 'Rough Lemon' Rootstock Seedlings

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ABSTRACT

Experiments were conducted in 2004 and 2005 at Maseno University, Kenya to investigate the effect of bud forcing method and root pruning on the growth of 'rough lemon' (*Citrus sinensis* L.) rootstocks budded on 'Washington Navel' citrus growing on polythene pots in a polythene-covered greenhouse. The treatments comprised three bud forcing methods: bending, looping, and cutting-off and root pruning on the growth of 8-month old seedlings. The cutting off method was superior to bending and lopping since it increased the dry weights of whole plants, stem, roots, scion leaves, shoot and scion length. Forcing method did not affect the root: shoot ratio or the interaction between forcing method and root pruning. Root pruning did not significantly ($P \leq 0.05$) affect whole plant dry weight but reduced scion leaves, stem and root. Both forcing method and root pruning reduced the dry weights of stem, scion leaves, stem, shoot and root and scion length. Thus, it can be concluded that the cutting-off method is superior to bending and lopping and that the forcing method is influenced by root pruning in affecting budded citrus growth.

Keywords: budding, citrus, forcing, growth, scion

INTRODUCTION

Cutting-off, looping or bending the rootstock shoot are common methods used in citrus nurseries to force scion bud growth (Tucker and Youtsey 1980; Rouse 1988; Williamson and Castle 1989). Forcing methods such as looping and bending, which leave rootstock shoots attached, usually result in greater nursery tree growth than cutting-off rootstock shoots (Amih 1980; House 1988; Williamson *et al*. 1992), most probably due to the photosynthates supplied by the attached rootstock shoots. It has been reported that ^{14}C-labelled photosynthates were found from rootstock shoots in scions and roots of Hamlin-Carrizo trees following bud forcing by bending or looping (Williamson *et al*. 1992). It has been consequently concluded that the benefit to nursery tree growth resulted from photosynthates produced in the rootstock shoot rather than from stored carbohydrate reserves (Williamson and Maust 1995). The main disadvantage of bending or looping is greater production costs which are associated with either of these methods compared to cutting-off rootstock shoots. More labour, irrigation, fertilizer, pesticide and space are usually required for the production of plants forced by bending or looping than for those forced by cutting-off (Williamson 1997).

Root pruning in fruit, forest and landscape tree nurseries is an old and varied practice (Hawley and Smith 1998; Anderson 2001). It has been used as a horticultural tool to produce sturdier trees, force development of a more compact fibrous root system, retard top growth and increase transplant survival and post transplant growth (Mullin 1988). The timing, frequency and location of root pruning are affected by practical experience and tradition than by scientific studies. Root pruning may increase fine root production in the root ball. According to Kramer and Kozlowski (1979) each species has a characteristic root: shoot ratio. When the ratio is changed as it is in transplanting, plants respond by redirecting assimilates to replace the removed parts. Root pruning, while reducing shoot growth, stimulates root growth as the plant attempts to restore the pre-pruning shoot: root ratio (Maggs 1964; Richards and Rowe 1977). Roots regenerate in response to root pruning and originate primarily at or just behind the cut (Wilcos 1955; Gilman 1992). Root pruning has generally reduced tree size and shoot growth (Schupp *et al*. 1992; Feree and Rhodus 1993; Elfving *et al*. 1996) and generally mixed results were obtained from the semi-dwarfing rootstocks of apple such as M7 (Feree and Rhodus 1993; Baugher *et al*. 1995; Miller 1995). Well established root systems with high fibrous root content have improved transplant survival or establishment of field grown citrus nursery trees (Grimm 1956). Many other perennial crops are routinely root pruned in field nurseries to develop more compact, fibrous root forms and higher root to shoot ratios (Geisler and Feree 1984) in some cases (Mullin 1966; Sutton 1967) but not others (Williamson 1997), this result has been correlated with high transplant survival rates and better growth following transplanting.

The present study attempts to investigate the effect of forcing method and root pruning on the growth of 'rough lemon' (*C. sinensis* L.) rootstocks budded on to 'Washington Navel' scions. 'Rough lemons' are the most common rootstocks used in Kenya by citrus nursery owners or managers and farmers and such studies have not been conducted on citrus rootstocks at all let alone 'rough lemon' with respect to forcing methods.

The objectives of the present study were: 1) To investigate the effect of different forcing methods on the growth of budded 'rough lemon' rootstocks; 2) To investigate the effect of root pruning on the growth of budded rootstocks.

The hypothes of the study was that bud forcing method and root pruning would affect the growth of budded 'rough lemon' rootstocks.

MATERIALS AND METHODS

Location of research site

The study was conducted at Maseno University, Kenya. The nurse-

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Table 1 Soil analysis report of Maseno University, Kenya.

