Site-specific fertilization approach increased productivity of rainfed 'Ataúlfo' mango
El enfoque de fertilización de sitio específico incrementó la productividad del mango 'Ataúlfo'

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SUMMARY

There is considerable diversity in fertilization management of 'Ataúlfo' mango (*Mangifera indica* L.) in the state of Nayarit, Mexico, and there is no systematic information available in this regard. The aim of this research was to evaluate the medium-term effect (2010-14) of the site-specific fertilization approach on fruit yield and size in 'Ataúlfo' mango grown under rainfed conditions (annual average summer rainfall 1300-1450 mm). Two commercial orchards at 8 × 8 m spacing, one each in San Blas and Compostela municipalities in Nayarit were chosen. Fertilization treatments were: 1) Normal dose, which considered tree nutrient demand, periods of maximum root growth, nutrients provided by the soil, leaf nutrient concentrations and fertilization efficiency; 2) High dose (1.5 times the normal dose); 3) Control, annual application of 3 kg per tree of 17-17-17 (N, P_2O_5, K_2O). Soil and leaf samples were taken for nutrient analysis throughout the study. Treatments were randomly applied to 20 single tree-replicates at each orchard. For cumulative yield and fruit size a 2 × 3 factorial arrangement (orchards × treatments) was used. For leaf nutrient concentrations, the year and fertilization treatments effect was analyzed using 10 replicates per treatment. Means comparison was performed with the Waller-Duncan test ($P \leq 0.05$). The Normal dose increased yield 38% as compared to the Control, as well as fruit size. The highest total fruit yield and C22 (196-220 g) and C20 (221-250 g), as well as the highest cost-benefit, were obtained with the Normal dose. This treatment consisted of applying per year and tree, depending on the orchard, 509-608 g N, 21-206 g P, 132-582 g K, 19-234 g Mg, 6.5-18 g Fe, 6-46 g Mn, 2-6 g Zn and 3-13 g B.

Index words: *alternate bearing, fruit size,* Mangifera indica *L., mineral nutrition.*

RESUMEN

Existe una amplia heterogeneidad en el manejo de la fertilización del mango (*Mangifera indica* L.) en el estado de Nayarit, México y no se dispone de información sistemática al respecto. El objetivo de esta investigación fue evaluar el efecto a mediano plazo (2010-14) de la fertilización de sitio específico sobre el rendimiento y tamaño del fruto de mango 'Ataúlfo' cultivado en condiciones de temporal (sin riego; promedio anual de lluvia de verano 1300-1450 mm). El estudio se realizó en dos huertos comerciales establecidos en cuadro a 8 × 8 m en los municipios de San Blas y Compostela, Nayarit. Los tratamientos de fertilización anual fueron: 1) Dosis normal, que consideró la demanda y condición nutrimental del árbol,

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la aportación de nutrientes por el suelo y la eficiencia de la fertilización; 2) Dosis alta (1.5 veces la dosis Normal); 3) Testigo, una aplicación anual de 3 kg por árbol de 17-17-17 (N, P_2O_5, K_2O). Se tomaron muestras de suelo y foliares para su análisis nutrimental. Para las variables rendimiento acumulado y tamaño de fruto se consideraron 20 repeticiones (árboles) por tratamiento y se utilizó un arreglo factorial 2 × 3 (huertos × tratamientos). Para la concentración nutrimental foliar, se analizó el efecto del año y los tratamientos de fertilización y se usaron 10 repeticiones por tratamiento y huerto. La comparación de medias se realizó con la prueba Waller-Duncan ($P \leq 0.05$). La dosis Normal incrementó 38% el rendimiento respecto al Testigo, así como el tamaño de fruto; también reflejó la mayor producción total y de frutos tamaño C22 (196-220 g) y C20 (221-250 g), así como el mayor beneficio-costo. Este tratamiento consistió en aplicar por año y por árbol, según el huerto, de 509-608 g N, 21-206 g P, 132-582 g K, 19-234 g Mg, 6.5-18 g Fe, 6-46 g Mn, 2-6 g Zn and 3-13 g B.

Palabras clave: *alternancia productiva, tamaño de fruto,* Mangifera indica *L., nutrición mineral.*

INTRODUCTION

In order to ensure proper nutrient management in mango (*Mangifera indica* L.) production, the nutrients provided by the soil, the nutrient requirement of the tree for a given crop target, tree phenology, and the efficiency of fertilization and/or manuring, among other factors, must be considered (Salazar-García, 2002). This implies the development of fertilization programs for each orchard type, taking into account the mango cultivar as well as the characteristics of each production area and orchard management practices.

