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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ADDITIONAL INDEX WORDS. **tropical horticulture, tropical fruits, soluble solids concentration, *Manilkara zapota***

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, Hanna, Jamaica-1, Larsen, Mendigo-1, Gallera, 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·L^{-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

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha^{-1}	0.8922
1.6093	mph	km·h^{-1}	0.6214
28.3495	oz	g	0.0353
1	ppb	nL·L^{-1}	1
1	ppm	mg·kg^{-1}	1
1	ppm	μg·g^{-1}	1
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

exudation of gummy latex the method is cumbersome. In Florida, budding, cleft, and side-veneer grafting techniques have been implemented with moderate success. Vegetative propagation promotes tree dwarfing, early bearing, and increase in yield (Morton, 1987). Little research has been conducted to evaluate sapodilla rootstocks. The objective of this work was to evaluate 16 sapodilla rootstock seedlings for fruit quality traits, scion/rootstock compatibility, 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 $mg\cdot kg^{-1}$ ammonium-N (NH_4-N), 14.0 $mg\cdot kg^{-1}$ nitrate-N (NO_3-N), 21.0 $mg\cdot kg^{-1}$ P, 570 $mg\cdot kg^{-1}$ K, 431 $mg\cdot kg^{-1}$ calcium (Ca), 219 $mg\cdot kg^{-1}$ magnesium (Mg), 107 $mg\cdot kg^{-1}$ iron (Fe), 51 $mg\cdot kg^{-1}$ manganese (Mn), 6.1 $mg\cdot kg^{-1}$ zinc (Zn), and 1.94% organic carbon. The 93-year (1919–2012) mean annual rainfall is 1649 mm and Class 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 absorption 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 determined 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', 'Blackwood', 'Blocksberg', 'Guilbe', 'Hanna', 'Jamaica-1', 'Larsen', 'Mendigo-1', 'Gallera', 'Morning Star', 'Russel', 'Prolific', 'Timothe', and 'Vasallo-1'. These introduced or locally selected sapodilla materials were obtained from the germplasm 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 seedlings were arranged in a randomized 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. Fertilization 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 Consolidated, Springfield, IL) was occasionally 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 purpose, 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 procedures (Perkin-Elmer, 1994). For this purpose, leaf samples were incinerated in crucibles at 500 °C for 4 h and allowed to cool overnight. The incinerated samples were digested with 20 mL of 33% HCl acid until 10 mL of solution remained in the crucible. After digestion was completed, each sample was filtered through Whatman No. 541 filter paper (GE Healthcare Life Sciences, Buckingham, United Kingdom) into a 100-mL volumetric flask. The solution was used for nutrient determination 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 catalyzing 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, Japan). 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 after harvest. The fruit length and diameter were measured with a caliper. Diameter was measured on the equatorial section of the fruit and length from the proximal to the distal end. Flowering normally occurred during April to November and fruit harvested from February to July peaking in March, April, and May. After a 7-year harvesting period, the experiment 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 $P \le 0.05$, 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 ($P \le 0.01$) 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 $kg \cdot ha^{-1}$. When 'Prolific' was grafted onto itself, production only averaged 2235 fruit/ha corresponding to 667 $kg \cdot ha^{-1}$ 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)[z]	Fruit yield ($kg \cdot ha^{-1}$)[z]	Fruit length (cm)[z]	Fruit diam (cm)[z]	Individual fruit wt (g)[z]	Soluble solids concn (%)	Compatibility rating (1 to 5 scale)[y]
Adelaide	1,034	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	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-1	3,090	894	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)[x]	2,076	594	1.29	1.31	34.3	2.91	1.11
Year (Y)	***	***	***	***	***	**	—[w]
Rootstock (R)	***	***	NS	NS	**	NS	**
Y × R	NS	NS	NS	NS	NS	NS	—

[z]1 fruit/ha = 0.4047 fruit/acre, 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre, 1 cm = 0.3937 inch, 1 g = 0.0353 oz.
[y]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.
[x]Tukey's honest significant difference test at $P = 0.05$.
[w]No year effect measured.
[NS, **, ***]Not significant or significant at $P = 0.01$ or 0.001, respectively, based on analysis of variance.

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

	Fruit (no./ha)[z]							
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
Aruz	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
Timothe	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[y]	2,076	1,408	2,564	4,270	5,876	7,574	6,914	8,134

[z]1 fruit/ha = 0.4047 fruit/acre.
[y]Tukey's honest significant difference test at $P = 0.05$.