Type	Contents	Amount
Acidic	Soil organic carbon	1.8%
	Soil photophorous	4 mg/kg
	pH	4.5-5.0
	Water holding capacity	40%

Source: Netondo GW (1999)

ries are located at 1515 metres above sea level and 34° and 35° East longitude and 0° latitude. The soils comprise a complex of excessively drained, shallow, stony and rocky soils of varying colour, consistency and texture (dystric regosoils with ferralic combisols, lithic phase and rock outcrops. The soils are acidic with highly extractable Ca and K ions (Netondo 1999). For other details of the soils see **Table 1** below. The site has a well-distributed annual rainfall of 1853 mm. The studies were conducted in a polythene-covered greenhouse. The maximum and minimum temperatures in the structure were 26 to 40°C respectively with a relative humidity of 60-70%.

Preparation of experimental materials

On January 20th 2005 rough lemon (*Citrus sinensis* L.) fruits were obtained from a well managed commercial farm near Kisumu City, Kenya, after harvesting. The fruits were transported to Maseno University over 20 km and stored in a refrigerator for two days at 50°C. The fruits were then washed and graded for uniformity of mass and freedom from blemishes. The fruits were subsequently cut in half and seeds extracted from them in warm (70°C) water (Hartmann *et al*. 2001). The seeds were then dried in ordinary metal trays briefly to ready them for planting in the field.

Land preparation, fertilization, planting and subsequent care

Nursery beds measuring 1.5 m × 20 m were well prepared to a fine tilth using hoes and machetes and well mixed with 8 kg of farm yard manure and 200 kg per hectare of Diammonious phosphate fertilizer containing 46% N and 18% P.

The seeds were planted on the nursery beds on January 23rd 2005 at a spacing of 40 cm × 15 cm and a layer of grass mulch put between the holes. The beds were watered daily at 8 a.m. and 5 p.m. to saturation using a watering can. For insect pest control Aldrin at 40% was applied at a rate of 5 g/kg of seed for the control of cut worms and Dimethoate (dimethyl-5-(N-methyl carbamathyl) phosphorothiolo thionate) 40% EC at a rate of 1 L in 500 L of water per ha sprayed at two week intervals. Diseases were controlled by benomyl(methyl[1-[butylamino)carbonyl]-1H-benzimidazol-2yl]carbamate at a rate of 20 g/20 L of water.

Transplanting of seedlings

The seedlings were transplanted into 4.5 L polythene pots at a rate of 6 seedlings per pot. Before the seedlings were transplanted the nursery beds were well watered to facilitate rooting and before that the seedlings were hardened-off by reducing shade which was assumed to increase the amount of light (light levels were not measured). Watering frequency and fertilizer application levels were also reduced.

The media applied to the pots comprised 17: 33: 50 sand: loam: compost. The compost used comprising decomposed crop residues. The media was amended with 2.4 g farm yard manure and 12 g diammonium phosphate $(NH_4)_2HPO_4$ containing 18% P and 46% N. After planting the seedlings were watered every two days in the morning hours. The spacing between the pots was periodically adjusted to minimize shading.

Experimental treatments and design

Budding was done when the seedlings were 8 months old. The budwoods were obtained from the Kodiaga Prison orchards, Kenya and refrigerated overnight at 5°C. The budwoods were cv. 'Washington Navel'. The treatments comprised three forcing methods namely: cutting-off, bending and looping. Cutting-off comprised cutting the rootstock shoot above the bud union three weeks after budding when the shoots from the bud were 10 cm high. Bending comprised bending the rootstock shoot above the bud union, i.e. 21 days after budding while looping comprised bending the rootstock shoot above the bud union, at about 100°, 21 days after budding and tying down the stem of the rootstock shoot of the budded shoots. Half the plants were root pruned once while the rest were not, using a shovel. Root pruning was done by inserting the shovel on the medium containing the plants and cutting all the roots 5 cm from the stem of the plants in all the directions of the pot. The latter operations were carried out two weeks before budding. The experiment was completed when all the plants that forced a scion bud had completed tree scion growth. Flushes of scion bud break were recorded daily for all the plants (data not included). At the conclusion of the experiment all plants were harvested and separated into scion leaves, stems, roots and shoots. All plant parts were dried in an oven at 70°C for 48 hrs and were weighed using a Mettler PE electronic scale (Mettler Instrument Corp. Hightown, NJ) and weight expressed in grams.

The above treatments were replicated three times in a completely randomised design. Analysis of variance (ANOVA) and mean separation using the Least Significant Difference Method was performed at $P \leq 0.05$. All these statistical analyses were done using SAS Institute software (1988).

