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Full Length Research Paper

Scion and stock diameter size effect on growth and fruit production of *Sclerocarya birrea* (marula) trees

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Sclerocarya birrea **(marula) is a highly valued fruit tree in southern Africa because of its products which have gained both regional and international markets. However, its fruits have been harvested from the wild with a few provenances being managed on farmland. Grafted marula trees have shown wide variations in scion and rootstock growth (for example, stem diameters), but effects of these variations on tree survival, growth and fruit production have not been evaluated. The objectives of this study were to (1) assess variations in growth of scions and their stocks and (2) evaluate the effect of scion and stock growth differences on overall grafted tree growth, survival, flower and fruit production on farmland, six to eight years after planting. Over 70% of the grafted trees had similar scion and stock diameters, while 24% had thicker (i.e, slow growing) scions than their stocks. Trees with similar scion and stock growth rate had a high flowering percentage (> 40%), but there was also significant fruit abortion during the three years of fruit production. Grafted trees with thicker scions than their stocks produced significantly more ($P < 0.05$) fruits than the rest. Such trees were also significantly ($P < 0.0126$, $N = 50$) taller than the rest. There was a low survival for grafted trees with either thick or thin scions relative to the stock diameters. It can be concluded that unequal growth rate of scion and stock in grafted marula trees has a negative effect on early tree survival and dwarfing characteristics, but this may not reduce fruit yield in the early years. Therefore, scion and stock selection is critical to reduce growth variations which have negative effects on grafted tree growth and fruit productivity.**

Key words: Fruit abortion, graft compatibility, phenotypic variations, tree dwarfing.

INTRODUCTION

Sclerocarya birrea (A. Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro also known as Marula is an economically important indigenous fruit tree in southern Africa (Leakey et al., 2005). It belongs to the Anacardiaceae family just like mango and cashew. Its fruits and other products have gained regional and international markets (Shackleton, 2002; Wynberg et al., 2002). The fruits are processed into traditional beer, 'Amarula cream' liqueur, jams, wine, juice and many other products (Leakey et al., 2005). The Amarula cream liquor, produced by Distell Corporation in South Africa, is commercially sold in 63 countries world-wide (Ham, 2005; Ham et al., 2008). It is estimated that the total value of the commercial marula trade to the rural communities is worth US$ 160,000 a year in South Africa (Mander et al., 2002). The marula fruits and kernels are potential sources of high quality oil that is rich in tocopherol (Leakey, 2005) used in the cosmetic industry (Wynberg et al., 2002). Despite the significant contributions of the marula trees to the livelihoods of many communities of southern Africa, there have been limited studies undertaken on the field cultivation and

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management of these trees. Currently, harvests of marula fruits and its other products depend entirely on wild populations, but this may not be sustainable as wild harvesting, especially on a large scale, can lead to overexploitation (Akinnifesi et al., 2008).

Marula is a deciduous tree with a dioecious reproduction system, but there are also claims that it is monoecious (Shackleton, 2002). It grows in a wide range of soils and preferably well-drained soils. The ideal altitude varies from 0 to 1800 m above sea level and the annual rainfall range from 200 to 1500 mm. However, it is sensitive to frost (Shackleton, 2002). The marula trees propagated from seeds have a long vegetative (juvenile) phase, but there are mixed reports regarding the time they take to first fruiting. Emanuel et al. (2005) reported that female trees take 19 years to first fruiting, while Moganedi et al. (2007) indicated about 8 to 10 years to first fruiting after planting. At Makoka in southern Malawi, marula trees fruited after 10 to 12 years, although the fruit loads were low (Akinnifesi et al., 2006). Differences in time to first fruiting could depend on both genetic and environmental factors as marula trees exhibit wide genetic variations (Kadu et al., 2006). According to Moganedi et al. (2007), grafted marula trees started producing fruits four years after planting in South Africa, but there were phenotypic variations in terms of flowering time and other traits within some lines. Morphological and molecular studies have shown growth variations among marula provenances (Rukuni et al., 2001; Chirwa et al., 2007; Kadu et al., 2006), but the effects of variations in scion and rootstock growth on the overall tree growth and fruit yield have remained unclear. Although, grafting is desirable to achieve fruiting precocity and dwarfing, graft failure has been reported in marula (Moganedi et al., 2007). The main cause of graft failure has remained unclear and complex as it is often linked to a number of factors including genetic constitution, graft incompatibility and the environment (Usenik and Štampar, 2000). Therefore, the objectives of this study were to (1) assess variations in growth of scions and their stocks and (2) evaluate the effect of scion and stock growth differences on overall grafted tree growth, survival, flower and fruit production on farmland six to eight years after planting.