Low yield can be the result of wrong fertilizer practices. Shaaban and Shaaban (2012) assessed the nutritional status of nine mango cultivars in sandy soils (57-90% sand; pH > 8) and under flood irrigation system in the Giza governorate, Egypt. Leaf nutrient concentrations were in the sufficient range; however, Ca, Mn and Zn were severely deficient and mentioned as the yield limiting factors. In another Governorate (Minufiya), the response of irrigated mature 'Zebda' mango tress planted at 7 × 7 m in a loamy sandy soil (85% sand) to four sources of potassium fertilization (feldspar, potassium carbonate, potassium citrate, and mono potassium phosphate) was evaluated. Yield and fruit quality improved with the potassium citrate at 1895 g tree^{-1} and potassium carbonate at 850 g tree^{-1} treatments (Taha *et al*., 2014).

Mango fertilization with NPK and other nutrients has provided mixed results. In Pakistan, Shakeel *et al*. (2001) obtained 61.2 kg tree^{-1} in mango cv. Anwar Ratoul fertilized with 1.5 kg N, 0.65 kg P and 0.62 kg K per tree. For 'Nam Dok Mai' in Thailand, 10.3 kg tree^{-1} (year 1) and 14.1 kg tree^{-1} (year 2) were obtained with 0.5 kg N, 0.17 kg P and 1.2 kg K (Suriyapananont, 1992). In China, the application of 400 g N, 54.5 g P, 265.6 g K, 40 g Mg and 80 g S per year per tree achieved a yield of 15.2 Mg ha^{-1} in 'Zihuaman' mango (Xiuchong *et al*., 2001). In India, 800 g N, 87.2 g P and 249 g K were applied to cv. Dashehari, obtaining 132 kg tree^{-1} (Sharma *et al*., 2000). In Taiwan, the application of 360 g N, 239.8 g P and 540.3 g K in seven mango cultivars produced 26.9 kg tree^{-1} (Shu *et al*., 2000).

A comparison of mineral (230-0-300 and 230-0-0 g NPK tree^{-1}) and organic (vermicompost, bokashi and chicken manure) at 5 and 10 Mg ha^{-1} fertilizers was conducted in the 'Manila', 'Tommy Atkins', and 'Ataulfo' mango cultivars spaced at 6 × 2.5 m, on in a slightly acid (pH 6.5) vertisol pelic soil in Veracruz, México. The results indicate that fertilizers did not influence tree trunk diameter, flowering nor yield although they overcome the non-fertilized control (Peralta-Antonio *et al*., 2014).

Mango fertilization in México is commonly based on the application of NPK, and varies with the mango cultivar and region. In the state of Jalisco, Ortega-Arreola *et al*. (1993) suggested fertilizing nine-year-old mango trees with 0.6 kg N, 0.1 kg P and 0.3 kg K per tree per year. In Campeche, Tucuch-Cahuich *et al*. (2005) recommended 1.4 kg N, 0.3 kg P and 1.2 kg K annually for 'Tommy Atkins' trees over 20 years old. In Colima, Prieto-Martínez (2005) suggested fertilizing trees ≥ 10 year-old of the cvs. Haden and Tommy Atkins with 1.0 kg N and 0.9 kg K per tree every year. In Guerrero, Noriega-Cantú *et al.* (2012) promoted fertilizing 'Manila' mango with N, P, K, Mg and B, with varying doses, depending on the type of soil.

In the state of Nayarit, México, the land with 'Ataúlfo' mango has increased in recent years. In 2004 there were 3403 ha, increasing to 11,879 ha in 2017, with an average yield of 11.7 Mg ha^{-1}, which is low compared to that obtained in 2004 (15 Mg ha^{-1}) (SIAP-

SAGARPA, 2018). According to Pérez-Barraza *et al*. (2007), in Nayarit only 62% of mango growers fertilize their orchards and 78% of them use 3 to 4 kg tree^{-1} of 17-17-17 commercial mixture, per year.

The site-specific fertilization (SSF) approach allows increases in yield and fruit quality and reduces environmental pollution due to excessive application of fertilizers and/or organic materials (Salazar-García, 2002; Salazar-García *et al*., 2009; Salazar-García *et al*., 2014). One of the possible causes for the low yield of 'Ataulfo' mango in Nayarit is insufficient and/or unbalanced orchard fertilization, so the SSF approach can provide significant increases in fruit yield and quality on a short-term basis (Salazar-García *et al*., 2014; García-Martínez *et al*., 2015). The objective of this research was to evaluate the effect of the SSF approach on fruit yield and size of rainfed 'Ataúlfo' mango in Nayarit, Mexico.