RESULTS

Forcing method significantly increased the dry weight of whole plants and cutting-off resulted in heavier whole plant dry weight than bending and looping in that order (**Table 1**). Conversely, root pruning had no significant effect on whole plant dry weight. Scion length was significantly increased by forcing method with cutting-off having the longest scions followed by bending and looping which were insignificantly different from each other. Conversely, root pruning reduced it. There was an interaction between root pruning and forcing method which caused a reduction in growth of the scion (**Table 2**). The dry weights of the scion leaves were also significantly affected by forcing method with cutting-off having the heaviest dry weights of scion leaves followed by bending and looping methods. Root pruning reduced the dry weights of scion leaves and interacted with forcing methods to reduce the dry weights of the scion leaves (**Table 2**). The weights of stems were significantly increased by the forcing method and the decreasing trends were cutting-off, bending then looping (**Table 3**). Root dry weight was increased by root pruning and forcing method. Similar trends were obtained with shoot dry weights (**Table 4**). In contrast, the root: shoot ratio was unaffected by both forcing method and root pruning (**Table 5**). There was an interaction between root pruning and forcing method for root and shoot dry weight, and at each forcing method root pruning increased these parameters. Shoot dry weights were highest where cutting-off method was used as compared to bending and looping. Looping resulted in significantly larger weights than bending (**Table 4**).

Table 2 Effect of forcing method and root pruning on the weight of whole 'rough lemon' rootstocks.

Forcing method	Dry weight of whole plant (g)
Bending	70.8
Looping	68.7
Cutting-off	71.6
Control	71.6
Root pruned	69.5
F Significance ($P \leq 0.05$)	
Forcing method	*
Interaction	NS

NS: Not Significant at $P \leq 0.05$
*: Significant at $P \leq 0.05$

Table 3 Effect of forcing method and root pruning on the scion length of whole 'rough lemon' rootstocks and dry weights of scion leaves.

Forcing method	Scion length (cm)	Dry weight of scion leaves (g)
Bending	70.6	71.1
Looping	69.8	68.5
Cutting-off	75.6	87.2
Control	73.4	78.0
Root pruned	70.6	73.4
F Significance ($P \leq 0.05$)		
Root pruning	*	*
Forcing method	*	*

*: Significant at $P \leq 0.05$

Table 4 Effect of forcing method and root pruning on the dry weight of stem 'rough lemon' rootstocks.

Forcing method	Dry weight of stem (g)
Bending	16.3
Lopping	11.2
Cutting-off	35.5
Control	25
Root pruned	20.9
F Significance ($P \leq 0.05$)	
Root pruning	*
Forcing method	*
Interaction	*

*: Significant at $P \leq 0.05$

Table 5 Effect of forcing method and root pruning on the dry weights of shoot, root and root: shoot ratio.

Forcing method	Root dry weight (g)	Shoot dry weight (g)	Root: shoot ratio
Bending	20.0	55.2	0.21
Lopping	17.9	85.6	0.20
Cutting-off	24.7	122.5	0.36
Control	15.7	73.2	0.26
Root pruned	22.8	102.3	0.27
F Significance ($P \leq 0.05$)			
Root pruning	*	*	NS
Forcing method	*	*	NS
Interaction	*	*	NS

NS: Not Significant at $P \leq 0.05$
*: Significant at $P \leq 0.05$

DISCUSSION

Scion bud break was excellent for the cutting-off method but was poor for the other forcing methods (data not shown). Cutting-off method was consistently superior to bending and lopping methods. This is in contrast to the reports by other workers which favoured the bending method (Amih 1980; Rouse 1988; Williamson *et al*. 1992). All the other growth parameters of the rootstock shoots were increased by the cutting-off method. These parameters were whole plant dry weight, dry weight of scion leaves, stem, root and shoot. The scion lengths were also increased. The superiorrity of the cutting-off method may be attributed to the extremely low bud break for the scions for bending and looping methods.

Actually, cutting-off is the main forcing method used in Kenya. The fact that bending and looping methods did more poorly than cutting-off may be the precise reason why the superiority of bending and lopping methods has not been adequately investigated i.e., it may not just be the presence of the leaves which manufacture carbohydrates as reported previously (Williamson and Maust 1995) that promote tree growth. Bending and looping methods performed poorly but bending was generally superior to the latter. Since bending and looping methods are associated with more production costs in terms of irrigation, labour, fertilizer, pesticide and space (Williamson 1997) they would not be ideal in a country like Kenya where these are the constraints to nursery production. Probably the reason why Kenyan nursery owners have resorted to the cutting-off method is the lower cost involved and the fact that it leads to increased nursery tree growth. Finally the fact that the 'rough lemon'–Washington Navel combination was used may have led to these results. Past workers have used 'Hamlin'–'Swingle' (Williamson and Maust 1996) and 'Hamlin' orange budded on *Carrizo citrange* (*C. sinensis* L.) *X Poncinus trifoliata* L.) and 'Cleopatra' mandarin (Williamson 1997).