MATERIALS AND METHODS

Study site

The study was carried out at ICRAF-Makoka in Zomba, Malawi with an altitude of 1029 m above sea level (masl), 15° 30' S latitude and 35° 15' E longitude. It has annual rainfall variations ranging from 560 to 1600 mm and temperatures vary between 16 and 32°C (Akinnifesi et al., 2008). The soils are Ferric Lixisol and the soil texture is 46% sand, 46% clay and 8% silt. The clay content increases with soil depth, but major chemical characteristics are relatively constant to >1 m depth. The soil chemical properties in the top 20 cm soil are: pH 5.62, 1.08% organic carbon, 38.31 mg kg^{-1} phosphorus, 1.30 cmol kg^{-1} potassium, 12.11 cmol kg^{-1} calcium and 0.86 cmol kg^{-1} magnesium. The soil organic carbon content decreased with depth. The soil exchangeable cations (Ca, Mg and K) were generally higher in the top 20 and 60 to 100 cm depths (Akinnifesi et al., 2008).

Plant materials

Marula fruits were collected from forest in Zomba and their seeds were used to raise rootstocks. Scions were collected from mature and bearing marula trees in Mangochi (14° 28′ S latitude, 35° 14′ E longitude and 469 masl with maximum temperatures of more than 32°C) in Malawi. Mangochi is more than 100 km from ICRAF-Makoka in Zomba. The scions were grafted onto one-year old marula seedling rootstocks at pencil thick size (10 mm in diameter) and 40 to 50 cm tall using a splice grafting method (Akinnifesi et al., 2008). At the time of grafting, all scions were grafted to rootstocks of almost similar sizes (that is, diameter size). After 6 months in the nursery, 96 grafted marula trees were planted at ICRAF-Makoka in December 2003 at the spacing of 2 m within rows and 5 m between rows (planting holes of 60 cm width and 60 cm deep) and in three blocks (arranged in a randomized complete block design). These grafted plants received different soil amendment (manure and fertilizer) and dry-season irrigation treatments in the first three years after planting, in order to improve their survival and growth. However, none of the different treatments either singly or in combination significantly influenced survival of the grafted marula trees (Akinnifesi et al., 2008). This trial has been managed by weeding only since then. The morphological growth similarities and differences between scions and their rootstocks (2009 to 2011) of 65 grafted trees were assessed visually and differences in scion and stock diameter were noted. As shown in Figure 1a and b, some grafted plants had similar scion and rootstock diameter, while others had thicker or thinner scion compared to their respective rootstocks. The second assessment was based on measurements to verify the observed growth variations between scions and their rootstocks and 50 grafted marula trees were measured. In this assessment, grafted trees were grouped into having either thinner, thicker or same (similar) scions compared to their respective rootstocks. “Thinner” represents faster growth in diameter of the rootstock relative to the scion, while “thicker” represents the opposite. “Similar” represents the same rate of growth in diameter of the scion and rootstock. The number of trees (out of a total of 50 trees) in each category (thinner, thicker or similar) was also calculated based on either ± 0.25, 0.5, 0.75, 1.0 or ±1.5 cm stem diameter size differences, and these measurement differences were selected to minimize subjectivity and match visual assessment and the actual measurements collected.