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 $km \cdot h^{-1}$ (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 at two locations in orchards of mamey 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' could not be attributed to these fruit traits (Table 1). Rootstock seedlings did not have a significant effect 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, 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

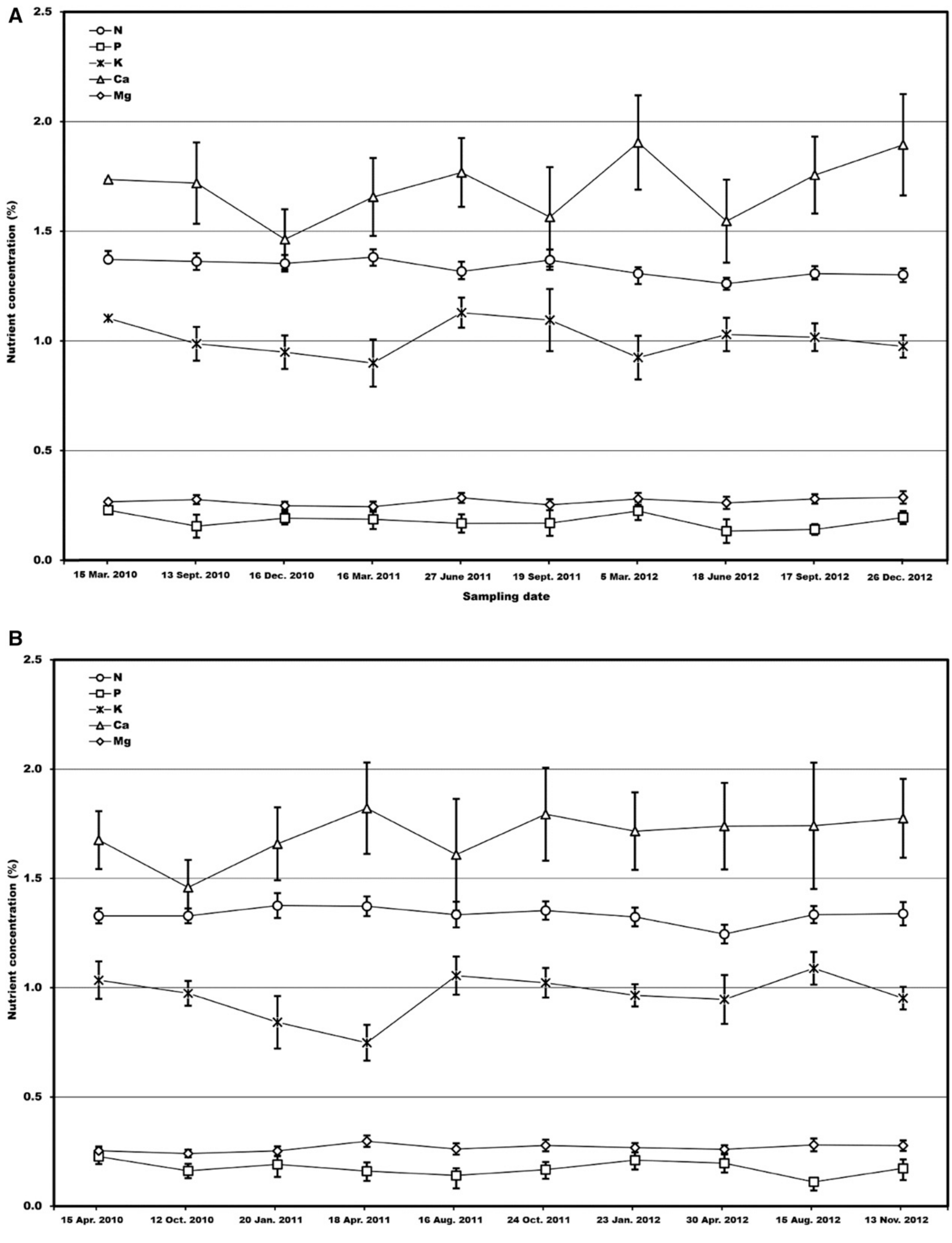

Fig. 1. Average leaf nutrient concentration of major elements [nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg)] in 'Prolific' sapodilla grafted onto seedlings of 16 sapodilla rootstocks sampled (A) before and (B) after fertilization events. Values are the mean and SD of four 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[z]								
		(%)					(μg·g⁻¹)[y]			
Fertilizer application	Rootstock	N	P	K	Ca	Mg	Fe	Mn	Zn	B
		(Mean ± SD)								
Before	Adelaide	1.34 ± 0.06	0.17 ± 0.04	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	1.33 ± 0.04	0.18 ± 0.04	0.95 ± 0.07	1.62 ± 0.21	0.27 ± 0.03	99.30 ± 29.11	228.50 ± 42.51	26.00 ± 16.47	43.67 ± 12.12
	Aruz	1.35 ± 0.04	0.15 ± 0.03	0.93 ± 0.06	1.77 ± 0.20	0.30 ± 0.02	86.20 ± 21.15	167.00 ± 32.15	18.20 ± 5.55	47.56 ± 11.39
	Blackwood	1.33 ± 0.05	0.17 ± 0.03	0.97 ± 0.08	1.71 ± 0.20	0.25 ± 0.02	92.00 ± 13.80	190.50 ± 22.62	22.10 ± 17.82	55.78 ± 14.25
	Bocksberg	1.31 ± 0.04	0.14 ± 0.03	1.07 ± 0.06	1.89 ± 0.17	0.28 ± 0.01	91.80 ± 25.66	184.00 ± 32.36	21.50 ± 13.81	47.89 ± 13.27
	Gilbe	1.31 ± 0.05	0.22 ± 0.06	0.97 ± 0.08	1.91 ± 0.23	0.25 ± 0.02	90.60 ± 21.18	136.50 ± 20.14	16.70 ± 7.73	48.22 ± 12.32