MATERIALS AND METHODS

Plant Material

This research was conducted during 2009-2014 in two commercial rainfed (annual average summer rainfall 1300-1450 mm) 'Ataúlfo' mango orchards: "Las Palmas" in the Municipality of San Blas (21º 36' 46.1" N, 105º 11' 19.6" W; elevation 193 m), and "El Divisadero" in the Municipality of Compostela (21º 07' 03.0" N, 105º 11' 04.6" W; elevation 104 m). Mango trees were 11-year-old, established in an orchard frame 8 × 8 m, and grown in a subhumid warm climate (maximum and minimum annual average temperatures above 28 and 18 °C, respectively) (García, 1998). Soil in orchards were a Humic Acrisol in Las Palmas and a Haplic Feozem in El Divisadero (INEGI, 1999). At the beginning of the study, difference in tree vigor was verified by means of an analysis of variance. No significant differences between orchards or groups of trees comprising the treatments for height (5.8 to 6 m) or trunk cross-sectional area 20 cm above the graft site (609-688 cm^2) were detected, so a completely randomized experimental design was used. In order to minimize the effect of initial tree crop load on subsequent harvests, in 2009, 60 trees of similar size and vigor that produced at least 80 kg tree^{-1} were selected throughout each orchard. Treatments were randomly assigned among the 60 trees in such a way that three groups of 20 individuals each were formed, and each group was assigned a different fertilization treatment.

Leaf and Soil Analysis

Before treatments, leaf sampling for nutrient analysis was carried out in February 2009, and every year in February 2011, 2012, and 2013. In each treatment, 10 trees were randomly selected for sampling, and from each one, 30 healthy, mature summer vegetative flush leaves (leaf blade + petiole), situated in basipetal positions 6 and 7 of non-fruiting terminal shoots were collected according to Salazar-García *et al*. (2011). Leaves were washed and dried in a digital forced-air oven (Thermo Scientific model WHO 180, Madison, WI, USA) at 70 °C, until constant weight. Subsequently, the samples were ground in a stainless steel mill (IKA Mod. MF 10 Wilmington, NC, USA) with a 40 caliber mesh and analyzed for N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, and B in Fertilab laboratory (Celaya, Guanajuato, México) which is accredited by The North American Proficiency Testing Program of the Soil Science Society of America.

In January 2010, before the application of fertilization treatments, soil sampling was performed at 0-30 cm depth. In each orchard, three trees were randomly selected per treatment and from each tree a sample composed of four sub-samples from the tree's shaded area was taken. Another soil sampling was collected in May 2013, after the fertilizations of summer 2010, 2011 and 2012. The following characteristics were determined in the aforementioned laboratory: texture, pH (1:2 water), organic matter, inorganic N, P-Bray, K, Ca, Mg, S, Na, Fe, Cu, Mn, Zn, and B.

Based on the soil analysis results, the hydrated lime [$Ca(OH)_2$] and/or calcium sulfate (gypsum; $CaSO_4$) requirements were determined (Table 1). The criteria for establishing the appropriate amount of lime were soil acidity ($pH \leq 5.5$), calcium saturation point, cation exchange capacity, bulk density, soil sampling depth, tree's shaded area and exchangeable aluminum. For gypsum, the same criteria as those used for lime, differing only in soil acidity ($pH \geq 5.5$).

Fertilization Treatments

They were calculated independently for each orchard and considered: fruit nutrient's needed to produce 20 Mg ha^{-1} (Salazar-García *et al*., 2010),

Table 1. Fertilization treatments (g tree^{-1}) applied to 'Ataúlfo' mango in "Las Palmas" and "El Divisadero" orchards.

Source of fertilizer	2010				2011				2012				2013				Application month
	Palmas		Divisadero		Palmas		Divisadero		Palmas		Divisadero		Palmas		Divisadero		
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	
ANP	-	-	-	-	1158	1737	702	1053	1126	1689	1162	1743	947	1420	528	792	july & sept.
$(NH_4)_2SO_4$	1063	1595	1068	1602	-	-	-	-	-	-	-	-	-		-	-	july & sept.
TSP	463	695	954	1430	917	1375	329	494	221	331.5	202	303	72	108	126	190	july
KCl	279	419	464	695	648	972	1142	1713	272	408	493	739.5	258	386	273	409	july & sept.
$Ca(OH)_2$	-	-	2668	2670	-	-	6578	9867	-	-	7266	-	5318	5318	4590	4590	june
$CaSO_4$	2952	4428	6069	10668	1042	1563	-	-	-	-	-	-	-	-	-	-	june
$MgSO_4$	118	117	1376	2064	128	192	152	229	128	192	241	361.5	133	200	113	170	july
$FeSO_4$	58	87	87	131	31	47	41	62	64	96	57	85.5	70	110	84	126	july
$MnSO_4$	171	256	93	140	81	122	33	50	43	64.5	21	31.5	87	130	87	131	july
$ZnSO_4$	11	17	16	23	9	14	6	9	5	7.5	13	19.5	5	10	7	10	july
Boronat	147	221	97	145	106	159	41	61	36	54	68	102	143	214	28	43	july

