Yield, Fruit Quality Traits, and Leaf Nutrient Concentration of ‘Prolific’ Sapodilla Grafted onto Seedlings of 16 Sapodilla Rootstocks in Puerto Rico

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Summary. Research on sapodilla (Manilkara zapota) has been very limited. A field study was conducted to determine the yield potential, fruit quality traits, leaf nutrient composition, and scion/rootstock compatibility of ‘Prolific’ sapodilla grafted onto 16 sapodilla rootstock seedlings. For this purpose, seedlings (maternal half-sibs) of cultivars Adelaide, Arcilago, Aruz, Blackwood, Blocksberg, Guilbe, Hamza, Jamaica-1, Larsen, Mendigo-1, Galleria, Morning Star, Russel, Prolific, Timothe, and Vasallo-1 were used as rootstock seedlings and evaluated during 7 years of production at Isabela, PR. Year showed a significant effect on the number of fruit per hectare, yield, individual fruit weight, fruit length and diameter, and total soluble solids. Rootstock seedlings had a significant effect on the number of fruit per hectare, yield, and individual fruit weight but had no effect on other fruit traits. The year × rootstock interaction was not significant for any of the variables measured in the study. Rootstock seedlings ‘Timothe’, ‘Vasallo-1’, ‘Larsen’, and ‘Aruz’ had the highest 7-year mean for number and the yield of fruit averaging 4479 fruit/ha and 1245 kg/ha–1, respectively. ‘Timothe’ and ‘Vasallo-1’ significantly out yielded the ‘Prolific’ rootstock seedling. The number of fruit per hectare and corresponding yield obtained in this study were very low probably as the result of wind exposure, the presence of the fungus Pestalotia causing floral necrosis, or both. Scion/rootstock incompatibility was not the cause of the low yield performance of grafted trees. The average individual weight of fruit was 282 g and ranged from 264 to 303 g. Averaged over rootstock seedlings, leaf tissue nutrient concentration did not vary greatly over time. Moreover, tissue nutrient concentration was similar before and after fertilization events.

Sapodilla is a member of the Sapotaceae family and is native to southern Mexico and Central America. The sapodilla is not strictly tropical as it can withstand freezing temperatures for several hours. It thrives well on sandy, clay, organic, or calcareous soils and is reputed to be drought tolerant (California Rare Fruit Growers, 1996; Morton, 1987). There are about 13 cultivars identified with commercial potential for Florida (Campbell and Ledesma, 2002; Crane and Balerdi, 2005). Two of these cultivars, Prolific and Russell, have been evaluated in the semiarid coast of Puerto Rico for yield, chemical composition, and flavor (Velez-Colon et al., 1989).

Recommended plant spacing for commercial production is 25 ft apart within a row and 15 ft between rows, about 330 trees/ha (Crane and Balerdi, 2005). The fertilizer recommendation for 8-year-old bearing trees is 800 g of nitrogen (N), 175 g of phosphorous (P), and 200 g of potassium (K) per year. Studies have shown that Thai cultivars respond well to pruning but those from Tropical America responded poorly (Wasielewski and Campbell, 1999).

Some cultivars fruit year-round. The fruit reaches maturity at 4–6 months after tree flowering. During a 4-year experimental harvest cycle conducted at the semiarid region of Puerto Rico, trees of ‘Larsen’, ‘Russel’, and ‘Prolific’ yielded 205, 175, and 91 kg of marketable fruit/tree per year, respectively (Velez-Colon et al., 1989). In Venezuela, Quijada et al. (2005) evaluated three, 8–10-year-old sapodilla cultivars grafted onto a Criollo rootstock during a 3-year harvest cycle. Tree yield as high as 436 kg/tree per year was reported; however, the authors found large variability in fruit production averaging 271% within the same cultivars and 872% between cultivars during the harvest cycle. Mature sapodilla fruit will ripen in 5–10 d at room temperature. The shelf life can be extended to about 15 d if the fruit is ripened at 20 °C. Treatment of fruit with 1-methylcyclopropene (1-MCP) at 100 nL–1 resulted in a shelf life of 38 d at 14 °C (Arevalo et al., 2007). The most reliable method of propagation is by grafting but because of the profuse fruit production and ease of care, sapodilla is easily grown by home gardeners.

