Pineapple growth and yield response to fertilizer and drip irrigation management[1,2]

Melissa Acevedo[3], Elvin Román-Paoli[4], Félix M. Román-Pérez[4], Elide Valencia[4] and Rebecca Tirado-Corbalá[5]

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ABSTRACT

Pineapple [*Ananas comosus* (L.) Merr.] is an important fruit crop cultivated in many tropical countries. This fruit crop requires large amounts of nitrogen (N) and potassium (K) to maximize yield. Although pineapple has low water requirements, extended drought can affect yield. Two experiments were conducted to study the effects of fertilizer application methods and drip irrigation management on pineapple yields. Pineapple cultivars MD-2 and Cabezona were planted at Isabela and Lajas, Puerto Rico, respectively. Fertilizer and irrigation treatments included: i) Control- application of 896 kg/ha of a granular fertilizer (12-6-10-3) at two, five and nine months after planting; ii) FS-R- application of 150-150-120-45 kg/ha at planting plus 20 foliar applications of urea and potassium sulfate (50 kg/ha) every three weeks, rainfed; iii) FS-DI- application of 150-150-120-45 kg/ha at planting plus 20 foliar applications of urea and potassium sulfate (50 kg/ha), drip irrigation applied every three weeks; iv) FERT- application of 150-150-120-45 kg/ha at planting, but urea and potassium sulfate (50 kg/ha) were applied throughout fertigation; and v) CRF- same amount of nutrients as FS-R but N was applied as a controlled release fertilizer every six months. At Isabela, treatment FS-R produced the highest fruit weight (2.5 kg per fruit) and 1.5% of N in tissue, but did not differ significantly from FS-DI and CRF. Plants under CRF registered the highest Brix (15.8°). Although foliar fertilizer tended to produce higher yields, controlled release fertilizer is recommended because it eliminates the need for frequent foliar application without compromising yield.

Key words: pineapple, yield, D-leaf nutrient content, fertigation

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[3]Graduate Student, Department of Agroenvironmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus.

[4]Professors, Department of Agroenvironmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus. Mayagüez, PR. 00681. Author for correspondence Email: elvin.roman@upr.edu

[5]Assistant Professor, Department of Agroenvironmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus. Mayagüez, PR. 00681

RESUMEN

Crecimiento y rendimiento de la piña en respuesta al manejo de fertilizante y riego por goteo

La piña [*Ananas comosus* (L.) Merr.] es una fruta cultivada en varios países tropicales alrededor del mundo. Esta fruta requiere grandes cantidades de nitrógeno (N) y potasio (K) para maximizar su rendimiento. Aunque las plantas de piña necesitan bajas cantidades de agua, los periodos prolongados de sequía pueden afectar sus rendimientos. Se realizaron dos experimentos para estudiar el efecto de aplicaciones de fertilizantes y riego por goteo en el rendimiento de piña. Los cultivares MD-2 y Cabezona se sembraron en Isabela y Lajas, Puerto Rico, respectivamente. Los tratamientos de fertilizantes y riego utilizados fueron: i) Control - aplicación de fertilizante granulado a razón de 896 kg/ha (12-6-10-3) a los dos, cinco y nueve meses después de la siembra; ii) FS-R - aplicaciones de 150-150-120-45 kg/ha a la siembra más 20 aspersiones de urea y sulfato de potasio (50 kg/ha) cada tres semanas sin riego por goteo; iii) FS-DI - aplicaciones de 150-150-120-45 kg/ha a la siembra más 20 aspersiones de urea y sulfato de potasio (50 kg/ha) cada tres semanas añadiendo riego por goteo; iv) FERT - aplicaciones de 150-150-120-45 kg/ha más las mismas cantidades de urea y sulfato de potasio usadas en FS-DI, aplicadas por fertigación; v) CRF - aplicación de las mismas cantidades que FS-R, pero utilizando una formulación de nitrógeno de liberación controlada cada seis meses. En Isabela el tratamiento FS-R obtuvo el mayor peso del fruto (2.5 kg/fruta), y una concentración de N de 1.5% en el tejido, sin ser significativamente diferentes de FS-DI y CRF. Las plantas bajo CRF tuvieron el mayor valor Brix (15.8°). Aunque las aspersiones foliares tendieron a producir los rendimientos más altos, se recomienda la utilización de fertilizantes de liberación controlada porque elimina la necesidad de aspersiones foliares frecuentes sin comprometer rendimiento.

Palabras clave: piña, rendimiento, contenido foliar de nutrimentos, fertiriego

INTRODUCTION

In Puerto Rico, pineapple ranks as the fourth most economically important fruit crop with an annual production of 3,810 MT and gross income of $3.2 million (Department of Agriculture, 2010). In 1980, production decreased by 50% and has continued to decline to 77% today (University of Puerto Rico, 1984). The decline in production over the years could be related to water and nutrient management problems, as well as to the lack of suitable propagation material. However, in the last decade, as a result of the introduction of the high yielding MD-2 cultivar, pineapple production has been increasing.

The most common pineapple cultivars that have been planted in Puerto Rico are Cabezona, Española Roja and Cayena Lisa. According to Ramírez and González (1983), the Cabezona cultivar, mostly planted in the southwest, has a yield potential of 72 MT/ha when planted in double rows. Back in the 60s, cultivar Cayena Lisa produced fruit that weighed between 1.5 and 3.0 kg with estimated yields of 40 to 54 MT/ha (Cibes and Samuels, 1961). Española Roja was the most popular cultivar grown in northern Puerto Rico, but by 1958 it was gradually being replaced by Cayena Lisa (University of Puerto Rico, 1984). This cultivar is susceptible to various diseases and pests but is resistant to *Phytophthora parasitica* and the collapse of the fruit caused by *Erwinia chrysanthemi* (Chan et al., 2003).

The MD-2 hybrid developed by the Pineapple Research Institute in Hawaii was released in 1996 (Frank, 2003) and has been planted by farmers throughout Puerto Rico since 2007 (Atenas Pineapple, 2013). Known and marketed as Golden Ripe or Extra Sweet by Del Monte Fresh Produce Hawaii, Inc., this cultivar is characterized by a golden color when ripe, sweet taste, low acidity, resistance to some pathogens and a good shelf-life when placed in cold storage for up to two weeks. The fruit is classified between medium and large with a weight ranging from 1.3 to 2.5 kg. It is resistant to internal decay, *Phytophthora* and wilting, shows low acidity, produces high yields and grows faster than Cayena Lisa (Bartholomew, 2009; Chan et al., 2003).