Root pruning increased the dry weights of roots but reduced the dry weights of the growth parameters. These findings are in agreement with the findings of Gilman *et al*. (1990), Gilman and Yeager (1987), Anderson *et al*. (2001), Gilman (1992), Richards and Rowe (1977), Khan *et al*. (1998), Schupp and Feree (1989), Elfving *et al*. (1996), Anderson *et al*. (2001), Perez-Perez *et al*. (2007) and Sylvertsen and Hanlon (2008), but the main difference with this study was that root pruning was carried out on bud-forced citrus seedlings. Root pruning, while reducing shoot growth, stimulates root growth as the plant attempts to restore the prepruning shoot: root ratio (Maggs 1964; Richards and Rowe 1977). Roots that regenerate in response to root pruning originate primarily at or just at the cut (Wilcox 1955; Gilman 1992). Root pruning apple trees at the same location over 9 years caused a significant reduction in the number of roots of all size classes on the trench face parallel to the root pruning cut (Ferre 1994). Root pruning studies with potted vegetative apple trees reported an increase in fine root growth in the first several weeks after pruning (Geisler and Ferre 1984; Maggs 1964; Schupp and Ferre 1990). Further, Ferre (1984) reported that the reduction of root growth occurred only in the immediate vicinity of the cut. Similar results have been reported by Carlson (1974) and Wilcox (1955). Pruning of the root system reduces regrowth in terms of total plant dry weight according to the severity of pruning, shoot dry weight being more affected than root dry weight (Anderson 2001; Sylvertsen and Hanlon 2008). Root pruning reduces shoot growth by limiting gibberellin activity in fruit trees (Saure 2007).

Root pruning in fruit, forest and landscape tree nurseries is an old and varied practice (Hawley and Smith 1998). It has been used as a horticultural practice to produce sturdier trees, force development of a more compact fibrous root system, retard top growth and increase transplant survival and post transplant growth (Mullin 1988). Several authors (Brouwer and Dewit 1960; Kramer and Kozlowski 1979; Brouwer 1983) have proposed that a functional equilibrium exists in plants and that after a portion of either the root or shoot system is removed, the growth of the remaining part is invigorated, which restores the root/shoot balance according to Kramer and Kozlowski (1979) each species has a characteristic root to shoot ratio. When the ratio is changed as it is in transplanting plants respond by reducing assimilates to replace the removed parts. Root pruning may increase fine root production in the root ball and while reducing shoot growth stimulates root growth as the plant attempts to restore the pre-pruning shoot to root ratio (Maggs 1964; Richards and Rowe 1977). Short term studies with small potted plants demonstrated that there is a redistribution of growth and translocation of assimilates in favour of the root system following root pruning (Maggs 1964; Alexander and Maggs 1971; Rook 1971; Richards and Rowe 1977; Ghobrial 1983; Geisler and Ferre 1984; Schupp and Ferre 1990). However, overall plant dry weight was reduced by root pruning in these studies. Roots regenerate in response to root pruning and originate primary at or just behind the cut (Wilcos 1955; Gilman 1992). Root pruning generally reduces tree size and shoot growth (Ferre and Rhodus 1993; Miller 1995; Elfving *et al*. 1996). A well established root system with high fibrous root content improved transplant survival or establishment of citrus trees (Grimm 1956). Many other perennial crops are routinely root pruned in field nurseries to develop more compact, fibrous root forms and higher root to shoot ratios (Geisler and Ferre

1984). In some cases (Mullin 1966; Sutton 1967) but not others (Janouch 1972), this result has been correlated with high transplant survival rates and better growth following transplanting. Further, root pruning reduces water uptake (Watson and Sydnor 1987; Moya *et al*. 2002; Perez-Perez 2007): in doing so it reduces shoot growth. In citrus trees there is usually less root dry weight than shoot dry weight and growers should avoid many changes in root to shoot ratio to maintain high yields by not doing too much root pruning (Sylvertsen and Hanlon 2008).

However, in the present study the root: shoot ratio was unaffected by root pruning unlike previous studies. Atkinson (1980) found that 70% of the root system of some fruit trees occurs at a 0-30 cm depth with declining root density with increasing depth. Greenhouse studies demonstrated that 30% or more of the roots needed to be pruned before shoot growth was reduced and as the severity of root pruning increased a corresponding growth reduction occurred (Geisler and Ferre 1984). The above mentioned observations may explain why the root: shoot ratio was unaffected in this study i.e. less roots were pruned to reduce the shoot growth sufficiently to affect the root to shoot ratio. More studies are needed to explain this latter reasoning.

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