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Units

| To convert U.S. to SI, multiply by | U.S. unit | SI unit |
|-----------------------------------|-----------|--------|
| 0.4047                            | acre(s)   | ha     |
| 29.5735                           | fl oz     | mL     |
| 0.3048                            | ft        | m      |
| 3.7854                            | gal       | L      |
| 2.54                              | inch(es)  | cm     |
| 25.4                              | inch(es)  | mm     |
| 0.4556                            | lb        | kg     |
| 1.1209                            | lb/acre   | kg/ha–1|
| 1.6093                            | mph       | km/h–1|
| 28.3495                           | oz        | g      |
| 1                                 | ppb       | nL–1   |
| 1                                 | ppm       | mg/ha–1|
| 1                                 | ppm       | μg/ha–1|
| 6.8948                            | psi       | kPa    |

For conversion from SI to U.S., multiply by:

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| 1      | ppm     | μg/ha–1|
| 6.8948 | psi     | kPa|

(°F × 1.8) + 32 for °F and °C.
Variety Trials

has a pH of 7.03, 29.8 mg perthermic Typic Hapludox). The soil (Coto clay: clayey, kaolinitic isohy-

patibility, and tissue nutrient quality traits, scion/rootstock com-

mited with moderate success. Vegetative propagation promotes tree
dwarfing, early bearing, and increase in yield (Morton, 1987). Little research has been conducted to evaluate
sapotilla rootstocks. The objective of this work was to evaluate 16
sapotilla rootstock seedlings for fruit quality traits, scion/rootstock com-

ity, and tissue nutrient concentration.

Materials and methods

This study was conducted in Puerto Rico at the U.S. Department
of Agriculture, Agricultural Research Service Research Farm in Isabela
(Coto clay: clayey, kaolinitic isohyperthermic Typic Hapludox). The soil
has a pH of 7.03, 29.8 mg kg⁻¹ ammonium-N (NH₄-N), 14.0 mg kg⁻¹
nitrate-N (NO₃-N), 21.0 mg kg⁻¹ P, 570 mg kg⁻¹ K, 431 mg kg⁻¹ calcium
(Ca), 219 mg kg⁻¹ magnesium (Mg), 107 mg kg⁻¹ iron (Fe), 51 mg kg⁻¹
manganese (Mn), 6.1 mg kg⁻¹ zinc (Zn), and 1.94% organic carbon. The
93-year (1919–2012) mean annual rainfall is 1649 mm and minimum A
pan evaporation is 1672 mm. Mean monthly maximum and minimum
temperatures are 29.8 and 19.9 °C.

Soil samples were taken 2 months before planting by taking 15 borings
at a depth of 0–25 cm from each of the projected tree rows. Samples were
air-dried and passed through a 20-mesh screen. Soil pH in water and
0.01 M calcium chloride (1 soil : 2 water) were measured with a glass
electrode. Exchangeable cations (K, Mg, and Ca) were extracted with
neutral 1 N ammonium acetate and determined by atomic absorp-
tion spectroscopy (Sumner and Miller, 2007). Phosphorus was extracted
with 1 N ammonium fluoride and 0.5 N hydrochloric acid (HCl) and determined using the
ascorbic acid method (Benton, 2001). Organic carbon was deter-
mined by the Walkley–Black method (Nelson and Sommers, 2007). Soil
ammonium and nitrate were determined by steam distillation
(Mulvaney, 2007).

Scionwood obtained from a single ‘Prolific’ tree was side-veneer grafted
onto open-pollinated seedlings (maternal half-sibs) rootstocks of
‘Adelaide’, ‘Arcilago’, ‘Aruz’, ‘Black-
wood’, ‘Blocksberg’, ‘Guilbe’ ‘Hanna’,
‘Jamaica-1’, ‘Larsen’, ‘Mendigo-1’,
‘Gallera’, ‘Morning Star’, ‘Russel’, ‘Pro-
lific’, ‘Timotie’, and ‘Vasallo-1’. These
introduced or locally selected sapodilla
materials were obtained from the germ-
plasm collection of the University of
Puerto Rico Agricultural Experiment
Station, Juana Diaz, PR.

Six-month-old grafted trees were
transplanted to the field on 2 May
2001. Trees of the 16 rootstock seed-
lings were arranged in a random-
ized complete-block design with four
replications. Before transplanting, the soil was chisel-plowed to a depth of
about 90 cm. Planting holes about
1.5-ft deep were dug with an auger
connected by a drive shaft to the
power-take-off unit of a tractor. On
transplanting, each tree received 11 g
granular P provided in the form of
triple superphosphate.