The most limiting nutrients in pineapple cultivation are nitrogen (N) and potassium (K^+), which affect fruit growth and quality (Cibes and Samuels, 1961; Souza et al., 2002; Spironello et al., 2004). The phosphorous (P) requirement is low (Ahmed et al., 2001; Cibes and Samuels, 1961; Souza et al., 2002); however, soil P values below 5.0 mg/kg affect root growth in its early stages, thereby affecting water and nutrient absorption (Bartholomew et al., 2003; Cibes and Samuels, 1961).

The nutritional status of crops has a direct influence on fruit growth and quality. To achieve optimum fruit production and quality, a fertilization management (i.e., foliar vs. granular, slow vs. fast release) program is needed. After determining the amount of nutrients available in soil and plants, fertilization management should be established to maintain a proper balance of nutrients and prevent environmental pollution. Pineapple composting studies conducted in Malaysia indicate that applied fertilizer had a utilization efficiency of 53% for P and 29% for K^+. Such low efficiency is due to losses by leaching and/or retention of P and K^+ in the soil (Ahmed et al., 2001; Giambelluca and Oki, 1985).

The excessive application of nutrients such as N has been reported as a major pollutant in groundwater. In Puerto Rico, Conde and Gómez (1999) found concentrations in the range of 6.8 to 10 mg/L NO_3^- in a Manatí municipality aquifer located near a pineapple production area. This high NO_3^- concentration was caused primarily by fertilizer applications. Potential N leaching could reach up to 760 kg/ha per year from the soils under pineapple cultivation. According to Ahmed et al. (2001) pineapple's N absorption peak occurs 263 days after planting.

Pineapple requires slightly acidic (pH 5.5) and well-drained soil to prevent its roots from rotting by waterlogging and diseases associated with it (Souza et al., 2002; Mite et al., 2009; Py and Tisseau, 1969; University of Puerto Rico, 1984; Gandía and Samuels, 1958). However, pineapples should not be planted on slopes greater than five degrees to prevent problems of machinery access.

Worldwide, pineapple is mostly grown without irrigation because of its low hydric requirements. The pineapple plant's high water use efficiency is due to its morphological, anatomical and physiological traits. However, prolonged drought periods can affect pineapple growth and fruit development primarily in quality and performance (Azevedo et al., 2007; Ekern, 1965; Theodore and Acevedo, 1974). Azevedo et al. (2007) reported pineapple evapotranspiration estimates of 4.6 mm per day during the vegetative growth stage and 3.5 mm/day in the reproductive stage (fruit harvest). During fruit development, evapotranspiration reaches 1.3 mm on a cloudy day and 2.77 mm on a sunny day (Malezieux et al., 2003). During hydric stress the plant slows growth and closes its stomata, reducing water loss and carbon dioxide (CO_2) intake (D'Eeckenbruge and Leal, 2003; Hslao and Acevedo, 1974). Hepton (2003) found that when precipitation was less than 50 mm per month, the pineapple growth cycle was delayed, affecting yields. For that reason, irrigation is essential to avoid affecting yields when rainfall is irregular and dry seasons are long (Imas, 1999). According to the Food and Agriculture Organization of the United Nations (FAO, 2017), 60 mm per month of water is sufficient for optimal pineapple plant growth; however, Azevedo (2007), Hepton (2003), and Py et al. (1987) found that 50 mm per month is sufficient. In areas with well-distributed rainfall it is not necessary to establish an irrigation system.

Currently, two types of irrigation systems (i.e., sprinkler and drip irrigation) are used worldwide on pineapple plantations. Molden et al. (2009) specified drip irrigation as the most efficient because of its capacity to apply fertilizers in-line. Applying fertilizers through the drip system benefits fertilizer efficiency while, at the same time, reducing the risk of contamination (Biswas, 2010). Furthermore, frequent use of drip irrigation causes lower salt concentrations in the soil solution, which makes it possible to use water with a higher salt content than with other irrigation methods (Santos et al., 2010). Irrigation water with high chlorine content affects pineapple yields and fruit quality (Alvarez and Carracedo, 1995); thus, chlorine and pH of irrigation water must be determined.

The pineapple crop removes large amounts of soil nutrients especially N and K^+. The amount of fertilizer to be applied depends on the cultivar, planting density, weather conditions, soil fertility, source of water, and soil chemical and physical characteristics (University of Puerto Rico, 1984). Fertilizers are applied mostly to the soil, but pineapple can absorb nutrients through its leaves and adventitious roots at the base of the leaves. It has been found that combined fertilization practices (i.e., soil and foliar application) have significantly improved yields and fruit quality (Ramos et al., 2009; University of Puerto Rico, 1984).

Pineapple leaves are identified according to size and age as A, B, C, D, E and F, from the oldest to the newest, respectively (Sideris and Kranss, 1928; Malezieux et al., 2003). Leaf 'D' is the largest of all, more easily identified, and physiologically active, which is why leaf 'D' is used as an indicator to determine the nutritional status of the crop. According to studies conducted by Malezieux and Bartholomew (2003) and Souza et al. (2002), an optimal N level in the soil is near 27 mg/kg while the N content in the D-leaf varies from 1.5 to 1.7%. A deficiency of N causes chlorosis of young leaves, while in severe cases the plant does not produce fruit (Betancourt et al., 2005; Cibes and Samuels, 1961).

As for soil, optimum levels of P, K^+ and magnesium (Mg^{2+}) for pineapple are close to 20, 150 and 50 mg/kg, respectively. By contrast, optimum tissue contents in the D-leaf are 800 mg/kg (0.08%) for P, 20,000 to 30,000 mg/kg (2 to 3%) for K^+ and 150 mg/kg (0.015%) for Mg nutrients (Malezieux and Bartholomew, 2003; Malezieux et al., 2003; Py et al., 1987). Py et al. (1987) reported pineapple nutrient extractions of 0.75 to 0.80 kg/ha N, 0.15 kg/ha P_2O_5 and 2 to 2.6 kg/ha K_2O from 907 kg (2,000 lb) of fruits. The N and K^+ requirements for the first 160 days after planting (DAP) are low; requirements increase up to flowering induction. Studies by Souza et al. (2002) indicated that total N and K^+ content remain constant from flowering to harvest. For this reason, it is not recommended to apply N and K^+ after flowering induction due to the lack of response. Also, the fruit is sensitive to the application of N, and malformation can occur by direct spraying on the fruit. Several N, P, and Mg^{2+} sources could be used to satisfy nutrient requirements of pineapple. Micronutrients are commonly applied as a commercial mix of iron, zinc, boron, and sulfate. The use of potassium chloride as a nutrient source should be avoided because chlorine is toxic to pineapple plants.

