Fertilization methods affecting 'Tahiti' lime (*Citrus latifolia*) fruit yield and profitability[1,2]

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ABSTRACT

In Puerto Rico, the most commonly planted citrus crops are oranges, mandarins and limes. Farmers still have an interest in citrus production despite the detrimental effect of the Huanglongbing (HLB) disease on island orchards. Vector control and use of slow-release fertilizers (SRF) and soluble fertilizer (SF) applications to the soil are among the recommended management practices to increase citrus production. In 2009, the Department of Agriculture of Puerto Rico (DAPR) appointed the fruit tree specialist from the University of Puerto Rico and a DAPR staff member to evaluate the condition of citrus production in Puerto Rico. Based on that evaluation, DAPR developed an initiative to increase the number of marketable fruits of oranges, mandarins, and limes from trees between five and 12 years of age by promoting the use of SRF in combination with SF applications to the soil. An experiment was established during 2011 in a seven-year-old 'Tahiti' lime orchard in Ciales, Puerto Rico, to compare fertilization methods promoted by the DAPR with conventional methods, estimating the profitability of each method. The DAPR fertilizer recommendations were developed specifically for situations where HBL is present. In the orchards under study, HBL was not observed and therefore not tested. This does not mean that trees were not infected because symptoms may take months or years to become visible. The fertilization methods evaluated were: (1) granular fertilizers applied every four months (conventional fertilization), (2) manual application of SRF twice a year plus the application of SF to the soil with a backpack sprayer four times a year (SRF+SF/backpack), (3) manual application of SRF twice a year plus the application of SF to the soil with a motorized sprayer four times a year (SRF+SF/motorized), and (4) manual application of SRF twice a year. Total fruit number, total fruit weight, and average fruit weight were measured. Harvests were carried out monthly for 15 months. In the first seven harvests,

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the performance of trees submitted to the combination of SRF and SF was more efficient than was conventional fertilization or SRF alone, since the same production was maintained using a considerably lower amount of nutrients. At 14 months, the application twice a year of SRF alone almost doubled yield although the effect of this treatment was inconsistent during the year. We estimate that the combination of SRF and SF applications to the soil will result in the highest profitability with an income of $27 per tree per year and a profitability of $8.05 per dollar spent.

Key words: 'Tahiti' lime, yield, income, expenses

RESUMEN

Métodos de fertilización afectan el rendimiento de fruta y la rentabilidad de la lima 'Tahití' (*Citrus latifolia*)

En Puerto Rico, los cítricos sembrados más comúnmente son: china (naranja), mandarina y lima. Los agricultores todavía tienen interés en la producción de cítricos a pesar del efecto perjudicial de la enfermedad conocida como Huanglongbing (HLB) en los huertos en la isla. Algunas de las prácticas de manejo recomendadas para aumentar la producción de cítricas son el control de vectores, el uso de fertilizantes de liberación lenta (SRF) y aplicaciones al suelo de fertilizante soluble (SF). En el 2009, el Departamento de Agricultura de Puerto Rico (DAPR) comisionó al especialista en frutales de la Universidad de Puerto Rico y un miembro del personal del DAPR para evaluar las condiciones de la producción de cítricas en Puerto Rico. Basado en esa evaluación, se desarrolló una iniciativa por el DAPR para aumentar la cantidad de frutas mercadeables de chinas, mandarinas y limas en árboles entre cinco y 12 años de edad promoviendo el uso de SRF en combinación con la aplicación de SF al suelo. En el 2011 se estableció un experimento en un huerto de siete años de lima 'Tahití', en Ciales, Puerto Rico, con el objetivo de comparar los métodos de fertilización promovidos por el DAPR con métodos convencionales y estimar la rentabilidad de cada método. Las recomendaciones de fertilizantes del DAPR se desarrollaron específicamente para huertos en donde hay presencia de HBL. En este estudio no se muestreó para HBL ya que no se observó síntomas en el huerto. Sin embargo, la ausencia de síntomas no es prueba de que los árboles no estaban infectados ya que los síntomas pueden tardar meses o años para hacerse visibles. Los métodos de fertilización evaluados fueron: (1) aplicación manual de fertilizantes granulares cada cuatro meses ('conventional fertilization'), (2) aplicación manual de SFR dos veces al año más cuatro aplicaciones de SF al suelo por año con bomba de espalda ('SFR + SF/backpack'), (3) aplicación manual de SFR dos veces al año más cuatro aplicaciones de SF al suelo por año con bomba motorizada ('SFR + SF/motorized'), (4) aplicación manual de SRF dos veces al año. Se midió el número total de frutas, peso total de frutas y peso promedio de frutas. La cosecha de frutas se realizó mensualmente por 15 meses. En las primeras siete cosechas, la producción de los árboles sometidos a la combinación de SFR + SF fue más eficiente que la de árboles con fertilización granulada o SFR solo, ya que mantuvo la misma producción con el uso de una cantidad considerablemente menor de nutrimentos. A los catorce meses, la aplicación de SRF dos veces al año casi duplicó el rendimiento, aunque el efecto fue inconsistente a través del año. Estimamos que la combinación de SRF y SF aplicados al suelo resulta en la mayor rentabilidad con un ingreso de $27 por árbol por año y una rentabilidad de $8.05 por dólar gastado.