Statistical analysis

Tree height, flowering, fruit yield, scion and rootstock diameters and tree survival data were statistically analyzed using PROC MIXED procedure of the Statistical Analysis System (SAS) (SAS, 1999). Three different scion and rootstock growth variations identified (thick, thin or similar scion diameter sizes) formed the random treatment components in the statistical analysis. Means, standard errors and percentages were calculated from the counts based on the five (5) categories of scion and rootstock diameter variations (that is, ± 0.25, ± 0.5, ± 0.75, ± 1.0 or ± 1.5 cm) selected during the scion/rootstock diameter measurement assessment.

RESULTS

Variations in tree survival

There was a significant increase ($P =$ 0.0141) in grafted

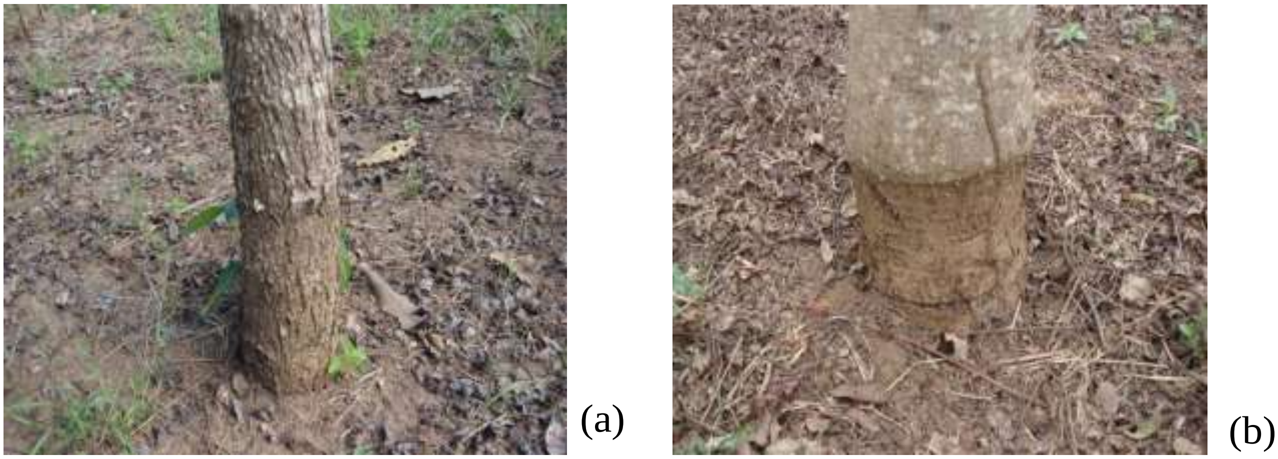

Figure 1. Grafted *Sclerocarya birrea* (marula) trees showing morphological growth differences between scion and rootstock (a) uniform scion and rootstock stem diameter (b) enlarged scion on a small rootstock at ICRAF-Makoka in Malawi.