Currently, there is a lack of knowledge and research on the effects of different methods of irrigation and fertilizer application on the size, quality and fruit yield of MD-2 in Puerto Rico. The aim of this study was to develop the necessary information on the effects of different water and fertilizer management practices on yield and production of pineapple.

MATERIALS AND METHODS

A study was conducted at the Isabela Agricultural Experiment Station (AES) located in northwestern Puerto Rico, using the MD-2 pineapple cultivar as test cultivar. The soil series at the experiment site is Coto clay (Typic Eutrustox), which is a well-drained Oxisol (Beinroth et al., 2003; USDA-NRCS, 1982). Coto clay is a deep red soil of moderate permeability, slightly acidic and clayey (USDA-NRCS, 1982). A similar study was established at the Lajas AES located in southwestern Puerto Rico on an Ultisol (Typic Haplohumult) Mariana series (USDA-NRCS, 2008). For the experiment, the Cabezona cultivar was planted because it is popular with farmers and had been planted for decades in the Lajas region. The chemical characteristics of both soils are described in Table 1.

Experiments at both locations consisted of five treatments, comparing the traditional granular fertilizer application recommended by UPR (1984) with four other application methods. The five treatments applied were: Control- application of 896 kg/ha of a granular fertilizer (12-6-10-3) at two, five and nine months after planting (MAP) under rainfed conditions; FS-R (Foliar spray-rainfed)- application of base fertilizers at rate of 150-150-120-45 kg/ha (N, P_2O_5, K_2O and MgO, respectively) plus 20 foliar applications of urea and potassium sulfate (50 kg/ha) every three weeks under rainfed conditions; FS-DI (Foliar spray-drip irrigation)- application of base fertilizers at rate of 150-150-120-45 kg/ha at planting plus 20 foliar applications of urea and potassium sulfate (50 kg/ha) every three weeks with drip irrigation; FERT (Fertigation)- application of base fertilizers at rate of 150-150-120-45 kg/ha at planting plus the same urea and potassium sulfate applied throughout fertigation (every three weeks) instead of foliar application; CRF (controlled release fertilizer)- same nutrient amounts as FS-R but N was applied as a controlled release fertilizer every six months (Table 2). Treatments were applied from two MAP until flowering induction. Urea, superphosphate, potassium sulfate, and magnesium sulfate were the nutrient sources used as base fertilizers for FS-R, FS-DI, and FERT treatments.

Total precipitation was 2,671 mm (16-month production cycle) and 2,794 mm (20-month production cycle) for Isabela and Lajas, respectively. Average temperatures were 29° C and 31° C for Isabela and Lajas, respectively. Flowering was induced at AES-Isabela 2 February 2011 (11 MAP) using Ethephon at recommended rates. However, natural induction of some pineapple plants occurred during the winter. Fruit harvest began 29 July 2011 (16 MAP) with a total of five harvests at both locations.

Table 1.—*Soil chemical characteristics at the experiment sites in Isabela and Lajas, Puerto Rico, in 2010.*

Location	Depth cm	pH	N %	NH_3	NO_3^-	P	K^+	Ca^{+2}	Mg^{+2}	Na^-	Al^{+3}	ECEC[1]
				---- mg/kg ----			---- cmol/kg ----					
Isabela	0-12	5.35	0.16	11	68	7.0	0.38	2.32	0.61	0.06	0.28	3.37
	12-30	5.40	0.16	9	61	7.0	0.32	2.38	0.60	0.06	0.18	3.36
Lajas	0-12	5.56	0.16	10	16	2.0	0.39	5.54	3.51	0.36	0.34	9.8
	12-30	5.47	0.14	7	14	0.0	0.27	4.88	2.89	0.38	2.22	8.42

[1]ECEC – Estimated Cation Exchange Capacity

The experimental plots were arranged in a randomized complete block design with four replications and five treatments (Table 2). Each plot consisted of three beds, and data were collected from the middle bed. Pineapple propagation material was sorted by size (> 0.4 kg, 0.2-0.4 kg and <0.2 kg) and planted by blocks. Seedlings of MD-2 cultivar were planted 29 March 2010 in 5.5-m double row beds. Plant spacing in a given bed was 0.31 m within rows and 0.40 m between rows. The beds were 1.2 m apart, for a final planting density of 40,617 plants/ha. Propagation material was obtained from a private company (Atenas Pineapple, located in Manatí, Puerto Rico). Cabezona cultivar was planted 8 March 2010 on 6.10-m long single row beds with spacing of 0.60 between plants and 0.91 m between beds for a final density of 17,943 plants per hectare.

At AES-Isabela, irrigation was applied through a commercially available polyethylene drip tape, with emitters spaced every 30 cm, connected to the main PVC pipe. At AES-Lajas, the irrigation system design consisted of a 1,900 L plastic container full of tap water. Plants were irrigated by gravity through polyethylene drip tape with emitters spaced every 30 cm.

TABLE 2.—*Fertilization rates, fertilization application methods and drip irrigation treatments applied to pineapple planted at Isabela and Lajas, Puerto Rico.*

Treatment		Treatment description
Control	Control	896 kg/ha granular fertilizers (12-6-10-3) applied at 2, 5 and 9 months after planting. Rainfed.
FS-R	Foliar spray, rainfed	150-150-120-45 kg/ha N, P_2O_5, K_2O and MgO, respectively, granular fertilizers applied at planting. Plus 20 foliar spray applications each of 50 kg/ha of urea and potassium sulfate every three weeks. Rainfed.
FS-DI	Foliar spray, drip irrigation	150-150-120-45 kg/ha N, P_2O_5, K_2O and MgO, respectively, granular fertilizers applied at planting. Plus 20 foliar sprays each of 50 kg/ha of urea and potassium sulfate every three weeks. Drip irrigated.
FERT	Fertigation	150-150-120-45 kg/ha N, P_2O_5, K_2O and MgO, respectively, granular fertilizers applied at planting. Plus applications, by fertigation every three weeks, equivalent to 20 foliar spray applications of 50 kg/ha of urea and potassium sulfate. Drip irrigated.
CRF	Controlled release fertilizer	150-150-120-45 kg/ha N, P_2O_5, K_2O y MgO, respectively, controlled release fertilizer applied at planting (controlled released urea as N source) plus 50 kg/ha protected urea and potassium sulfate applied to soil every six months. Rainfed.