Palabras claves: lima Tahití, rendimiento, ingresos, gastos

INTRODUCTION

In the humid central region of Puerto Rico, the largest citrus production areas are in Lares, Adjuntas and Utuado. The most common citrus species cultivated are oranges [(*Citrus sinensis* (L.) Osbeck)], mandarins (*Citrus reticulata* Blanco), grapefruit (*Citrus paradisi* Macf.), lemons (*Citrus limon* (L.) Osbeck), and limes (*Citrus latifolia*). During 2013-2014, citrus (mostly oranges) was categorized as the second highest-producing commodity among fruit crops produced in Puerto Rico (Department of Agriculture, 2019). It has been shown that a balanced application of N, P_2O_5 and K_2O fertilization increases 'Tahiti' lime productivity (De Jesús-Vanegas, 2002). In a study conducted in Veracruz, Mexico, it was reported that for each metric ton of Persian lime ('Tahiti' lime) produced 1.86 kg of N, 0.17 kg of P, and 2.25 kg of K were extracted (Maldonado et al., 2008).

The Asian psyllid (Huanglongbing disease vector) was reported for the first time in 2001 at the Adjuntas Agricultural Experiment Substation (AES), University of Puerto Rico; it was not until 2009 that the disease was detected at the Isabela AES in mature oranges trees (Halbert and Núñez, 2004; Estévez de Jensen et al., 2010). Once the disease was identified in Puerto Rico, both the University of Puerto Rico (UPR) and the Department of Agriculture of Puerto Rico (UPR) established an aggressive educational plan for HLB identification and for the management of citrus orchards to control it.

In 2014, an economic study performed by University of Florida on the profitability of producing 'Tahiti' limes was carried out under three different scenarios. These scenarios consisted of controlling or not controlling Huanglongbing (HLB) or canker diseases. Scenario 1 consisted of not managing these diseases, scenario 2 consisted of controlling both diseases without removing or replanting diseased trees and scenario 3 consisted of controlling the diseases and removing and replanting diseased trees (Evans et al., 2014). Scenario 3 produced the highest profitability with $14.33/tree; scenario 1 produced the lowest profitability of $6.82 per tree.

Among the main strategies for HLB control are vector control, use of disease-free propagation material, and intensive fertilization management. As a result of the education program, farmers became aware of the importance of early HLB identification, vector control and citrus response to foliar fertilizer applications (Zamora, 2013). The first affirmative step to reduce the incidence and severity of the disease is to deliver healthy trees to the field. To achieve this, the Agricultural Experiment Station-University of Puerto Rico was the first to establish a facility to produce young HLB-free citrus trees in protected green-

houses. The initiative was accepted by private growers building their protected greenhouse structures. Also, intensive foliar and soil fertilization management was carried out by UPR in 'Tahiti' lime trees infected with HLB at the Corozal and Isabela substations (Román-Pérez et al., 2017).

In mid-2009, the Puerto Rico Secretary of Agriculture commissioned Prof. José L Zamora, fruit tree specialist, Agricultural Extension Service (Ag. Ext. Serv.), University of Puerto Rico, and agronomist Manuel Barreto, Department of Agriculture of Puerto Rico (DAPR), to lead a study on the condition of citrus production in Puerto Rico. The study found that citrus production on the island was abundant, but the fruits were mostly of low quality. Hence, the UCAR (Spanish acronym for Quality and High-Performance Unit) citrus initiative was developed to improve the quality of oranges, mandarins and limes, thus increasing the percentage of marketable fruits produced by farmers. This initiative impacted 100 farmers with five- to 12-year-old citrus orchards. Each farmer was given the financial assistance necessary to purchase the products and fertilizers to carry out a citrus quality improvement program developed by Ag. Ext. Serv. for 2 ha in production. The application rate of the slow-release fertilizers (SRF) was developed based on tree age, and the soluble fertilizer (SF) application rate was based on conventional granular fertilizer application. Fertilizer recommendations were easy to follow by farmers, regardless of the accessibility of a soil nutrient analysis. Some farmers applied SF fertilizers using backpack sprayers while others used motorized sprayers. The relative profitability and application efficiency of these two methods has not been tested by DAPR or UPR.