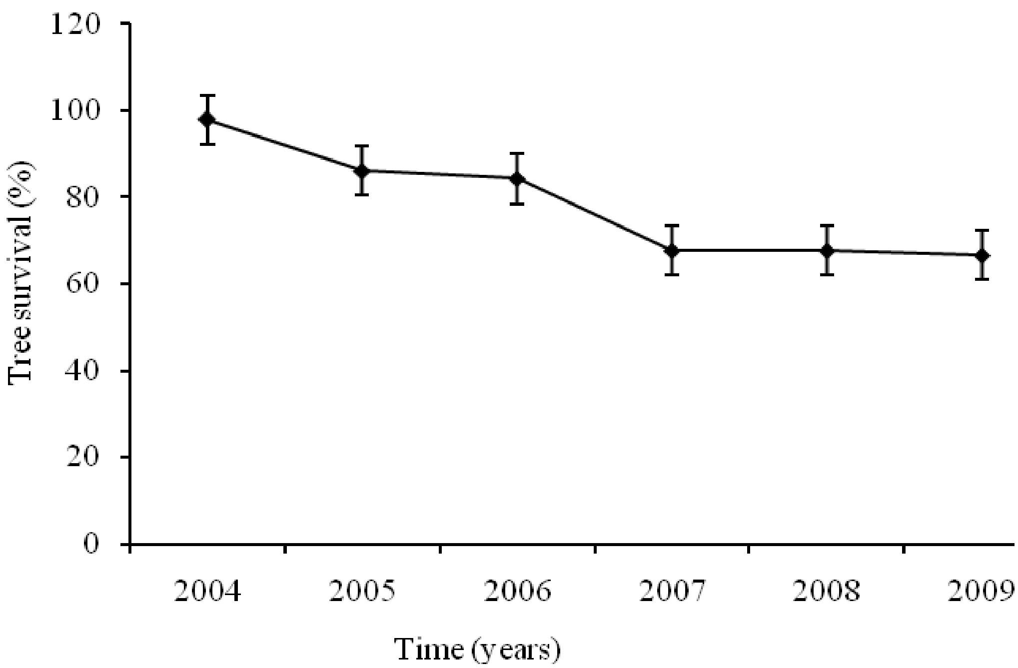

Figure 2. Survival (%) of *Sclerocarya birrea* (marula) trees seven years after planting at ICRAF-Makoka in Malawi.

tree mortality (67%) six years after planting (Figure 2). The highest tree mortality (16.5%) was from the third year to the fourth year after planting (2006 to 2007) and then tree survival remained almost stable until 2009 (Figure 2).

Scion and stock variations

Over 70% of grafted trees had similar scions and rootstocks (that is, diameter), while 6% had scions thinner than their rootstocks and 24% had scions thicker than the respective rootstocks (Table 1) based on visual assessment. Measured scion and rootstock diameters (Table 2) indicated an increase in number of trees whose scions and rootstocks were similar in stem diameter at any selected interval (with a mean of 67.6% ± 5.27). This was followed by those with thicker scions than their rootstocks (a mean of 21.6% ± 3.37). At ±1.5 cm stem diameter size differences between scions and their rootstocks, there were 84% of grafted trees whose scions

Table 1. Visual assessment of *Sclerocarya birrea* (marula) morphological growth patterns at the graft union interfaces at ICRAF- Makoka fruit orchard (*N* = 65).

Scion/stock stem diameter size	Number of trees (%)
Scions similar to rootstocks	70
Scions thicker than rootstocks	24
Scions thinner than rootstocks	6

Table 2. Counts based on stem diameter size differences of grafted *Sclerocarya birrea* (marula) trees (*N* = 50).

Stem diameter	0.25 cm	0.5 cm	0.75	1.0 cm	1.5 cm	Mean
Similar size	27	30	33	37	42	33.8±2.63
Thicker Scions	15	13	11	10	5	10.8±1.69
Thinner Scions	8	7	6	3	3	5.4±1.03
Percentages (%) of each stem diameter size						
Similar size	54	60	66	74	84	67.6±5.27
Thicker scions	30	26	22	20	10	21.6±3.37
Thinner scions	16	14	12	6	6	10.8±2.06