A backpack sprayer was used for the foliar applications (FS-R and FS-DI treatments). At Isabela, soluble fertilizers (FERT treatment) were applied by using a Dosatron® (commercial device designed to accurately dispense fertilizers and other chemicals through the irrigation system). To ensure that the complete nutrient mixture was injected into the irrigation water, system pressure needed to be adjusted to 131 kPa for the FERT treatment and 182 kPa for FS-DI. At Lajas, fertilizers were delivered through the irrigation system from a fertigation tank. Plants with supplemental drip irrigation (FS-DI and FERT) were watered weekly when the amount of rain registered at the location (Lajas or Isabela) did not exceed 15 mm per week (15 mm represents the minimum precipitation required per week for the crop). Pineapple plants were watered until reaching the 15 mm per week threshold.

To keep the amount of drip irrigation applied to treatments FS-DI and FERT equal, when fertilizers were applied to pineapple under the FERT treatment, those under FS-DI were also watered. During weeks when rainfall exceeded the minimum required (15 mm/week), the FS-DI and FERT treatments received a small amount of irrigation water (less than 0.02 mm), which was used to dissolve fertilizers and delivered through the Dosatron® system.

Pineapple fruits were harvested at maturity (when over half the fruits were ripe or turned yellow). Variables measured were fruit size, weight, crown weight, brix (soluble sugars taken with a hand-held optical refractometer at the base of the fruit) and number of slips. Plants were pulled out of the soil and the number of suckers, sucker weight, the number of leaves, and moisture percentage were determined; absorption of N, P and K was estimated by measuring nutrient content in the leaves. To determine postharvest moisture and nutrient content, two plants were sampled and triturated using a machine. A subsample of the triturated material was taken and weighed before and after being oven-dried at 60° C to determine moisture content and then sent to a lab for nutrient content analysis.

Data were statistically analyzed; Fisher's LSD test or orthogonal contrasts at 5% probability level were used for mean separation. Repeated measurements over time were analyzed as a complete block design with a split-plot arrangement. Four orthogonal contrasts between treatments were performed. In the first orthogonal contrast, the control treatment (granulated fertilizer) was compared to all other treatments. In the second, plants with drip irrigation were compared with plants without drip irrigation (rainfed). Other orthogonal contrasts compared the use of foliar spray fertilizer applications with fertigation; and foliar spray fertilizers versus controlled release fertilizer applications.

RESULTS AND DISCUSSION

At Lajas, Cabezona was affected by pineapple wilt (Marchitez Roja), apparently caused by a virus transmitted by the pineapple mealybug (*Dysmicoccus brevipes*) (Rohrbach and Johnson, 2003; Verle-Rodrigues, Agricultural Experiment Station, Univ. P.R., personal communication, 2015). As a result, yield and plant growth data were not representative of those obtained in the region. Because of high incidence of pineapple wilt in the Lajas Valley area, along with a lack of suitable propagation material, Cabezona producers in the area have switched to MD-2 (José Zamora, Agricultural Extension Service, Univ. P.R., personal communication, 2015).

Plant Growth

Flowering induction occurred approximately at 12 MAP. Variables measured during vegetative growth stage (before flowering induction) were plant height, stem diameter, leaf number, and foliar N (Table 3). Regarding plant height of MD-2, no significant differences were found among FS-R (spraying), FS-DI, and CRF treatments. Nonetheless, plants under the treatments had a greater height compared with the control for MD-2. In addition, there was no difference in plant height among treatments for Cabezona (Table 3). For MD-2, the maximum plant height achieved was 99 cm measured at 9 MAP. It can be inferred that plants were ready for flowering induction at 9 MAP, since no growth was recorded between 9 and 12 MAP for all treatments. In January (10 MAP), plants with maximum height began flowering naturally. Bartholomew et al. (2003) indicated that a decrease in day length and temperature might induce natural flowering.

The MD-2 plants achieved the maximum number of leaves (37) at 9 MAP (Table 3). However, the number decreases to 34 leaves at 12 MAP. There were no significant differences in leaf number for Cabezona among treatments. Stem diameter was similar for both varieties (Table 3); no differences were observed among treatments. The average stem diameter for the whole growing cycle was 8.31 cm. The largest stem diameter (9.61 cm) for MD-2 was recorded at 3 MAP decreasing at 6 MAP, since by then plants had shed their first leaves (fallen from stem), causing a reduction in diameter. After six months, stem diameter increased again up to 12 MAP, coinciding with floral induction. Cabrera et al. (2007) and Azevedo et al. (2007) reported 39 and 43 leaves, respectively, for MD-2 propagated in vitro. A stem diameter of 5 cm is used as an indicator to artificially induce flowering in Cabezona.

No significant differences were detected in the percentage of tissue moisture or sucker weight. In MD-2, tissue moisture varied from 81 to 83%, sucker weight varied from 260 to 839 g and the number of suckers

TABLE 3.—*Plant height, stem diameter, leaf number and D-leaf nitrogen content in response to fertilization application methods and drip irrigation treatments applied to MD-2 and Cabezona pineapple cultivars planted at Isabela and Lajas, Puerto Rico, respectively.*

Location	Cultivar	Treatments (TRT)[1]	Plant height	Stem diameter	Leaf number	Foliar N %
			------------------- cm	--------------------		
Isabela	MD-2	Control	72.7 b[2]	7.62	28.6	1.13 c
		FS-R	85.9 a	8.27	32.2	1.46 a
		FS-DI	87.1 a	8.31	32.5	1.39 ab
		FERT	80.7 ab	7.99	30.3	1.20 bc
		CRF	83.5 a	7.97	30.4	1.29 bc
		Significance[3]	*	NS	NS	*
		Month after planting (MAP)				
		3	48.7 c	9.61 a	22.6 d	1.17 c
		6	80.4 b	6.46 c	30.0 c	1.35 ab
		9	99.2 a	7.95 b	36.6 a	1.41 a
		12	99.6 a	8.11 b	33.9 b	1.24 bc
		Significance[3]	*	*	*	*
		TRT*MAP	NS	NS	NS	*