Within a replication, plots for
each treatment (rootstock seedlings)
contained two trees spaced 20 ft apart
and 30 ft between adjacent rows (179
trees/ha) in a triangular array. The experiment was surrounded by a
guard row of ‘Prolific’ seedlings.
Irrigation was provided with spinner
jets (model DXMAG368X; Maxijet,
Dundee, FL) spaced 20 ft apart and
providing 13.5 gal/h at 20 psi when
the soil water tension at a depth of
30 cm exceeded 50 kPa. Fertiliza-
tion was provided every 3 months
using a 15N–2.2P–16.3K–1.8 Mg
commercial mixture by applying
350 g of fertilizer per plant from
2001 to 2005, 500 g from 2006 to
2008, and 1000 g from 2009 to
2012. Herbicide (glyphosate) for
weed control was applied only in
strips within the planting row. Weeds
between rows were controlled with a tractor mower. Oil
spray (Saf-T-Side; Brandt Consoli-
dated, Springfield, IL) was occa-
sionally used during rainy periods
to control sooty mold.

Beginning in Mar. 2010 until
Dec. 2012, about four mature leaves
taken around the tree canopy from the
third node were collected from all
treatment trees and composited for
each treatment (rootstock seedling)
to assess tree nutrition. For this pur-
pose, leaves were ground using a Wiley mill (No. 1; Arthur H.
Thomas Co., Philadelphia, PA) and
analyzed for N, P, K, Ca, Mg, Fe, Mn,
Zn, and boron (B) concentration
using recommended digestion pro-
cedures (Perkin-Elmer, 1994). For
this purpose, leaf samples were inci-
cinerated in crucibles at 500 °C for 4
h and allowed to cool overnight. The inco-
cinerated samples were digested with
20 mL of 33% HCl acid until
10 mL of solution remained in the
crucible. After digestion was com-
pleted, each sample was filtered
through Whatman No. 541 filter
paper (GE Healthcare Life Sciences,
Buckingham, United Kingdom) into
a 100-mL volumetric flask. The solu-
tion was used for nutrient determina-
tion using an inductively coupled
plasma-optical emission spectrometer
(PE 7300DV; Perkin-Elmer, Shelton,
CT). Total N was determined by
a modification of the micro-Kjeldahl
method (Foss Tecator, 2002). For
this purpose, 0.2 g of tissue was
weighed and transferred to a Kjeldahl
tube. The following compounds were
added to each tube: 6 mm Hengar
granules (Fisher Scientific, Fair Lawn,
NJ) for smooth boiling, one catalyz-
ing tablet (1.5 g potassium sulfate +
0.15 g copper sulfate), 5 mL of
concentrated sulfuric acid, and 3 mL
of 30% hydrogen peroxide. Samples
were digested in a digestion block for
2 h at 380 °C.

Harvests were initiated in Apr.
2006. At this time, grafted trees were
about 5.5 years old. At harvest, fruit
were cut either manually or with
telescopic long reach pruners (model
160ZR-3.0-5; ARS Corp, Osaka, Ja-
pan). Representative fruit totaling
10% of those harvested were used to
determine the fruit diameter and
fruit length as well as soluble solids
with a temperature-compensated
digital refractometer (Packet PAL-1;
ATAGO, Tokyo, Japan) about 5 d af-
after harvest. The fruit length and
diameter were measured with a cali-
iper. Diameter was measured on the
equatorial section of the fruit and
length from the proximal to the distal
dend. Flowering normally occurred
during April to November and fruit
harvested from February to July peak-
ing in March, April, and May. After
a 7-year harvesting period, the ex-
periment was ended in Dec. 2012. At
this time, compatibility between scion
and rootstock seedling was assessed
using a compatibility rating based
on the degree of deformity at the
scion-rootstock junction at the grafted area. Treatment trees were given an overall compatibility rating as follows: 1 = no deformity, 2 = slight deformity, 3 = moderate deformity, 4 = marked deformity, and 5 = severe deformity.

Analysis of variance was carried using the GLM procedure of SAS (release 9.4 for Windows; SAS Institute, Cary, NC). After significant F test at \( P \leq 0.05 \), mean separation was performed with the Tukey’s honest significant difference range test.