The UCAR's main objective was to improve the production and fruit quality in five-, eight- or 12-year-old citrus trees. For five- and eight-year-old plantings, a program of foliar sprays and SRF would be applied to improve the quality of the fruits. In 12-year-old plantings a renewal pruning and then, a program of foliar sprays and SRF would be carried out. In total, 121 ha (300 acres) of oranges, 61 ha (150 acres) of mandarin and 20 ha (50 acres) of limes in organized orchards were expected to be impacted. Oranges are marketed according to size in 18.1 kg (40 pound) boxes with 56, 64, 80, 100, and 125 fruits per box. The goal was to increase fruit size (fruit quality), increasing marketable fruits by approximately 21%. Increasing fruit size, which decreases the number of fruits per box from 100 to 80 or from 80 to 64, raises farmers' incomes because the number of boxes per unit of land harvested is increased.

To obtain an acceptable and profitable yield from a citrus plantation, the previously mentioned aspects such as tree's nutritional status, severity of HLB disease and profitability of different fertilization

management practices should be considered. The main objective of this research was to test the effectiveness and net profit of alternative fertilization methods in adult 'Tahiti' lime trees promoted by DAPR compared to conventional methods.

MATERIALS AND METHODS

Site description and orchard management

A study of four fertilization methods began in March 2011 in a seven-year-old 'Tahiti' lime orchard located at a private farm in the central highlands of Puerto Rico ('Barrio Frontón', Ciales, Puerto Rico; 18°17'34.6"N, 66°32'04.7"W). Seedlings had been grafted onto 'Cleopatra' rootstock (*Citrus reshi*, Hort, Ex, Tan) and planted in 2004 at a distance of 4.2 m within rows and 5.8 m between rows. The farmer established *Schizocentron elegans* ('Mantilla Española') as cover crop throughout the field forming a dense layer of plant material about 5 cm high. The soil at the experimental site is classified as Alonso clay [Very-fine, parasesquic, isohyperthermic Typic Humudepts (Muñoz et al., 2018)]. Initial foliar nutrient content ranges for N, P, and K were 2.46 to 2.91, 0.14 to 0.26, 1.94 to 2.54 %, respectively. According to the soil analysis (Table 1) and plant nutrient content, nutrients were adequate for a suitable citrus production (Aguilar et al., 1987; Crane, 2018; Rodríguez-Polanco et al., 2018).

The orchard was not sampled for HLB because no HLB-related symptoms were observed (Marroquín-Guzmán and Estévez de Jensen,

TABLE 1.—*Initial soil chemical properties for seven-year-old 'Tahiti' lime trees growing in Ciales, Puerto Rico.*

	Soil depth (cm)	
Soil variables	15	30
pH	5.59	4.89
electric conductivity, µS/cm	300	140
Organic matter, %	3.00	1.42
P, mg/L	18	3
K, mg/L	280	97
Ca, mg/L	1,483	767
Mg, mg/L	220	76
Na, mg/L	9	11
Al, mg/L	nd[1]	321
ECEC[2], cmol/kg	10	9

[1]not detectable
[2]ECEC – Estimated Cation Exchange Capacity

2013). This does not mean that trees were not infected because symptoms may take months or years to become visible. Conventional granular fertilization was the fertilization regime used during the first six years of growth (Table 2).