[1]See Table 2 for treatment descriptions
[2]Means followed with the same letter are not significantly different according to LSD Fisher ($\alpha \leq 0.05$).
[3]* significant $\alpha \leq 0.05$, NS - not significant

TABLE 3.—(Continued) *Plant height, stem diameter, leaf number and D-leaf nitrogen content in response to fertilization application methods and drip irrigation treatments applied to MD-2 and Cabezona pineapple cultivars planted at Isabela and Lajas, Puerto Rico, respectively.*

Location	Cultivar	Treatments (TRT)[1]	Plant height	Stem diameter	Leaf number	Foliar N %
			------------------- cm	--------------------		
Lajas	Cabezona	Control	57.3	6.48	21.4	0.99 b[2]
		FS-R	60.5	6.66	22.7	1.29 a
		FS-DI	60.6	6.76	22.8	1.29 a
		FERT	60.5	6.75	22.3	1.07 b
		CRF	62.7	7.03	22.9	1.10 b
		Significance[3]	NS	NS	NS	*
		Month after planting (MAP)				
		3	46.3	6.21	23.6	0.79
		6	66.0	7.42	22.7	1.42
		9	61.8	6.76	20.8	1.21
		12	61.2	7.05	21.6	1.32
		15	66.3	6.23	23.4	1.01
		Significance[3]	*	*	NS	**

[1]See Table 2 for treatment descriptions
[2]Means followed with the same letter are not significantly different according to LSD Fisher ($\alpha \leq 0.05$).
[3]*significant $\alpha \leq 0.05$, NS - not significant

per plant ranged from 1.15 to 3.03. Cibes and Samuels (1961) studied plant weight at the end of the production cycle under controlled conditions. They reported that the weight of the main plant reached 4.7 kg, the root 0.168 kg and suckers 1.22 kg (with an average of two suckers). In the same study, plant moisture percentages of treatments with less N decreased to 85% moisture compared to 89% for full N treatment. In our study, moisture percentage did not reach such values in any of the treatments. Even though no statistical difference is observed, plant fresh weight recorded from Control treatments was 62 to 46% lower than from FS-R and CRF treatments for MD-2 and Cabezona, respectively (Table 4).

Foliar N Content

As for foliar N, significant differences were found among treatments at both locations and between sampling dates for MD-2 at Isabela (Table 3). The N content changed significantly over time, as affected by the fertilization application methods and drip irrigation. From three to six MAP, N content in D-leaf increased because the plant was absorbing nutrients applied in the fertilizers (Vélez-Ramos and Ramos, 1995; Samuels et al., 1955). During the first three MAP, the average foliar N content in MD-2 was 1.17%, while at six and nine MAP, it increased to 1.35 and 1.41%, respectively. However, the foliar N content decreased (1.24%) at 12 MAP. This decrease in foliar N content is due to a reduction in nutrient uptake as the plant transitioned from vegetative to reproductive stage (Malezieux and Bartholomew, 2003).

Further analysis of significant interaction among treatments and foliar N content indicate that at 9 MAP, plants submitted to CRF scored the highest N-tissue percentage, 1.41% (data not shown). The lowest N percentage (1.13%) was obtained by the control at 12 MAP and was statistically lower than that of all other treatments because the N applied to the control was lower (321 kg/ha) than that in the other treatments (610 kg/ha). Data of foliar N in Cabezona are not discussed because plants were severely attacked by a disease, preliminarily identified as a virus; thus, values are considered as not representative.

Plants submitted to foliar spraying (FS-R) had tissue with higher N percentages, 1.46% compared with 1.20% in the fertigation (FERT) treatment (Table 3). Fertigation effects depend on soil conditions; if the soil is saturated with water when making the application, nutrient losses may occur (Biswas, 2010). At Isabela-AES, N losses were expected due to the abundant precipitation registered during the growing cycle, evidenced, in fact, by the low N percentage in plants receiving the FERT treatment. Orthogonal contrasts comparing non-drip irrigated treatments (FS-R vs. CRF) indicated that foliar applications (FS-R)

TABLE 4.—*Effect of fertilization application methods and drip irrigation treatments on postharvest pineapple plants, MD-2 and Cabezona varieties grown at Isabela and Lajas, Puerto Rico, respectively.*

Location	Cultivar	Treatment[1]	Plant fresh weight with suckers	Suckers weight	Suckers number	Tissue moisture
			---g---		--- (#) ---	---%---
Isabela	MD-2	Control	2,317 b[2]	260	1.15	81.7
		FS-R	3,741 a	839	3.03	83.4
		FS-DI	3,690 a	508	2.68	82.6
		FERT	3,433 a	507	2.43	81.8
		CRF	3,159 ab	315	2.00	82.3
		Significance[3]	*	NS	NS	NS
Lajas	Cabezona	Control	724 a	195	0.42	54.0
		FS-R	1,136 ab	79	0.33	72.8
		FS-DI	1,238 ab	293	0.42	74.3
		FERT	922 a	52	0.17	72.5
		CRF	1,567 b	546	0.58	77.3
		Significance[3]	*	NS	NS	NS

[1]See Table 2 for treatment descriptions
[2]Means followed with the same letter are not significantly different according to LSD Fisher ($\alpha \leq 0.05$).
[3]*significant $\alpha \leq 0.05$, NS - not significant

resulted in higher foliar N percentages than in plants fertilized with controlled release fertilizer (CRF), with averages of 1.46 and 1.29%, respectively (Tables 3 and 7). The advantage of foliar application is that the soil conditions do not interfere with the mechanism of absorption, whereas for common granular fertilizer (Control) and CRF, absorption mechanisms are affected by soil moisture and plant status.