	Hanna	1.33 ± 0.05	0.17 ± 0.04	0.96 ± 0.07	1.85 ± 0.14	0.27 ± 0.02	86.70 ± 27.35	198.90 ± 34.79	20.20 ± 18.10	41.44 ± 11.11
	Jamaica-1	1.38 ± 0.05	0.28 ± 0.07	1.16 ± 0.08	1.45 ± 0.20	0.24 ± 0.02	91.20 ± 33.05	195.10 ± 38.66	21.80 ± 6.78	43.22 ± 10.45
	Larsen	1.30 ± 0.06	0.20 ± 0.05	1.03 ± 0.11	1.77 ± 0.27	0.27 ± 0.03	93.20 ± 23.42	136.50 ± 53.20	19.50 ± 7.89	49.56 ± 16.86
	Mendigo-1	1.33 ± 0.05	0.17 ± 0.03	1.00 ± 0.09	1.87 ± 0.14	0.27 ± 0.02	87.50 ± 20.06	148.20 ± 35.85	17.40 ± 9.64	51.56 ± 11.86
	Gallera	1.33 ± 0.04	0.19 ± 0.04	1.05 ± 0.10	1.55 ± 0.17	0.25 ± 0.02	84.90 ± 25.01	131.40 ± 15.72	20.10 ± 12.34	37.22 ± 9.73
	Morning Star	1.35 ± 0.04	0.20 ± 0.05	1.06 ± 0.13	1.61 ± 0.21	0.27 ± 0.02	97.00 ± 22.57	204.70 ± 19.89	19.30 ± 10.25	47.22 ± 11.83
	Russel	1.31 ± 0.05	0.18 ± 0.04	1.03 ± 0.14	1.52 ± 0.18	0.26 ± 0.02	83.80 ± 23.62	156.00 ± 16.20	19.30 ± 7.59	38.89 ± 8.51
	Prolific	1.33 ± 0.05	0.14 ± 0.02	1.06 ± 0.16	1.52 ± 0.19	0.26 ± 0.03	83.50 ± 19.45	270.20 ± 54.00	23.60 ± 11.96	44.67 ± 11.87
	Timothe	1.35 ± 0.05	0.18 ± 0.04	0.98 ± 0.12	1.72 ± 0.18	0.30 ± 0.02	87.20 ± 31.54	90.20 ± 12.29	20.60 ± 11.48	46.89 ± 12.02
	Vassallo-1	1.37 ± 0.07	0.14 ± 0.03	0.99 ± 0.12	1.81 ± 0.22	0.26 ± 0.02	77.40 ± 20.27	116.70 ± 19.03	17.60 ± 10.15	48.89 ± 12.59
After	Adelaide	1.32 ± 0.04	0.17 ± 0.04	0.94 ± 0.10	1.59 ± 0.11	0.29 ± 0.02	93.90 ± 26.94	192.50 ± 24.55	19.40 ± 24.11	45.10 ± 10.04
	Arcilago	1.31 ± 0.07	0.17 ± 0.04	0.90 ± 0.11	1.55 ± 0.14	0.26 ± 0.02	94.50 ± 32.82	224.60 ± 25.01	13.40 ± 6.31	39.78 ± 8.35
	Aruz	1.32 ± 0.05	0.14 ± 0.03	0.90 ± 0.10	1.68 ± 0.16	0.29 ± 0.02	84.20 ± 21.69	164.90 ± 44.51	22.80 ± 16.78	42.78 ± 8.67