Treatments

Four fertilizer treatments were evaluated: (1) granular fertilizer (conventional fertilization), (2) SRF with SF applied with a 15 L backpack sprayer (SRF+SF/backpack), (3) SRF with SF (SRF+SF/motorized) applied with a motorized sprayer with a 7.6 m (25 ft) long hose connected to a 96 L (25 gal) tank which was transported to the site in an all-terrain vehicle, and (4) SRF alone applied to the soil twice a year. At the beginning of the study, 'Tahiti' lime trees were seven years old, therefore fertilizer treatments were designed based on recommendations for trees of that age (Table 2). The granular fertilizer control treatment consisted of broadcast application of 10-5-20 granular fertilizer to 'Tahiti' lime trees at the rate of 6.36 kg of N per year split into three applications. The two SRF+SF treatments consisted of the use of SRF applied twice a year combined with four SF applications to the soil. In this experiment the slow-release formulation was 13-5-13 in which 8.52% is slow-release N. This was supplemented with 1,657 ml of soluble fer-

TABLE 2.—*Recommendations, based on citrus tree age, for application of conventional granular fertilizer and for slow-release fertilizer (SRF) plus soluble fertilizer (SF) applied to the soil [guidelines of the Department of Agriculture of Puerto Rico (DAPR) for citrus potentially infected by Huanglongbing (HLB)].*

Tree age (years)	Conventional granular fertilizer[1] (kg of N/tree/year)	DAPR recommendation[2]	
		SRF (g of N/tree/year)	SF applied to soil[3] (ml of solution/tree/year)
1-2	1.82	170	474
3	2.72	170	710
4	3.64	227	947
5	4.54	227	1,184
6	5.45	284	1,420
7	6.36	284	1,657
8	7.27	340	1,894
9	8.18	340	2,131
10	9.09	340	2,368

[1]Fertilizers high in nitrogen (20-5-10-3, 15-5-10) are recommended for young trees, while fertilizers high in potassium (10-5-15, 10-5-20) are recommended for trees in production.

[2]The DAPR recommends the alternate use of SRF twice a year with SF applications to the soil four times a year. The recommendations presume all citrus trees would eventually be infected by HLB.

[3]The soluble fertilizer is prepared by diluting the SF in water. The dilution is based on the corresponding amount of granular fertilizer. The total volume of the solution is divided in four applications per year.

tilizer (10-5-20) to the soil, divided into four applications. The DAPR recommendations consisted of diluting 119 g of SF in 1 L of water, then applying 118 ml of the solution annually per each 454 g of granular fertilizer applied during the year. Finally, the fourth treatment was the application of SRF (15-3-19) twice a year at a rate of 1.3 kg N per tree per year. The total amounts of N, P and K are shown in Table 3.

Experimental design, variables measured and data analysis

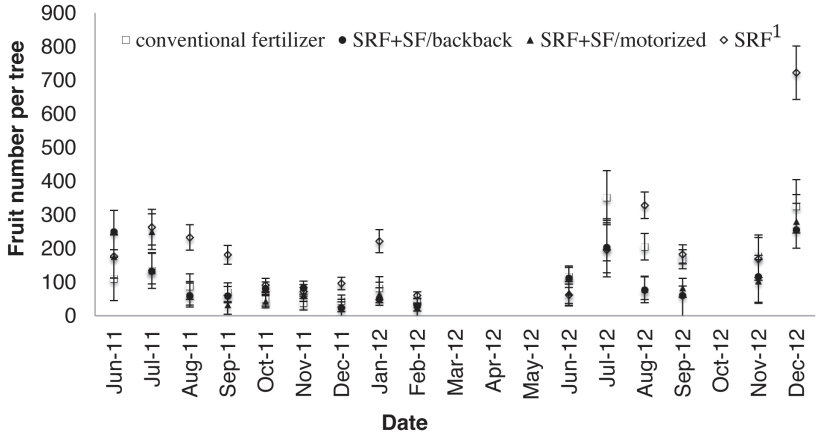
The experiment was arranged in a completely randomized design with four replications. Plots consisted of six 'Tahiti' lime trees, but data was measured from the middle four trees. A total of 15 harvests were performed from June 2011 to December 2012. The response variables measured were fruit number, total fruit weight, and average fruit weight. Data for each harvest were statistically analyzed by analysis of variance and mean separation by using Fisher's LSD at the 5% probability level (SAS Institute, 2013).