Plants in FS-R had an average N percentage of 1.46% in the D-leaf, which was not significantly different from that of the other treatments, except for the control. An optimum N in tissue ranges from 1.5 to 1.7% (Malezieux and Bartholomew, 2003; Souza et al., 2006). An N content of less than 1.25% generally causes severe deficiencies, turning leaves yellowish (Malezieux and Bartholomew, 2003; Samuels et al., 1958). In Española Roja cultivar, Samuels et al. (1958) found that N values less than 1.66% on D-leaf were related to N deficiencies and lower yields. These values were higher than optimum values in the Cayena Lisa cultivar (Gandía and Samuels, 1958).

Fertilization application methods did not have a significant effect on N, P and K contents in MD-2 tissue (Table 6). However, further analyses throughout orthogonal contrasts comparing granular fertilizers application (Control treatment) against all other treatments indicate that the control has lower N content (Table 6 and 7). Another important orthogonal comparison is foliar spray vs. fertigation where N in the tissue of MD-2 plants submitted to FS-DI (1.24%) is significantly higher than that of FERT (1.17%). Under rainfed conditions, N in the tissue of plants submitted to FS-R (foliar spray) was higher than in plants in the CRF treatment. Whereas the most relevant orthogonal comparison of Cabezona cultivar is that CRF is always higher than FS-R for N, P, K in the tissue (unlike MD-2 cultivar).

Yields and Fruit Brix

Pineapple plants were harvested at five different dates because fruit ripening was not uniform. Most of the fruits were collected during the first (21%), third (35%), and fifth (20%) harvests (Data not shown). Plants in the CRF treatment showed a delay in reaching physiological maturity; 37% of the fruits in this treatment were harvested on the fifth harvest with an average fruit weight of 2.20 kg (Data not shown). Plants under the Control treatment reached maturity earlier; about 29% of the fruits were harvested at the first pick with an average fruit weight of 2.13 kg.

At Isabela, significant treatment differences were found only for Brix and fruit weight (including the fruit crown) (Table 5). The FS-R treatment produced the highest fruit weight (2,538 g) but it was not significantly different from that of FS-DI and CRF. MD-2 plants sub-

TABLE 5.—*Effect of fertilization application methods and drip irrigation treatments on variables measured for MD-2 and Cabezona pineapple fruits grown at Isabela and Lajas, Puerto Rico, respectively.*

Location	Cultivar	Treatment[1]	Fruit weight with crown	Crown height	Fruit height with crown	Crown height	Slips number	°Brix
			--------g--------		--------cm--------			
Isabela	MD-2	Control	1,856 c[2]	399	49.9	22.8	1.25	15.5 b
		FS-R	2,538 a	436	53.5	35.0	2.69	13.8 a
		FS-DI	2,525 a	428	49.1	30.8	2.50	13.5 a
		FERT	2,094 bc	433	50.6	33.8	1.63	15.5 b
		CRF	2,272 ab	410	53.9	34.9	2.69	15.6 b
		Significance[3]	*	NS	NS	NS	NS	*
Lajas	Cabezona	Control	555	175	24.6	16.5	—	12.7
		FS-R	501	222	25.6	18.6	—	12.6
		FS-DI	442	141	23.2	16.6	—	12.3
		FERT	519	181	28.5	21.0	—	11.9
		CRF	803	366	35.4	27.3	—	9.39
		Significance [3]	NS	NS	NS	NS		NA

[1]See Table 2 for treatment descriptions

[2]Means followed with the same letter are not significantly different according to LSD Fisher ($\alpha \le 0.05$).

[3]*significant $\alpha \le 0.05$, NS - not significant

TABLE 6.—*Effect of fertilization application methods and drip irrigation treatments on N, P and K content of post-harvest pineapple leaf tissue of MD-2 and Cabezona varieties grown at Isabela and Lajas, Puerto Rico, respectively.*

Location	Cultivar	Treatments[1]	N	P	K
			------------------	%	------------------
Isabela	MD-2	Control	1.02	0.15	1.92
		FS-R	1.25	0.12	2.43
		FS-DI	1.24	0.13	2.16
		FERT	1.17	0.15	2.01
		CRF	1.16	0.14	2.52
		Significance[3]	NS	NS	NS
Lajas	Cabezona	Control	0.78 a	0.10 ab[2]	1.00 a
		FS-R	0.85 a	0.09 a	1.21 a
		FS-DI	0.81 a	0.08 a	1.19 a
		FERT	0.81 a	0.10 ab	1.03 a
		CRF	1.04 b	0.12 b	1.79 b
		Significance[3]	**	*	**

[1]See Table 2 for treatment descriptions.
[2]Means followed with the same letter are not significantly different according to LSD Fisher ($\alpha \leq 0.05$).
[3]*significant $\alpha \leq 0.05$, ** significant $\alpha \leq 0.01$, NS - not significant

jected to CRF obtained the highest Brix value (15.6°), which was not significantly different from the Brix values of fruits harvested in the Control and FERT treatments (Table 5).

The data obtained in our experiment confirms data reported by other authors. For instance, Rebolledo et al. (1993) studied fruit weight at two planting densities (41,000 and 46,000 plants/ha) obtaining fruits of 2.8 and 2.0 kg, respectively, for Cayena Lisa. Azevedo et al. (2007) reported pineapple (cv. Perola) plants weighing 1.6 kg (without crown), for non-water stressed plants. Studies in Puerto Rico indicate that fruit weight reached up to 4.4 kg and crown weight 0.54 kg (Cibes and Samuels, 1961). The Pineapple Technological Package (University of Puerto Rico, 1984) reports fruit weight of up to 3.5 kg, and Brix values of up to 14° related to potassium applications.

Fruit weight decreases with increasing plant density, but this is offset by the increase in weight per unit area (Sanford, 1962; Rebolledo et al., 1993; Vélez-Ramos et al., 1991). For planting densities varying from 22,000 to 64,000 plants per hectare, Sanford (1962) indicated that there is a decrease of 0.45 kg in fruit weight per each increase of 2,405 plants per hectare. The reason for this reduction is that yield is a function of the photosynthetic action per unit area (Bartholomew et al., 2003). At higher planting densities, a lower leaf area is required to produce one kilogram of fruit (Bartholomew et al., 2003). Yields of 115

TABLE 7.—*Relevant orthogonal contrast analysis among fertilization management treatments on D-leaf N content for MD-2 at Isabela; and N, P and K content for postharvest, Cabezona, whole-plant tissue at Lajas, Puerto Rico.*