	Blackwood	1.34 ± 0.04	0.17 ± 0.04	0.91 ± 0.12	1.67 ± 0.16	0.25 ± 0.03	94.40 ± 22.63	191.30 ± 25.91	14.50 ± 6.31	51.89 ± 12.13
	Bocksberg	1.32 ± 0.06	0.14 ± 0.03	1.01 ± 0.11	1.84 ± 0.13	0.28 ± 0.02	95.70 ± 28.90	191.10 ± 23.03	19.50 ± 14.56	43.89 ± 9.43
	Gilbe	1.31 ± 0.06	0.20 ± 0.05	0.90 ± 0.13	1.94 ± 0.20	0.25 ± 0.03	88.40 ± 15.03	126.50 ± 32.33	17.50 ± 8.36	45.44 ± 11.96
	Hanna	1.33 ± 0.06	0.16 ± 0.04	0.92 ± 0.10	1.80 ± 0.16	0.27 ± 0.02	88.30 ± 36.75	190.90 ± 25.00	19.60 ± 10.89	35.78 ± 9.51
	Jamaica-1	1.38 ± 0.05	0.25 ± 0.05	1.08 ± 0.12	1.47 ± 0.10	0.23 ± 0.01	89.50 ± 22.25	201.70 ± 33.41	17.80 ± 10.62	41.44 ± 9.34
	Larsen	1.30 ± 0.04	0.19 ± 0.06	0.96 ± 0.12	1.86 ± 0.29	0.28 ± 0.03	84.30 ± 19.30	110.70 ± 21.87	16.60 ± 9.20	48.11 ± 8.52
	Mendigo-1	1.33 ± 0.08	0.17 ± 0.05	0.95 ± 0.12	1.86 ± 0.23	0.27 ± 0.02	82.50 ± 20.86	137.80 ± 18.14	11.80 ± 4.61	48.33 ± 10.40
	Gallera	1.35 ± 0.07	0.19 ± 0.05	0.98 ± 0.15	1.61 ± 0.20	0.26 ± 0.03	83.20 ± 20.50	136.10 ± 21.76	22.10 ± 16.18	36.56 ± 7.95
	Morning Star	1.34 ± 0.04	0.19 ± 0.05	1.05 ± 0.13	1.64 ± 0.20	0.28 ± 0.03	88.90 ± 18.01	212.60 ± 33.35	14.70 ± 8.18	45.33 ± 9.97
	Russel	1.33 ± 0.04	0.18 ± 0.04	0.99 ± 0.14	1.50 ± 0.15	0.26 ± 0.02	95.60 ± 35.95	157.20 ± 15.53	19.50 ± 22.93	36.00 ± 6.82
	Prolific	1.35 ± 0.04	0.14 ± 0.02	1.01 ± 0.11	1.60 ± 0.17	0.27 ± 0.02	89.00 ± 22.22	295.30 ± 47.07	32.50 ± 36.09	45.11 ± 6.57
	Timothe	1.34 ± 0.05	0.19 ± 0.04	0.94 ± 0.13	1.75 ± 0.18	0.29 ± 0.02	80.70 ± 24.16	93.40 ± 13.92	16.70 ± 11.27	44.22 ± 8.77
	Vassallo-1	1.37 ± 0.05	0.15 ± 0.03	0.96 ± 0.12	1.86 ± 0.18	0.26 ± 0.02	77.20 ± 17.47	114.70 ± 23.87	20.10 ± 16.87	47.78 ± 7.63