RESULTS AND DISCUSSION

Figure 1 presents data for total fruit number per tree for each harvest during the 19-month evaluation period (June 2011 to December 2012). The amount of N, P_2O_5 and K_2O applied in the SFR+SF treatments were considerably lower than the amount applied in the granular fertilizer and the SRF treatments (Table 3). In the first seven months of the experiment (from June to December 2011), the two SRF+SF treatments tended to be more efficient than the granular fertilizer or SRF treatments because the same production was maintained with significantly less fertilizer (see treatment description in Table 3). No final soil and foliar tissue nutrient content are available to corroborate 'Tahiti' lime trees nutrient status after evaluation period. During this period, no significant differences were detected between treatments for the June, July, October and November 2011 harvests. The SRF treatment produced significantly higher fruit number for harvests carried out in August, September and December 2011; in 2012 this treatment produced the highest fruit number for harvests in January, February, August, September and December. Fruit number varied from 32 to 722 fruits per tree among all treatments. Combined average fruit number for all harvests were 203, 132, 105 and 104 fruits per tree for granular fertilizer, SRF+SF/backpack, SRF+SF/motorized and SRF, respectively. Lime trees treated with SRF produced a total fruit weight significantly higher than the other three treatments in August, September, December 2011, and January, February, August, September and December 2012 (Figure 2). Minimum, average, and maximum fruit weight per

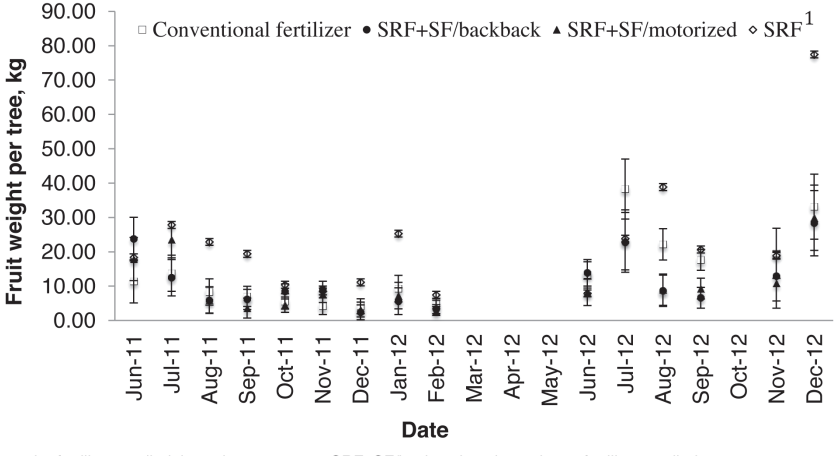
TABLE 3.—*Fertilization treatments and corresponding nutrients applied to seven-year-old 'Tahiti' lime trees growing in Ciales, Puerto Rico.*

Treatment	Treatment description	N kg/tree/year	P_2O_5 kg/tree/year	K_2O kg/tree/year
Conventional fertilizer	Conventional fertilizer (10-5-20) applied three times per year (Control).	0.63	0.780	1.27
SRF+SF/backpack	Slow-release fertilizer (15-3-19) applied twice a year plus four applications of soluble fertilizer (13-5-13) to the soil applied by a backpack sprayer.	0.07	0.018	0.04
SRF+SF/motorized	Slow-release fertilizer (15-3-19) applied twice a year plus four applications of soluble fertilizer (13-5-13) to the soil applied by a motorized sprayer.	0.07	0.018	0.04
SRF	Slow-release fertilizer (15-3-19) applied twice a year	1.36	0.270	1.72



[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

FIGURE 1. Average number of fruit per tree for each fertilization treatment and harvest date of a seven-year-old 'Tahiti' lime orchard, Ciales, Puerto Rico.

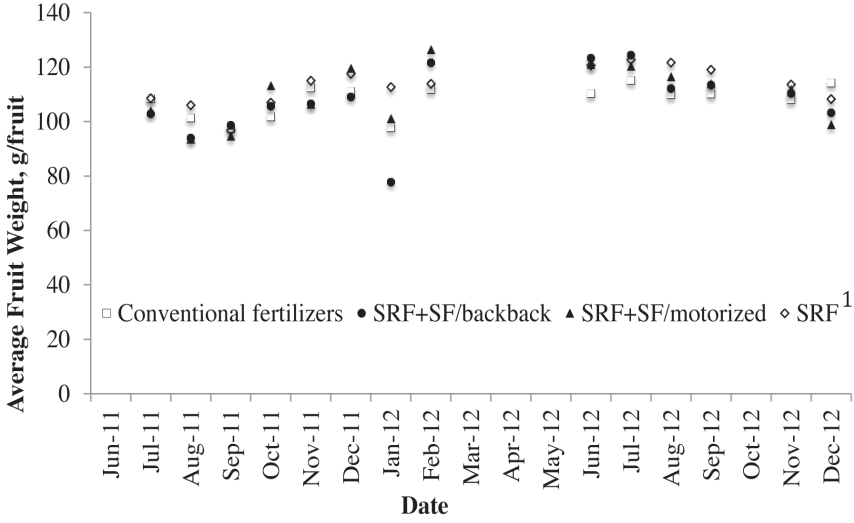


[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

FIGURE 2. Total fruit weight for each fertilization treatment and harvest date of a seven-year- old 'Tahiti' lime orchard, Ciales, Puerto Rico.