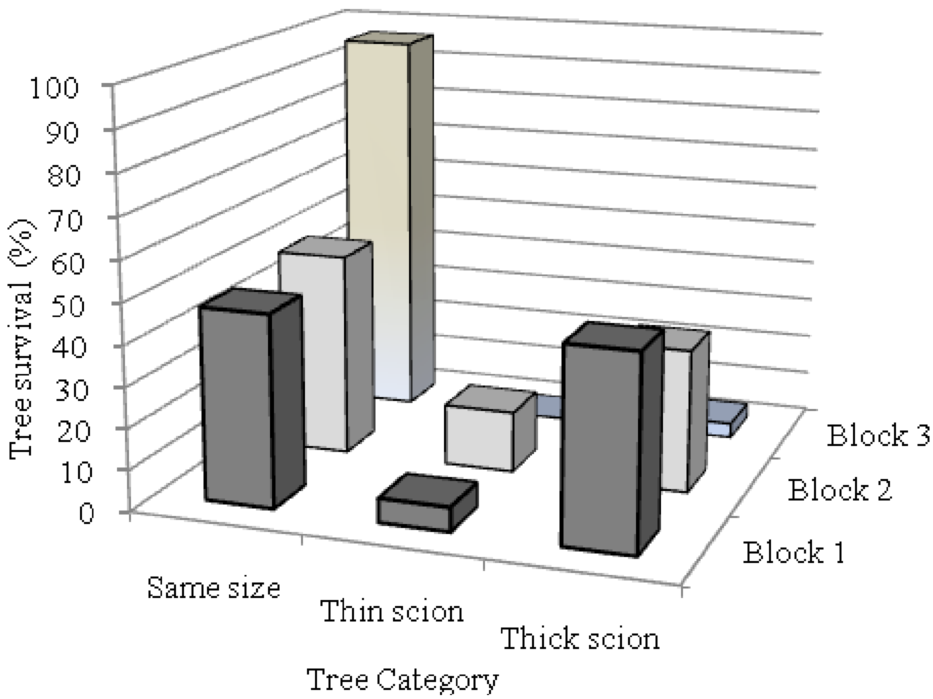

Figure 3. Survival (%) of *Sclerocarya birrea* (marula) trees with respect to the three different scion diameter sizes (same/similar, thinner and thicker scions) in three blocks.

and rootstocks were similar in diameter, while only 10% of them had thicker scions than their rootstocks (Table 2). The data in Figure 3 shows distribution of grafted marula trees per block with respect to survival (*N* = 65). A high mean percentage (64% ± 16) of trees whose scions and rootstocks were similar in stem diameters survived. This was followed by those trees whose scions were thicker than their rootstocks (29% ± 13). The remaining grafted trees (7% ± 4.4) had thinner scions relative to their respective rootstocks. Grafted trees with similar sized