**Results and discussion**

The year × rootstock interaction was not significant for any of the variables measured in the study. However, year and rootstock seedlings had a significant effect (\( P \leq 0.01 \)) on the number of fruit per hectare, yield, and individual fruit weight. Year had a significant effect on fruit length, diameter, and total soluble solids, but rootstock seedlings had no effect on these fruit traits. Compatibility between scion and rootstock seedling made at the end of the experimental period was significant (Table 1).

As expected, trees exhibited an overall increase in the number of fruit produced during the first 4–5 years of production as trees increased in age (Table 2). The magnitude of this response was similar among rootstock seedlings as noted by the lack of a significant year × rootstock interaction (Table 1). It is noteworthy that at the end of the 7-year harvest cycle, fruit production of trees grafted onto ‘Morning Star’ was exactly the same as the average production, 1009 fruit/ha (Table 2).

There were no significant differences in the number of fruit per hectare and yield when scionwood of ‘Prolific’ was grafted onto rootstock seedlings of ‘Timothe’, ‘Vasallo-1’, ‘Larsen’, and ‘Aruz’. During the 7-year harvest cycle ‘Prolific’ grafted onto these rootstock seedlings averaged 4479 fruit/ha equivalent to 1245 kg·ha\(^{-1}\). When ‘Prolific’ was grafted onto itself, production only averaged 2235 fruit/ha corresponding to 667 kg·ha\(^{-1}\) or about a 50% reduction in yield. Among the four most promising rootstock seedlings, only the local selections ‘Timothe’ and ‘Vasallo-1’ significantly out yielded the rootstock seedling ‘Prolific’ (Tables 1 and 2).

‘Morning Star’ had the lowest 7-year mean for the number of fruit and yield although values for this rootstock seedling were not significantly different from those obtained for many of the other rootstock seedlings (Table 1). The number of fruit per hectare and corresponding yield obtained in this study were very low (Table 1). Although not supported with experimental data from replicated experiments, Balerdi and Shaw (1998) reported that some sapodilla cultivars are capable of producing 90–200 kg of fruit per tree. Velez-Colon et al. (1989) reported tree yield of 103 kg/tree per year for cultivar Prolific; however, data from this experiment were not statistically analyzed by the authors because of the large variability found in their experimental data. A possible explanation for the low yield and fruit number found in this study could have been the result of the experiment being located in a very windy area of the research farm. In fact, the number of fruit produced in the most exposed areas of the experiment (replications 2 and 3) was 39%.

### Table 1. Yield and fruit quality traits of ‘Prolific’ sapodilla grafted onto seedlings of 16 sapodilla rootstocks planted in Puerto Rico. Values are means of four replications and 7 years (2006–12).

| Rootstock | Fruit (no./ha) | Fruit yield (kg·ha\(^{-1}\)) | Fruit length (cm) | Fruit diam (cm) | Individual fruit wt (g) | Soluble solids concn (%) | Compatibility rating (1 to 5 scale) |
|-----------|---------------|-------------------------------|-------------------|----------------|------------------------|--------------------------|----------------------------------|
| Adelaide  | 1,054         | 289                           | 7.9               | 7.9            | 279.6                  | 17.1                     | 2.90                             |
| Arcilago  | 2,475         | 663                           | 7.5               | 7.6            | 264.8                  | 16.6                     | 2.06                             |
| Aruz      | 3,491         | 995                           | 7.9               | 7.9            | 281.4                  | 17.0                     | 3.04                             |
| Blackwood | 3,055         | 856                           | 7.9               | 8.2            | 281.3                  | 16.8                     | 3.28                             |
| Bocksberg | 2,997         | 845                           | 8.0               | 8.5            | 280.9                  | 17.2                     | 3.53                             |
| Gilbe     | 1,921         | 548                           | 8.0               | 7.9            | 282.7                  | 17.1                     | 2.87                             |
| Hanna     | 2,302         | 678                           | 7.9               | 7.9            | 287.5                  | 17.1                     | 3.09                             |
| Jamaica   | 1,764         | 485                           | 7.9               | 8.0            | 268.9                  | 17.5                     | 2.39                             |
| Larsen    | 4,189         | 1,165                         | 8.2               | 8.1            | 277.4                  | 17.8                     | 3.27                             |
| Mendigo   | 3,090         | 893                           | 7.9               | 8.0            | 284.9                  | 16.9                     | 2.81                             |
| Gallera   | 1,835         | 564                           | 8.0               | 8.3            | 287.6                  | 17.5                     | 2.65                             |
| Morning Star | 1,009     | 298                           | 7.5               | 7.6            | 292.6                  | 15.9                     | 3.06                             |
| Russel    | 1,178         | 369                           | 7.4               | 7.8            | 301.0                  | 16.3                     | 2.84                             |
| Prolific  | 2,235         | 667                           | 7.3               | 7.5            | 303.4                  | 15.6                     | 2.68                             |
| Timothe   | 5,444         | 1,483                         | 7.6               | 7.6            | 275.9                  | 16.9                     | 2.90                             |
| Vassallo-1| 4,794         | 1,336                         | 8.3               | 8.1            | 269.9                  | 17.7                     | 2.96                             |
| Average   | 2,676         | 758                           | 7.8               | 7.9            | 282.3                  | 16.9                     | 2.89                             |
| HSD (0.05) | 2,076     | 594                           | 1.29              | 1.31           | 34.3                   | 2.91                     | 1.11                             |