tree were 2.39, 14.8 and 77.5 kg, respectively. No significant differences were detected for average fruit weight. Fruit weight varied from 77.8 to 127.0 g with a mean of 110 g per fruit (Figure 3). In general, there was no difference between using a backpack sprayer or a motorized sprayer for the application of SF.

Data obtained from a 'Tahiti' lime orchard planted at Isabela-AES, Puerto Rico (Coto series, Typic Haploudox) grafted onto five different rootstocks produced between 532 and 1,032 fruits per tree with an average total fruit weight varying from 8.02 to 20.40 kg per tree for seven-year-old trees (Tirado-Corbalá et al., 2018). The same orchard produced 239 to 424 fruits per tree, while total fruit weight varied from 23.6 to 42.7 kg per tree during 2010 to 2013 (Román-Pérez et al., 2017). Román-Pérez et al. (2017) also reported 273 to 465 fruits per tree and 27.7 to 52.7 kg per tree for 'Tahiti' lime trees established at Corozal-AES, Puerto Rico [the soil series at the experimental site is Corozal (Aquic Haplohumults)]. A comparison of lime production between Ciales and Corozal is better than between Ciales and Isabela because the edaphic and environmental conditions prevailing at both Ciales and Corozal locations are similar. The range of yields registered at Ciales is



[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

FIGURE 3. Average fruit weight for each fertilization treatment and harvest date of a seven-year -old 'Tahiti' lime orchard, Ciales, Puerto Rico.

greater than at Corozal (also Isabela). Curti-Díaz et al. (2012) reported a mean yield of 196 kg per tree across four rootstocks ('Carrizo', 'Rough lemon' 'Swingle', 'Volkameria') at Veracruz, Mexico. They also reported 2,189 total average fruit number per tree per year with a mean fruit weight of 87.7 g per fruit across four rootstocks. A fruit yield of 21.1 Mg/ha (47.8 kg per tree) was reported in Veracruz, Mexico, with one application per tree of 0.310 kg of N, 0.242 kg P_2O_5, and 0.470 kg of K_2O (Maldonado et al., 2008).

Fertilizing with conventional granular fertilizer and DAPR's recommended practices of SRF+SF (applied either by backpack or motorized sprayer) had a similar effect on the production of 'Tahiti' lime. As previously mentioned, the amount of N, P_2O_5 and K_2O applied in the SFR+SF treatments were considerably lower than rates applied in the granular fertilizer and SRF alone treatments (Table 3), and lower than rates applied by Román et al. (2017) or Maldonado et al. (2008). The strategy of applying slow-release fertilizer split two times per year combined with four applications of a solution of soluble fertilizer to the soil (treatments SRF-SF/backpack and SRF-SF/motorized) maintains a nutrient supply easily available to the lime trees.

The use of SFR at a rate of 1.36 kg N/tree/year (Treatment 4) showed an inconsistent tendency to increase fruit yields. Only in December 2012 did this treatment double the production of the other treatments.

Profitability analysis

In order to make an informed decision regarding the fertilization method to be used, the response of lime trees as well as an economic analysis of inputs is needed. 'Tahiti' lime trees treated with SRF alone produced the highest yield (Table 4) totaling 1,358 kg per plot

TABLE 4.—*Estimated income per tree based on observed fruit production for each fertilization treatment in a 'Tahiti' lime orchard in Ciales, Puerto Rico, and the market price in 2012.*

Fertilizer treatment[1]	Total fruit production[2] (kg)	Market price ($0.715/kg)	Income/tree
Granular	864	$617.91	$38.62
SRF+SF/backpack	682	$487.60	$30.47
SRF+SF/motorized	670	$479.23	$29.95
SRF	1,358	$970.79	$60.67

[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

[2]Total production of sixteen trees (four per replication).