	MD-2	Cabezona		
	N	N	P	K
Orthogonal contrasts[1]	----------	---------- %	----------	----------
Comparison of Control vs. FS-R, FS-DI, FERT and CRF treatments (granular fertilizers application against all other)	*[2]	*	NS	NS
Comparison of treatments FS-DI and FERT vs. FS-R and CRF (drip-irrigated treatments against rainfed treatments)	NS	**	NS	**
Comparison of treatments FS-DI vs. FERT (foliar spray fertilizer application against fertigation)	*	NS	NS	NS
Comparison of treatments FS-R vs. CRF (foliar spray fertilizer application against controlled release fertilizer application)	*	**	*	**

[1]See Table 2 for treatment descriptions
[2]*significant $\alpha \leq 0.05$, **significant $\alpha \leq 0.01$, NS - not significant

and 80 MT/ha have been reported in Mexico and Hawaii, respectively (Rebolledo et al., 1993). Other countries reporting high yields are Indonesia and Costa Rica with 61.2 and 48 MT/ha, respectively. At the Isabela AES, the MD-2 plants under the FS-R, FS-DI and CRF treatments showed the highest yields ($P<0.05$) with 103, 103 and 92.3 MT/ha, respectively, compared with the control (75 MT/ha) and FERT (85 MT/ha) (Data not shown). While at AES-Lajas, the Cabezona under all treatments did not achieve fruit yields higher than 18 MT/ha (Data not shown).

Correlation Analysis

Sets of variables were submitted to a correlation analysis. Only relevant significant correlations are discussed (Data not shown). For MD-2, there was a positive significant correlation between the percentages of N in D-leaf before flowering induction with fruit weight with crown ($r = 0.61$) and leaf number and plant height ($r = 0.85$). Also, a significant correlation was determined between plant height at flowering induction and fruit weight ($r = 0.71$) indicating that taller plants at flowering induction produce heavier fruits.

SUMMARY AND CONCLUSIONS

Pineapples planted at AES-Isabela (MD-2) showed significant fruit yield differences associated with the methods of fertilization and drip irrigation. However, at AES-Lajas (Cabezona) there were no differences in most variables, because a disease greatly affected growth and development. At both AES locations, foliar N levels during vegetative growth were more stable with foliar spray applications every three weeks than with the other fertilization methods, keeping foliar N in the optimal range (1.5 to 1.7%). The efficiency of fertilization through fertigation, granular fertilizer and controlled release fertilizer is limited by the prevailing soil conditions and moisture. There were no differences in pineapple growth and yield between foliar spray fertilization treatments with and without drip irrigation. The data indicate that the use of fertigation is not a good alternative for growing pineapples. The results suggest that flowering can be induced at nine months after planting instead of twelve, since by this time vegetative growth was complete. With good management fertilization can be reduced by one to two months from current farming practices.

Although, controlled release fertilizer was at least as effective as frequent foliar sprays, it is important to consider that prices of controlled release fertilizers are higher than those of soluble fertilizer sources. On the other hand, using foliar sprays increases labor costs and often promotes weed growth.

LITERATURE CITED

Ahmed, O., M. Husni, A. Anuar and M. M. Hanafi, 2001. Some observations in pineapple production under different fertilizer programs and different pineapple residue management practices. Pertanika. *J. Trop. Agric. Sci.* 24(2): 115-121.

Atenas Pineapple, 2013. http://www.bumbia.com/dateelgusto/atenaspineappleincenmanatidateelgusto-152332.html.

Álvarez, C. and A. Carracedo, 1995. Pineapple yield and quality on a banana soil of the Canary Islands irrigated with acid and saline water. *Trop. Agric.* 73(3): 220-224.

Azevedo, P., C. Souza, B. da Silva and V. da Silva, 2007. Water requirements of pineapple crop growth in a tropical environment, Brazil. *Agric. Water Management* 88 (1-3): 201-208.

Bartholomew, D. P., 2009. 'MD-2' Pineapple transforms the world's pineapples fresh fruit export industry. *Pineapple News* 16: 2-5.

Bartholomew, D., E. Meluzieus, G. M. Sanewki and E. Sinclair, 2003. Inflorescence and fruit development and yield: pp. 167-169, *In*: D. Bartholomew, R. Paull, and K. Rohrbach (eds.) The Pineapple: Botany, Production and Uses. CABI Publishing. 320 pp.

Beinroth, F. H., R. J. Engel, J. L. Lugo, C. Santiago, S. Ríos and G. R. Brannon, 2003. Updated taxonomic classification of the soils of Puerto Rico, 2002. Bulletin 303. Agricultural Experiment Station, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus.

Betancourt, P., Y. Montilla, C. Hernández and E. Gallardo, 2005. Fertilización nitrogenada en el cultivo de pina (*Ananas comosus* L. Merr) en el sector Paramo Negro, municipio Iribarren estado Lara. *Rev. Fac. Agro.* 22: 377-387.

Biswas, B. C., 2010. Fertigation in high tech agriculture: A success story of a lady farmer. *Fertiliser Marketing News* 41(10): 4-8.

Cabrera, J., R. Keifer and V. Galán, 2007. Introducción y evaluación preliminar del cultivar de piñas tropical MD-2 bajo invernadero en las Islas Canarias. *Actas Hort.* 48: 693-696.

Chan, Y., G. C. D'Eeckenbruge and G. Sanewski, 2003. Breeding and variety improvement: pp. 33-55 *In:* D. Bartholomew, R. Paull and K. Rohrbach (eds.) Pineapple: Botany, Production and Uses CABI Publishing.

Cibes, H. and G. Samuels, 1961. Mineral-deficiency symptoms displayed by smooth Cayenne pineapple plants grown under controlled conditions. Univ. of P.R., Agric. Exp. Station. Bull. 31. pp. 1-30.

Conde, C. and F. Gómez, 1999. Nitrate concentration of the upper aquifer in the Manatí-Vega Baja area, Puerto Rico. Proceedings of the Third International Symposium on Water Resources, Fifth Caribbean Islands Water Resources Congress, American Water Resources Association: pp. 15-20.

D'Eeckenbruge, G. C. and F. Leal, 2003. Morpghology, anatomy and taxonomy: pp. 13-32., *In*: D. P. Bartholomew, R. Paull, and K. G. Rohrbach (eds.). The Pineapple: Botany, Production and Uses, CABI Publishing. 320 pp.