[z]Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), boron (B).
[y]1 μg·g⁻¹ = 1 ppm.

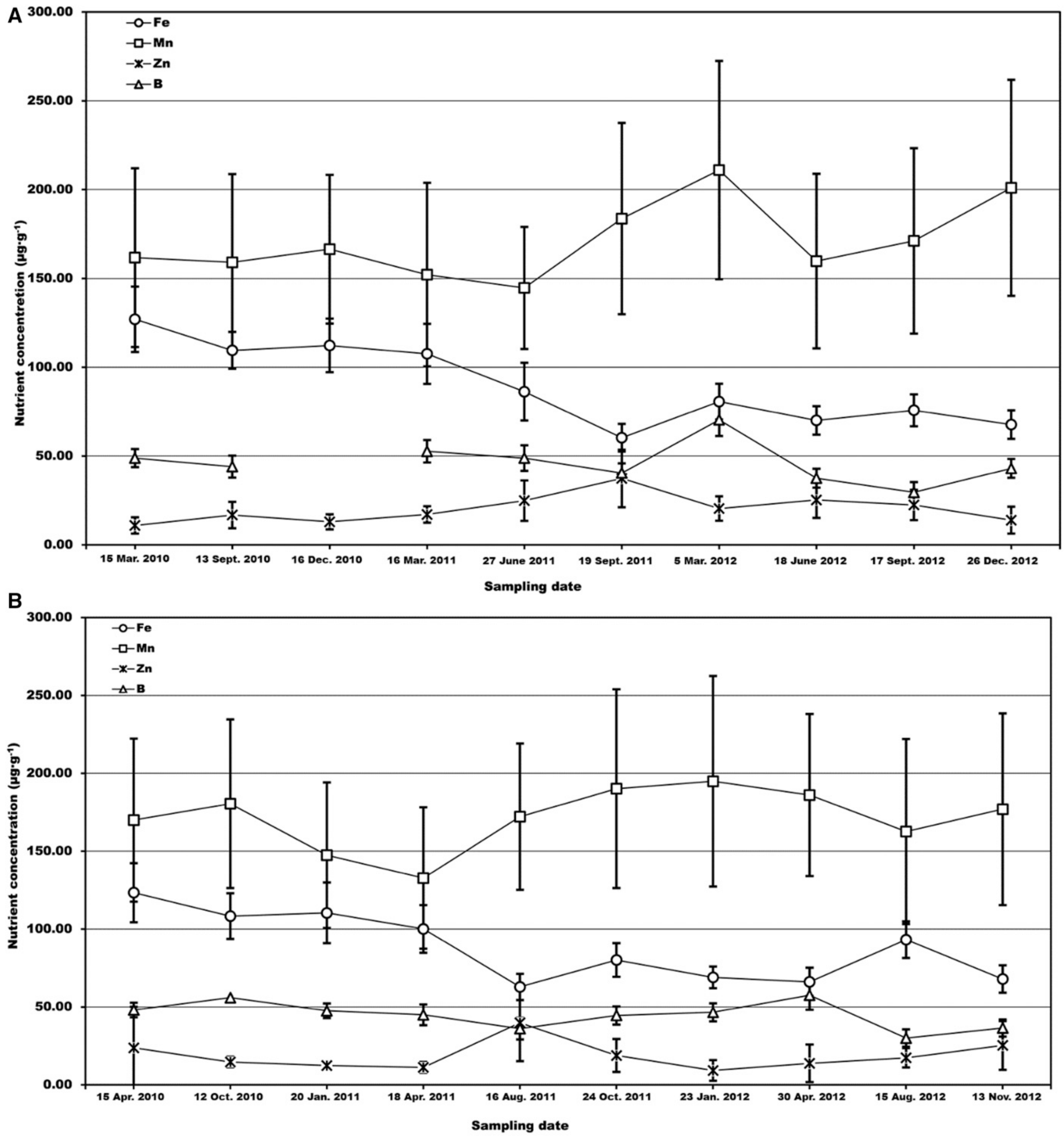

Fig. 2. Average leaf nutrient concentration of minor elements [iron (Fe), manganese (Mn), zinc (Zn), boron (B)] in 'Prolific' sapodilla grafted onto seedlings of 16 sapodilla rootstocks sampled (A) before and (B) after fertilization events. Values are the mean and SD of four replications and 16 rootstocks; 1 $\mu g \cdot g^{-1}$ = 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 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 1.32%, 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 $\mu g \cdot g^{-1}$ and from 63 to 123 $\mu g \cdot g^{-1}$ before and after fertilization events, respectively (Fig. 2A and B). Average leaf Mn concentration ranged from 145 to 211 $\mu g \cdot g^{-1}$ and from 133 to 195 $\mu g \cdot g^{-1}$ 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', 'Timothe', and 'Vasallo-1' was 132.3 and 126.3 $\mu g \cdot g^{-1}$ before and after fertilization, respectively, whereas it averaged 249 $\mu g \cdot g^{-1}$ for 'Arcilago' and 260 $\mu g \cdot g^{-1}$ 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 $\mu g \cdot g^{-1}$ before fertilization and from 9.25 to 39.8 $\mu g \cdot g^{-1}$ after fertilization. Average leaf B concentration ranged from 29.5 to 70.3 $\mu g \cdot g^{-1}$ and from 30 to 57 $\mu g \cdot g^{-1}$ 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 sufficiency 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 'Timothe', 'Vasallo-1', 'Larsen', and 'Aruz' had the highest mean number and yield of fruit. Both 'Timothe' 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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