(84.4 kg per tree), whereas the lowest yields were in plots treated with SRF+SF/motorized, amounting to 670 kg per plot (41.8 kg per tree). The average income per tree was calculated using the market price in 2012 (Table 4). Input expenses for each treatment are estimated in Table 5. The treatment using SRF alone generated the highest expenses with $36.09 per tree. By contrast, applying DAPR'S recommendation of SRF+SF by backpack sprayer or motorized sprayer generated expenses of $3.35 per tree. The expense generated by the use of inputs for granular fertilizer was $11.51 per tree (Table 6).

For the economic analysis, market prices for inputs and outputs were used. Labor was valued according to the minimum wage established by law. The profitability factor was calculated by using the following formula:

$$R = IN / EXPENSES$$

Where R is the profitability factor, IN is income and EXPENSES are the costs of inputs, labor, etc. This factor, R, indicates the amount

TABLE 5.—*Expenses generated by the implementation of fertilization treatments in a 'Tahiti' lime orchard in Ciales, Puerto Rico, in 2011 to 2012.*

	Fertilization treatment[1]			
Item	Granular	SRF+SF/ backpack	SRF+SF/ motorized	SRF
Materials				
Granular fertilizer (10-5-20-3)	$178.41			
Slow release fertilizers (15-3-19+EM)		$17.80	$17.80	
Soluble fertilizer		$19.36	$19.36	$569.60
Water		$8.00	$8.00	
Labor	$5.74	$7.86	$7.52	$7.84
Backpack sprayer use		$0.64		
Motorized sprayer			$0.96	
Total expenses per treatment	$184.15	$53.64	$53.64	$577.44
Expenses per tree	$11.51	$3.35	$3.35	$36.09

[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

TABLE 6.—*Economic balance and profitability (R) generated by the implementation of each fertilization method treatment in a 'Tahiti' lime orchard in Ciales, Puerto Rico.*

	income/ tree	expenses/ tree	balance/ tree	R
Fertilizer treatment[1]	- - - $ - - -	- - - $ - - -	- - - $ - - -	$ earned/ $ expended
Granular	$38.62	11.51	$27.11	2.35
SRF+SF/backpack	$30.47	3.35	$27.11	8.09
SRF+SF/motorized	$29.95	3.35	$26.60	7.94
SRF	$60.67	36.09	$24.64	0.68

[1]Granular fertilizer applied three times per year; SRF+SF/backpack = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a backpack sprayer; SRF+SF/motorized = slow-release fertilizer applied two times per year plus soluble fertilizer applied to the soil four times per year with a motorized sprayer; SRF = slow-release fertilizer applied manually to the soil two times per year.

of net dollars (after deducting spending) that each dollar of spending generates. The two SRF+SF treatments generated similar returns of $8.09 and $7.94, respectively. The granular fertilizer treatment followed with a return of $2.35. Using SRF alone resulted in the lowest profitability of $0.68 (Table 6).

All the treatments were economically viable: they generated enough income to cover the expenses incurred. However, from a decision-making point of view, the goal is to maximize the net income generated by each dollar spent. The items of type, quantity and cost of inputs, yield, and product sale price are essential for the profitability of any agricultural practice. In addition, it is important to emphasize that using SRF+SF might be a more environmentally sustainable practice since less fertilizer is used.

CONCLUSION

A farmer's main goal is to maintain profitable production. Maximizing the productivity of crops does not necessarily result in maximizing profits. The DAPR recommended fertilization methods easy to implement by a traditional farmer. Generally, producers do not have the resources to carry out soil foliar analyses to design a specific fertilization plan. Although the University of Puerto Rico and the DAPR recommend soil and foliar analyses, these recommendations are not always adopted by growers. The emergence of HLB makes maintaining citrus fruits with adequate nutrition even more important since it is a possible control measure. The DAPR recommendation of applying SRF in combination with applications of SF to soil did not maximize 'Tahiti' lime yields. However, the DAPR's fertilization recommendation to use SRF+SF generated the highest profits for every dollar spent. The SRF

rate of 1.36 kg of N per tree resulted in the highest productivity during several monthly harvests. However, this significant response was inconsistent from harvest to harvest, and produced the lowest profitability among the different fertilization methods with $0.68 for every dollar spent. This treatment would also have a greater negative environmental impact due to the higher amount of fertilizer used because just 8% of the N is in a slow-released form. This economic study was carried out using 2011 prices; however, it is presumed that under current conditions where the demand for limes and lemons has increased and prices at the farm level are higher, the profitability of following the DAPR recommendations are higher. The DAPR fertilizer recommendations were developed specifically for situations where HBL is present. HBL was not observed in the orchards under study. It is possible that DAPR recommendations will prove to be even more profitable when HBL is present. This should be evaluated in future studies. After evaluating the evidence presented, the combination of SFR + SF applied with a backpack sprayer or motorized sprayer is recommended. It is also recommended that foliar tissue and soil be sampled to confirm that nutrient levels are adequate to meet 'Tahiti' lime requirements.