**Year (Y)**

|                | *** | *** | *** | *** | *** | ** | ** |

**Rootstock (R)**

|                | *** | *** | NS  | NS  | NS  | NS |

**Y X R**

|                | NS  | NS  | NS  | NS  | NS  | NS |

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1 fruit/ha = 0.4047 fruit/acre, 1 kg·ha\(^{-1}\) = 0.8922 lb/acre, 1 cm = 0.3937 inch, 1 g = 0.0353 oz.

2 Compatibility between scion and rootstock based on the degree of deformity at the scion-rootstock junction at the grafted area: 1 = no deformity, 2 = slight deformity, 3 = moderate deformity, 4 = marked deformity, 5 = severe deformity.

3 Tukey’s honest significant difference test at \( P = 0.05 \).

4 No year effect measured.

5 ** Not significant or significant at \( P = 0.01 \) or \( P = 0.001 \), respectively, based on analysis of variance.
lower than in less exposed areas (replications 1 and 4). Flight activity of honeybees (Apis mellifera) and the main pollinator of sapodilla decreases with increasing wind speed (Winston, 1987). In avocado (Persea americana) and blueberry (Vaccinium corymbosum), wind speeds greater than 15–16 km h−1 (9.3–9.9 mph) reduce bee activity (Dixon, 2004; Tuell and Isaacs, 2010). In our experiment, average daily wind speed was 5.1 mph, but the average maximum wind speed, which normally occurs during the day when bees are active, was 18.1 mph. This high wind speed may have reduced bee foraging and consequently pollination. Growers may consider locating sapodilla orchards in areas not exposed to high winds. Also and perhaps compounding the wind effect, the collection of flower samples demonstrated the presence of the fungus Pestalotia. This fungus is known to cause floral necrosis and a reduction in orchard productivity of mamey sapote (Pouteria sapota), a close relative of sapodilla (Vasquez-Lopez et al., 2012). Although tree size was not measured, the authors estimate that tree height and canopy width did not exceed 13 and 16 ft, respectively, at the end of the experimental period. Therefore, the authors suggest that using a higher tree density, perhaps 20 ft between trees and 20 ft between rows (269 trees/ha) in a triangular array, is totally feasible to increase yield per acre. Crane and Balerdi (2015) recommend minimum planting distances for sapodilla of 25 × 15 ft, 25 × 20 ft, or 25 × 25 ft. A distance of 20 × 20 ft has been used with great success in two locations in orchards of maney sapote which grows to a similar size as grafted sapodilla (Goenaga and Jenkins, 2012).