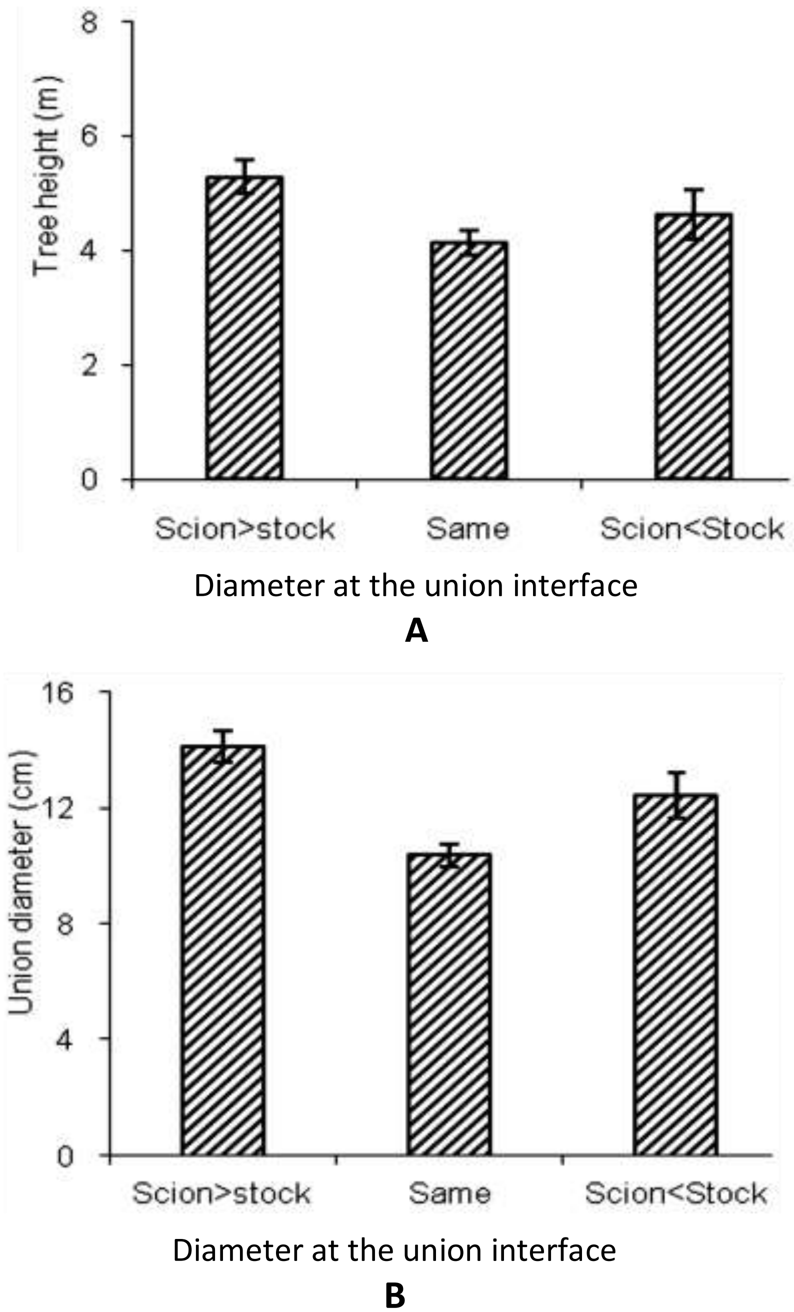

Figure 4. *Sclerocarya birrea* (marula) growth (a) tree height (m) in relation to their stem diameter sizes of the scions and rootstocks (b) stem diameter at the graft union.

scions and rootstocks were significantly (P = 0.0126, N = 50) shorter (4.14 ± 0.21 m) than the rest (Figure 4a). A similar trend is also shown with respect to stem diameter size at the union interface (Figure 4b).

Variations in flower and fruit production

The grafted trees with similar scion and rootstock diameter produced significantly (P = 0.0401) larger number of flowers six years after planting (Figure 5a). A similar trend was also obtained seven years after planting (Figure 5b). This was followed by those with thicker scions than their rootstocks.

Grafted trees with scions thicker than their respective rootstocks had a significantly (P < 0.050) higher fruit load than the rest of the tree categories, six to eight years (2009 to 2011) after planting (Figure 6). However, there