LITERATURE CITED

Aguilar, A., J.D. Etchevers and J.Z. Castellanos, 1987. Análisis químico para evaluar la fertilidad del suelo. Sociedad Mexicana de la Ciencia del Suelo, Chapingo, Mexico. http://www.agrolab.com.mx/sitev002/sitev001/assets/interpretacion_fertsuel.pdf

Crane, J., 2018. Growing 'Tahiti' limes in the home landscape. University of Florida. http://edis.ifas.ufl.edu.

Curti-Díaz, S. A., C. Hernández-Guerra and R. X. Loredo-Salazar, 2012. Productividad del limón 'persa' injertado en cuatro porta injertos en una huerta comercial de Veracruz, México. *Revista Chapingo, Serie Horticultura* 18(3): 291-305.

De Jesús-Vanegas, M., 2002. Guía técnica: cultivo del Limón Pérsico. http://repiica.iica.int/docs/B0217E/B0217E.PDF.

Department of Agriculture of Puerto Rico, 2019. Ingreso bruto de la agricultura de Puerto Rico. Cifras revisadas 2013/2014 y preliminares 2015/2016, 2016/2017, 2017/2018. Oficina Estadísticas Agrícolas. Gobierno de Puerto Rico, San Juan.

Estévez de Jensen, C., A. Vitoreli and F. Román, 2010. Citrus greening in commercial orchards in Puerto Rico. *Phytopathology* 100:S34.

Evans, E.A., F.H. Ballen and J.H. Crane, 2014. Economic potential of producing Tahiti limes in Southern Florida in the presence of citrus canker and citrus greening. *HortTechnology* 24(1): 99-106.

Halbert, S. E. and C.A. Núñez, 2004. Distribution of Asian Citrus psyllid *Diaphorina citri* Kuwayama (Rhynchota: Psyllidae) in the Caribbean Basin. *Fla. Entomol.* 87(3): 401-402.

Maldonado, R., G. Almaguer, M.E. Álvarez and E. Robledo, 2008. Diagnóstico nutrimental y validación de dosis de fertilización para Limón Persa. *Terra Latinoamericana* 26(4): 341-349.

Marroquín-Guzmán, M.R. and C. Estévez de Jensen, 2013. Dissemination of citrus greening in Puerto Rico. *J. Agric. Univ. P.R.* 97(3-4): 119-134. https://doi.org/10.46429/jaupr.v97i3-4.2991

Muñoz, M.A., W.I. Lugo, C. Santiago, M. Matos, S. Ríos and J. Lugo, 2018. Taxonomic classification of the soils of Puerto Rico, 2017. Bulletin 313. Agricultural Experiment Station, College of Agricultural Science, University of Puerto Rico, Mayagüez Campus.

Rodríguez-Polanco, E., J.S. Gutiérrez Díaz and J.O. Orduz Rodríguez, 2018. Diagnóstico nutricional del cultivo de la lima ácida Tahiti [*Citrus latifolia* (Yu Tanaka) Tanaka] en el departamento del Tolima (Colombia). *Temas Agrarios* 23(2): 144-153.

Román-Pérez, F.M., A. González-Vélez, R. Macchiavelli and C. Estévez de Jensen, 2017. Performance of 'Tahiti' lime (*Citrus latifolia* Tan) grafted onto five citrus rootstocks in two production areas of Puerto Rico. *J. Agric. Univ. P.R.* 101(2): 225-236. https://doi.org/10.46429/jaupr.v101i2.15791

SAS Institute, 2013. SAS 9.4 Language reference: Concepts. Cary, NC.

Tirado-Corbalá, R., D. Rivera-Ocasio, A. Segarra-Carmona, E. Román-Paoli and A. González, 2018. Performance of two citrus species grafted to different rootstocks in the presence of Huanglongbing disease in Puerto Rico. *Horticulturae* 4 (38): 1-9.

Zamora, J., 2013. Manejo nutricional del "Citrus Greening" y su costo. El Frutal. Universidad de Puerto Rico, Servicio de Extensión Agrícola. Vol. 9(1): (1-5).