Departamento de Agricultura. Estadísticas Agrícolas, 2010. http://www.gobierno.pr/NR/rdonlyres/4A81AD1D-4A66-46C9-95AD 6A3C56F2EF48/0/DistribucionIngresoBruto-AgricolaProductos.pdf

Ekern, P. C., 1965. Evapotranspiration of pineapple in Hawaii. *Plant Physiol.* 40: 736-739.

FAO, 2017. Crop Water Information: Pineapple. http://www.fao.org/nr/water/cropinfo_pineapple.html.

Frank, R., 2003. Going for 'The Gold' turns pineapple world upside down. Wall St. J. 7 (Oct).

Gandía, H. and G. Samuels, 1958. Cultivo y Elaboración de la piña en Puerto Rico. Estación Exp. Agric. Univ. de Puerto Rico. Boletín 145.

Giambelluca, T. and D. Oki, 1985. Deep percolation of water from pineapple fields. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii. Special report, 7.4: 85.

Hepton, A., 2003. Cultural System: pp. 109-140, *In*: D. P. Bartholomew, R. E. Paull and K. G. Rohrbach (eds.) The Pineapple: Botany, Production and Uses. CABI Publishing. 320 pp.

Hslao, H. and E. Acevedo, 1974. Plant responses to water deficits, water use efficiency and drought resistance. *Agricultural Metereology* 14: 59-84.

Imas, P., 1999. Manejo de nutrientes por fertirriego en sistema frutihortícolas. XXII Congreso Argentino de Horticultura. International Potash Institute.

Malezieux, E. and D. Bartholomew, 2003. Plant nutrition: pp. 143-163. *In*: D. P. Bartholomew, R. E. Paull and K. G. Rohrbach (eds.) The Pineapple: Botany, Production and Uses. CABI Publishing. 320 pp.

Malezieux, E., F. Cote and D. P. Bartholomew, 2003. Crop environment, plant growth and physiology: pp. 69-101, *In*: D. P. Bartholomew, R. E. Paull and K. G. Rohrbach (eds) The Pineapple: Botany, Production and Uses. CABI Publishing. 320 pp.

Mite, F., L. Medina and J. Espinosa, 2009. Efecto de la corrección de pH en el rendimiento piña en suelos volcánicos. International Plant Nutrition Institute. p. 73.

Molden, D., T. Owesis, P. Steduto, P. Bindraman, M. Hanjra and J. Kijne. 2009. Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management.* 2774: 1-8.

Py, C. and M. Tisseau, 1969. La Piña Tropical. Primera Edición. Editorial Blume, Barcelona, Spain. 278 pp.

Py, C., J. J. Lacoeuilhe and C. Teison, 1987. The pineapple, cultivation and uses. G. P. Maisonneuve and Larose, Paris: p. 568.

Ramírez, C. T. and E. González, 1983. Spacing, nitrogen and potassium on yield and quality of 'Cabezona' pineapple. *J. Agric. Univ. P.R.* 67(1): 1-10.

Ramos, M. J. M., P. H. Monnerat, A J. . Carvalho, J. L. A. Pinto and J. A. Silva, 2009. Visual symptoms of macronutrients and boron deficiency in 'imperial' pineapple. *Rev Bras Frutic.* 31: 252-256.

Rebolledo, M. A., V. R. Mosqueda and R. A. E. Balerril, 1993. Growth analysis of smooth cayenne pineapple grows under four fertilizer rates in Vera Cruz, México. *Acta Hort.* 334(1): 159-169.

Rohrbach, K. and M. Johnson, 2003. Pests, diseases and weeds: pp. 203-250, *In*: D. P. Bartholomew, R. E. Paull and K. G. Rohrbach (eds.) The Pineapple: Botany, production and uses. CABI Publishing. 320 pp.

Samuels, G., S. Alers-Alers and G. Jackson, 1958. Influence of fertilizers on yields of pineapple on a Coto clay. *J. Agric. Univ. P.R.* 42(1): 12-26.

Samuels, G., P. Landrau and R. Olivencia, 1955. Response of pineapple to the application of fertilizers. *J. Agric. Univ. P.R.* 39(1): 1-11.

Sanford, W., 1962. Pineapple crop-log: concept and development. *Better Crop with Plant Food* 46: 32-43.

Santos, L., J. Valero, M. Picornell and J. Tarjuelo, 2010. El riego y sus tecnologías. Universidad Técnica de Lisboa CREA-UCLM.

Sideris, C. and B. Kranss, 1928. Water relations of pineapple plants. *Soil Sci.* 26(4): 305-316.

Souza, L. F. D., O. A. Almeida, R. C. Caldas and D. H. Reinhardt, 2002. Effect of soil moisture and fertilization on Perola pineapple in coastal tableland areas of Brazil. *Trop. Agric.* 79(2): 83-87.

Souza F. V. D., J. R. S. Cabral, J. A. dos Santos-Serejo, A. P. de Matos, D. H. Reinhardt, G. A. P. da Cunha, F. R. Ferreira and J. A. Pereira, 2006. Identification and selection of ornamental pineapple plants. *Acta Hortic.* 702: 93-97.

Spironello, A., J. A Guaggio, L. A. Junqueira, P. R. Furlani and J. M. Monteiro, 2004. Pineapple yield and fruit quality affected by NPK fertilization in a tropical soil. *Rev. Bras. Frutic. Jaboticabal.* 26: 155-159.

Theodore, C. and E. Acevedo, 1974. Plant responses to weather deficits, water use efficiency and drought resistance. *Agric. Mete.* 14: 59-84.

University of Puerto Rico, Agricultural Experiment Station, 1984. Conjunto Tecnológico para la producción de piñas. Publication 106.

USDA-NRCS, 1982. Natural Resources Conservation Services. Web soil survey- Arecibo Area- Northern Puerto Rico. http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

USDA-NRCS, 2008. Natural Resources Conservation Services. Web soil survey- San Germán Area- Northern Puerto Rico. http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

Vélez-Ramos, A. and J. Ramos, 1995. Foliar application of nitrogen, potassium and magnesium, and pineapple yield and quality. *J. Agric. Univ. P.R.* 79(3-4): 111-119.

Vélez-Ramos, A., P. Márquez and C. de Báez, 1991. Effect of N and K levels and planting density on pineapple fruit yield and quality. *J. Agric. Univ. P.R.* 75(4): 319-328.