Individual weight of fruit averaged over rootstock seedlings was 282.3 g (Table 1). This weight is consistent with fruit graded as medium–large (Balerdi et al., 2013). The highest individual fruit weight (303.4 g) was produced by ‘Prolific’ (grafted onto itself), but this value was not significantly higher than that obtained for other rootstock seedlings except for ‘Jamaica-1’ and ‘Arcilago’ which averaged significantly lower individual fruit weight (266.8 g). There were no significant rootstock seedling effects on fruit length and diameter; therefore, higher individual fruit weight obtained by ‘Prolific’ over ‘Jamaica-1’ and ‘Arcilago’ which averaged significantly lower fruit weight (266.8 g). There were no significant rootstock seedling effects on fruit length and diameter; therefore, higher individual fruit weight obtained by ‘Prolific’ over ‘Jamaica-1’ and ‘Arcilago’ could not be attributed to these fruit traits (Table 1). Rootstock seedlings did not have a significant influence on soluble solids concentration, which averaged 16.9% (Table 1). There are few reports on soluble solid concentration values of sapodilla cultivars. Shende (1993) reports soluble solids values ranging from 23.8% to 24.1% in cultivar Kalipatti. Kader (2009) reported values between 13% and 26% in sapotes in general. Velez-Colon et al. (1989) reported average soluble solid concentration of 18.5% for ‘Prolific’.

There were significant differences in rootstock-scion compatibility (Table 1). The highest value (3.53) corresponding to “moderate deformity” between scion and rootstock seedling was obtained in ‘Bocksberg’. The lowest value (2.23) corresponding to “slight deformity” was obtained in rootstock seedling ‘Jamaica-1’ and ‘Arcilago’; however, these were not significantly different from most other rootstock seedlings suggesting that they are not necessarily more suited for commercial propagation. None of the 16 rootstock seedlings received a rating of 4.0 or higher indicating a “marked or severe deformity”. Fifteen of the 16 rootstock seedlings used in this study had a compatibility value between 2 and 3 (slight to moderate deformity) but these included both, high and low yielders. Therefore, the authors conclude that scion-rootstock compatibility is not the cause of the overall low yield performance of trees in this study.

Averaged over rootstock seedlings, the leaf tissue nutrient concentration of major elements (N, P, K, Mg, Ca, and S) was not significantly different among rootstocks. However, shoot nutrient concentration was significantly different among rootstocks. Shoot N concentration was highest in ‘Bocksberg’ and lowest in ‘Russel’. Shoot P concentration was highest in ‘Vasallo-1’ and lowest in ‘Mendigo-1’. Shoot K concentration was highest in ‘Adelaide’ and lowest in ‘Russel’.

Table 2. Yearly fruit production of ‘Prolific’ sapodilla grafted onto seedlings of 16 sapodilla rootstocks. Values are means of four replications.

| Rootstock  | Mean production | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  |
|------------|----------------|-------|-------|-------|-------|-------|-------|-------|
| Adelaide   | 1,034          | 179   | 538   | 964   | 1,412 | 1,614 | 1,076 | 1,457 |
| Arcilago   | 2,475          | 336   | 1,233 | 2,062 | 3,026 | 3,273 | 3,071 | 4,326 |
| Araz       | 3,491          | 672   | 2,286 | 3,430 | 4,573 | 5,290 | 3,587 | 4,595 |
| Blackwood  | 3,055          | 381   | 1,345 | 2,533 | 4,035 | 4,102 | 3,878 | 5,111 |
| Bocksberg  | 2,997          | 291   | 874   | 2,712 | 3,519 | 4,842 | 3,901 | 4,842 |
| Gilbe      | 1,921          | 314   | 1,076 | 1,816 | 2,623 | 3,161 | 1,928 | 2,533 |
| Hanna      | 2,302          | 672   | 1,210 | 2,152 | 3,340 | 4,035 | 1,704 | 3,004 |
| Jamaica-1  | 1,764          | 157   | 1,233 | 1,816 | 2,040 | 2,825 | 1,883 | 2,399 |
| Larsen     | 4,189          | 852   | 1,592 | 3,833 | 5,111 | 6,837 | 5,201 | 5,896 |
| Mendigo-1  | 3,090          | 538   | 1,726 | 2,399 | 4,595 | 4,394 | 4,080 | 3,901 |
| Gallera    | 1,835          | 403   | 1,345 | 1,367 | 2,309 | 3,094 | 1,659 | 2,668 |
| Morning Star| 1,009         | 45    | 628   | 1,098 | 1,435 | 2,018 | 829   | 1,009 |
| Russel     | 1,178          | 112   | 605   | 852   | 1,973 | 1,726 | 1,524 | 1,457 |
| Prolific   | 2,235          | 179   | 1,166 | 2,152 | 2,399 | 4,125 | 2,780 | 2,847 |
| Timoteo    | 5,444          | 650   | 2,376 | 4,192 | 6,770 | 8,249 | 7,218 | 8,653 |
| Vasallo-1  | 4,794          | 1,771 | 2,600 | 3,676 | 5,873 | 7,599 | 5,313 | 6,725 |
| HSD†        | 2,076          | 1,408 | 2,564 | 4,270 | 5,876 | 7,574 | 6,914 | 8,134 |