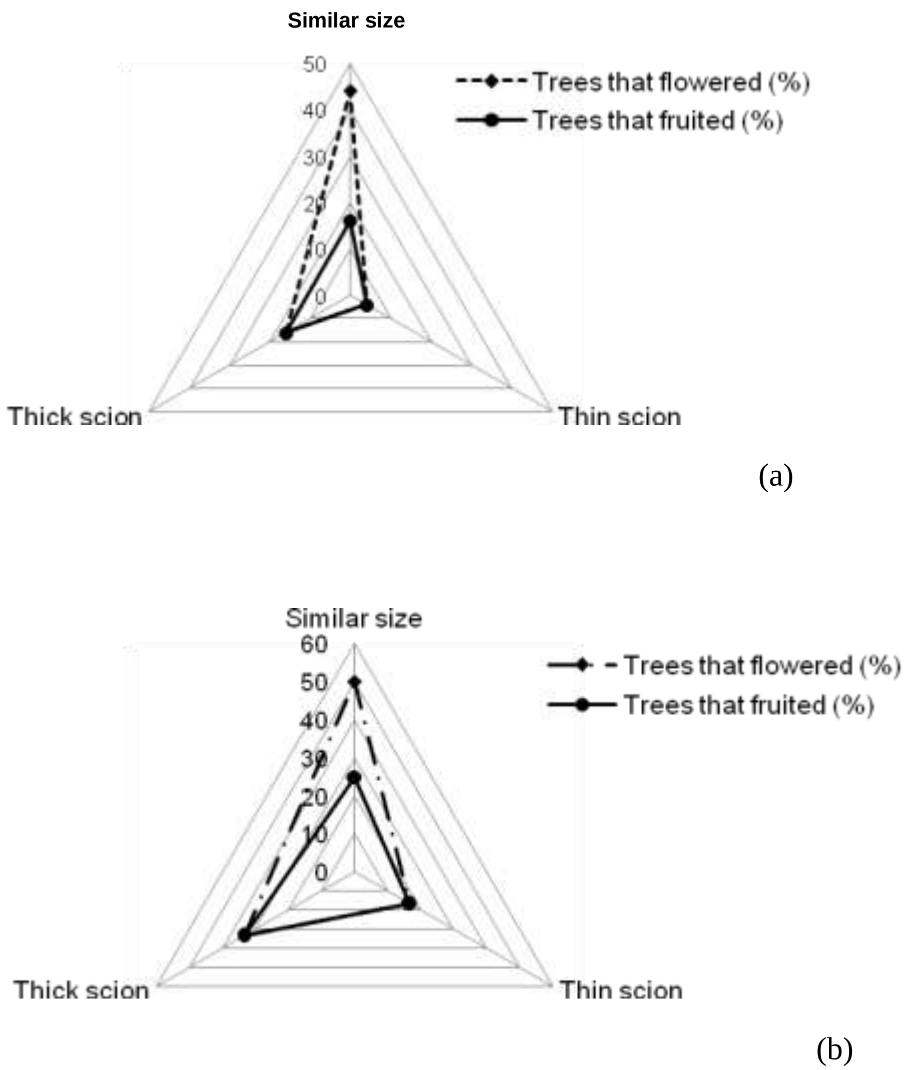

Figure 5. *Scerocarya birrea* (marula) flowering and fruiting patterns at ICRAF Makoka (a) six (2009) and (b) seven (2010) years after planting at ICRAF-Makoka in Malawi.

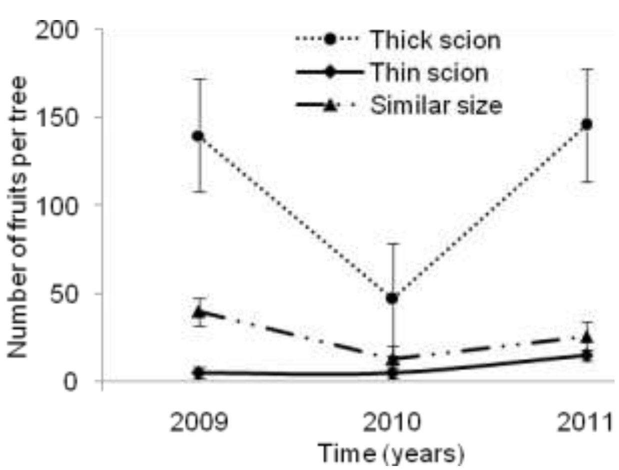

Figure 6. *Sclerocarya birrea* (marula) fruit yield after six to eight years after planting at ICRAF-Makoka in Malawi.

was a lower fruit production in the second year (2010) followed by an increase in fruit load in next fruit production season (2011).

DISCUSSION

An increase in tree mortality indicates that graft failure in marula can occur in an orchard after a successful graft-take in the nursery. The harsh field conditions, scion and rootstock growth variations and other factors could promote early mortality of the grafted trees. In this study, high tree mortality, three years after planting, could partially be attributed to no further application of dry-season irrigation and soil amendment (Akinnifesi et al., 2008). They found low growth of grafted marula trees at 33 months, despite soil amendment and dry-season irrigation. Mateke (2000) reported that survival of grafted marula trees ranged from 0 to 100% in Botswana, and this depended upon the location. Furthermore, Mhango and Akinnifesi (2001) reported low survival and growth of grafted marula trees in the field. These reports indicate that the low survival and growth of the grafted marula trees could not be attributed to poor soil and water stress alone. Other factors such as graft incompatibility, irregularities and/or failure could significantly contribute to poor survival of marula trees. Genetic and environmental differences between the source populations for scions (from Mangochi district) and rootstocks (from Zomba district) could have contributed to the observed graft problems. This study highlights the fact that morphological growth irregularities could occur if scions are collected at random from different mother trees with no traceable relation to the rootstocks. This can contribute to scion/rootstock morphological growth irregularities which could lead to graft compatibility problems. Leakey (2005) reported tree-tree phenotypic variations for marula provenances in South Africa and Namibia, and hence selection of compatible scions and rootstocks is critical to reduce growth irregularities.

In this study, both assessments (observations and measurements) indicated that trees whose scions and rootstocks were similar in stem diameters were abundant (>50%), then followed by those with thicker scions (Tables 1 and 2). Also, findings obtained through observation assessment matched with the actual measurements of the stem diameters, especially at ± 1.0 cm stem diameter difference. Assessment by observation was also reliable in classifying the three categories of scion and rootstock stem diameters. The presence of many trees with either thicker or thinner scions than their rootstocks contributed to high tree mortality. For instance, block 3 with a high number of trees (96%) whose scions and rootstocks were similar in stem diameters had a higher total tree survival than the other scion and rootstock categories. This reinforces the fact that morphological growth irregularities between scions and their rootstocks bring some graft problems. According to Rouphaela et al. (2010), tissue and structure growth differences can bring graft problems apart from other factors. In this study, grafted trees with similar scion and rootstock sizes exhibited significant dwarfing in growth, compared to those where scions and rootstocks grew at different rates. Tree dwarfing is a desirable trait, as it allows harvesting of fruits easily and efficient resource utilization, including close tree spacing (less land area) and less tree pruning. Grafted marula trees with morphological growth irregularities were tall and this is critical as marula fruits fall when ripe (Emanuel et al., 2005), which could increase incidences of fruit damage due to impact upon hitting the ground. Furthermore, marula trees with thick scions compared to their rootstocks are highly prone to graft failure due to a heavy load of the scion (huge mass of scions and high fruit load) being imposed on small rootstocks. This could be a threat to the survival of such trees. Grafted marula trees whose scions and rootstocks grew at the same rate produced more flowers than the rest (unlike trees with irregular scion and rootstock growth). Surprisingly, trees with irregular scion and stock growth rate had minimal fruit abortion. Marula trees with thick scions compared to their rootstocks had a high fruit load. Possibly, their prolific growth (tall trees with thick stem sizes) contributed to prolific fruit production in this study. The trees exhibited alternate bearing as evidenced by low fruit production in 2010 and high in both 2009 and 2011 fruiting season. Alternate bearing is common in mango trees, which belong to the same Anacardiaceae family. However, this may need further research for confirmation, as the present fruit yield data (three years) collected might not be sufficient to be conclusive. Marula trees are known to be prolific in fruit production. Mojeremane et al. (2010) reported production of 50,000 to 90,000 fruits per year from trees derived from seeds/seedlings. In this study, the trees were still in their early years of production and possibly the low temperatures at the study site (Zomba) might be too low for optimal marula fruit production, compared to their usual (natural) environment. In Mangochi, marula fruit production has been observed to be high and this could be attributed to fairly drier and high temperatures. Furthermore, marula trees in Mangochi have been observed to start bearing fruits six years after planting.

Conclusion

There have been significant morphological growth irregularities for both the marula scions and rootstocks and these scion and rootstock growth variations have negative effect on grafted tree survival and dwarfing characteristics in a marula fruit orchard. Although, these morphological growth variations might not have negative effect on fruit production, graft failure poses a great threat to the old, huge and fruit loaded grafted marula trees, especially those with thicker scions than their rootstocks. The findings indicate that scion and rootstock selection is critical in grafting marula trees to reduce scion and rootstock morphological growth irregularities which could bring graft failure in an orchard. This study warrants further studies to select marula genotypes or provenances with insignificant morphological growth irregularities between scions and their rootstocks when grafted. Furthermore, other practices such as tree pruning and training needs investigations to ascertain their effects on dwarfing, scion/rootstock growth patterns and promoting early fruit production for the grafted marula trees.

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