†1 fruit/ha = 0.4047 fruit/acre.
†Tukey’s honest significant difference test at P = 0.05.
Ca, and Mg) in ‘Prolific’ trees grafted onto the 16 rootstock seedlings did not vary greatly over time. Moreover, tissue nutrient concentration was similar before and after fertilization events (Fig. 1A and B). During the 33-month leaf-sampling period for nutrient analyses, average leaf N concentration ranged from 1.26% to 2.5%.

![Graph showing nutrient concentrations over time](image)

**Fig. 1.** Average leaf nutrient concentration of major elements [nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg)] in ‘Prolific’ sapodilla grafted onto seedlings of 16 sapodilla rootstocks sampled (A) before and (B) after fertilization events. Values are the mean and SD of four replications and 16 rootstocks.
Table 3. Average leaf nutrient concentration of ‘Prolific’ sapodilla grafted onto seedlings of 16 sapodilla rootstock planted in Puerto Rico. Values are means and standard deviations of four replications and 3 years (2010–12).

| Nutrient (%) (mg/C1 g–1) | Fertilizer application | Rootstock | K | Ca | Mg | Fe | Mn | Zn | B |
|--------------------------|------------------------|------------|---|----|----|----|----|----|---|
|                          | Before                 | Adelaide   | 0.95 ± 0.07 | 1.65 ± 0.14 | 0.30 ± 0.02 | 103.00 ± 36.60 | 182.50 ± 29.97 | 19.60 ± 9.40 | 45.89 ± 13.16 |
|                          |                        | Arcilago   | 0.95 ± 0.07 | 1.62 ± 0.21 | 0.30 ± 0.02 | 86.00 ± 13.80 | 188.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Aruz       | 0.93 ± 0.06 | 1.77 ± 0.20 | 0.30 ± 0.02 | 92.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Blackwood  | 0.93 ± 0.06 | 1.77 ± 0.20 | 0.30 ± 0.02 | 92.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Gallera    | 0.97 ± 0.08 | 1.68 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Hanna      | 0.97 ± 0.08 | 1.68 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Jamaica-1  | 0.96 ± 0.07 | 1.66 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Morning-Star | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Monteleone-1 | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Russel     | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Vassallo-1 | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          | After                  | Adelaide   | 0.95 ± 0.07 | 1.65 ± 0.14 | 0.30 ± 0.02 | 86.00 ± 13.80 | 188.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Arcilago   | 0.95 ± 0.07 | 1.62 ± 0.21 | 0.30 ± 0.02 | 86.00 ± 13.80 | 188.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Aruz       | 0.93 ± 0.06 | 1.77 ± 0.20 | 0.30 ± 0.02 | 86.00 ± 13.80 | 188.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Blackwood  | 0.93 ± 0.06 | 1.77 ± 0.20 | 0.30 ± 0.02 | 86.00 ± 13.80 | 188.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Gallera    | 0.97 ± 0.08 | 1.68 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Hanna      | 0.97 ± 0.08 | 1.68 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Jamaica-1  | 0.96 ± 0.07 | 1.66 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Morning-Star | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Monteleone-1 | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Russel     | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |
|                          |                        | Vassallo-1 | 0.99 ± 0.07 | 1.69 ± 0.16 | 0.25 ± 0.02 | 88.00 ± 20.00 | 198.00 ± 31.51 | 21.50 ± 13.81 | 48.22 ± 11.45 |

**Notes:**
- N: Nitrogen, P: Phosphorous, K: Potassium, Ca: Calcium, Mg: Magnesium, Fe: Iron, Mn: Manganese, Zn: Zinc, B: Boron.
- 1 mg/C1 g–1 = 1 ppm.
1.38% and from 1.25% to 1.38%, before and after fertilization events, respectively (Fig. 1A and B). Similar seasonal values have been found in leaf litter of tropical fruits such as avocado, mango (*Mangifera indica*), and litchi (*Litchi chinensis*) (Murovhi et al., 2012). Average leaf P concentration ranged from 0.13% to 0.23% and from 0.11% to 0.23%, before and after fertilization events, respectively. These values are within the P concentration range in leaf tissue of three apple (*Malus* sp.) cultivars grown in Brazil during fruit maturation (Nachtigall and Dechen, 2006) and mango (Prado, 2010). Average leaf K and Ca concentrations were more variable than the rest of the major elements (Fig. 1A and B). Leaf K concentration before fertilization events ranged from 0.90% to 1.13% and from 0.75% to 1.09% after fertilization events. Average leaf Ca

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**Fig. 2.** Average leaf nutrient concentration of minor elements [iron (Fe), manganese (Mn), zinc (Zn), boron (B)] in ‘Prolific’ sapodilla grafted onto seedlings of 16 sapodilla rootstocks sampled (A) before and (B) after fertilization events. Values are the mean and so of four replications and 16 rootstocks; 1 mg/L = 1 ppm.
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concentration ranged from 1.46% to 1.9% before fertilization and 1.46% to 1.82% after fertilization. Average leaf Mg concentration varied very little and averaged 0.26% before and after fertilization events, a similar concentration to that reported for mango by Salazar-Garcia et al. (2014). Overall, leaf N, P, and K concentrations were higher in leaf tissue of trees grafted onto rootstock seedlings ‘Jamaica-1’ and ‘Vasallo-1’ before and after fertilization events (Table 3). Average N, P, and K in leaf tissue of these trees were 1.38%, 0.26%, and 1.12%, respectively, whereas it was 1.52%, 0.17%, and 1.02%, respectively, for the other rootstock seedlings.

Overall, minor elements (Fe, Mn, Zn, and B) showed more variation in leaf tissue concentration than major elements. During the last 33 months of the experimental period, average leaf Fe concentration ranged from 60 to 127 µg g⁻¹ and from 63 to 123 µg g⁻¹ before and after fertilization events, respectively (Fig. 2A and B). Average leaf Mn concentration ranged from 145 to 211 µg g⁻¹ and from 133 to 195 µg g⁻¹ before and after fertilization, respectively. The large variability in leaf Mn concentration at each sampling date was the result of trees grafted onto rootstock seedlings ‘Arcilago’ and ‘Prolific’ having higher leaf Mn concentration than those grafted onto other rootstock seedlings (Table 3). For example, average leaf Mn concentration for trees grafted onto rootstock seedlings ‘Aruz’, ‘Gilbe’, ‘Larsen’, ‘Mendigo-1’, ‘Gallera’, ‘Timoteo’, and ‘Vasallo-1’ was 132.3 and 126.3 µg g⁻¹ before and after fertilization, respectively, whereas it averaged 249 µg g⁻¹ for ‘Arcilago’ and 260 µg g⁻¹ for ‘Prolific’. Therefore, these two rootstock seedlings appear to be more efficient in taking up Mn than the former. Average leaf Zn concentration ranged from 13 to 37 µg g⁻¹ before fertilization and from 9.25 to 39.8 µg g⁻¹ after fertilization. Average leaf B concentration ranged from 29.5 to 70.3 µg g⁻¹ and from 30 to 57 µg g⁻¹ before and after fertilization, respectively. As with Mn, leaf Zn concentration was higher in trees grafted onto ‘Prolific’, whereas leaf B was higher in trees grafted onto ‘Blackwood’ (Table 3).

To our knowledge, this is the first report of leaf nutrient concentration values in sapodilla. Overall, leaf nutrient concentration values reported in this study are within sufficient levels for other tropical fruit and nut crops such as mango, avocado, litchi, and guava (*Psidium guajava*) (Mills and Benton-Jones, 1996).

In conclusion, sapodilla ‘Prolific’ sapodilla was grafted onto 16 rootstock seedlings and evaluated during a 7-year harvest cycle. Rootstock seedlings ‘Timoteo’, ‘Vasallo-1’, ‘Larsen’, and ‘Aruz’ had the highest mean number and yield of fruit. Both ‘Timoteo’ and ‘Vasallo-1’ significantly out yielded the ‘Prolific’ rootstock seedling. Long-term leaf nutrient concentration for major and minor elements are reported for the first time for sapodilla and should serve as a reference for future nutritional studies with this crop.

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