T1 = Normal dose; T2 = High dose. ANP = Ammonium nitrate-phosphate (NH_4NO_3): 33% N + 1.3% P; Ammonium sulphate $(NH_4)2SO_4$: 21% N + 24% S; TSP = Triple superphosphate [$Ca(H_2PO_4)_2$]: 20% P + 13.2% Ca; Potassium chloride (KCl): 51% K; Calcium sulphate ($CaSO_4{\cdot}2\,H_2O$): 22.2% Ca; Magnesium sulphate ($MgSO_4$): 17% Mg; Iron sulphate ($FeSO_4$): 21% Fe; Manganese sulphate ($MnSO_4{\cdot}4\,H_2O$): 27% Mn + 18% S; Zinc sulphate ($ZnSO_4$): 35.5% Zn; Boronat; 9% B.

available nutrients and other chemical characteristics from soil analyses, leaf nutrients concentration which were transformed to a nutrient balance index (Salazar-García *et al*., 2011), fertilization efficiency for N, P, K, Ca, Mg, Fe, Mn, Zn, and B (40, 20, 60, 80, 60, 5, 5, 10, and 5%, respectively), tree's shaded area, and periods of greatest root growth (July and September). During 2010, 2011, 2012 and 2013, three fertilization doses were applied: 1) "Normal" for a yield of 20 Mg ha^{-1}; 2) "High", 1.5 times the normal dose (Table 1); 3) Control, an annual application of 17 N, 7.4 P, 14.1 K as 17-17-17 commercial mixture at a dose of 3 kg tree^{-1}.

Fertilizers were distributed around the tree in a 50 cm wide band and 15-20 cm deep, initially at 1.5 m from the trunk and then progressively farther way from the trunk in each subsequent application. Every year, the fertilizer program was slightly modified according to the soil and leaf analyses.

Yield

Fruit yield was evaluated in each tree the first week of June 2011 to 2014. Fruit size (C) was classified according to regional mango packinghouses: C22 (196-220 g), C20 (221-250 g), C18 (251-283 g), C16 (284-315 g), C14 (316-365 g), and C12 (> 366 g).

Alternate Bearing Index

To determine treatment effects on bearing regularity, the alternate bearing index (ABI) was calculated using the equation suggested by Pearce and Dobersek-Urbanc (1967):

ABI = (difference in yield between the previous and present year) / (sum of yields of both years) × 100. ABI ranges from 0 (no alternate bearing) to 1 (complete alternate bearing).

Data Analysis

For cumulative yield and fruit size (2011+2012+2013+2014), a 2 × 3 factorial arrangement (orchards × treatments) was used. In the case of leaf nutrient concentrations, the year (2011, 2012 and 2013) and fertilization treatments (Normal dose, High dose and Control) effect was analyzed. For fruit yield and size, 20 replicates (trees) per treatment and per orchard were considered. In the case of leaf nutrient concentrations, 10 samples per treatment per orchard were used. Analyses of variance were carried out with the SAS software (2008). Means comparison was performed with the Waller-Duncan test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Soil Characteristics

In 2013, three years after the start of the research, soil chemical properties varied among treatments. In El Divisadero orchard, the pH dropped from 4.7 (Control) to 4.3 and 4.2 (Normal and High doses, respectively). The same occurred in Las Palmas, where it dropped from 6.6 (Control) to 5.3 and 5.0 (Normal and High doses, respectively) (Table 2). The pH was more acid but within appropriate limits for mango (Castellanos *et al*., 2000). Overall, fertilization increased the levels of most nutrients in the soil (K, Ca, Fe, Zn, Mn, and B), improving and/or maintaining its fertility (Table 2). In some cases, increases in the levels of some soil nutrients, due to fertilization, promoted higher concentration of some nutrients in leaves, specifically of Mg, Fe and B. However, it is not common to find a relationship between the concentration of these nutrients in the soil and leaves of fruit trees (Salazar-García, 2002).

Leaf Elemental Concentrations

The average of leaf nutrient concentrations of all treatments varied with the year of evaluation. The highest concentrations of N, Mg, and Fe were recorded in 2011, a year after the start of the study, but for 2012, concentrations of K, S, Cu, Mn, Zn, and B were higher than those of 2011. In 2013, P concentrations were higher than in 2011 and 2012, and the Mn concentration showed no differences compared to 2012 but was higher than in 2011 (Table 3). In fruit trees grown under rainfed conditions, leaf nutrient concentrations usually show a slow change in response to soil fertilization. This was the case in other species, such as 'Hass' avocado in Nayarit, Mexico, where changes in leaf nutrient concentrations occurred after several years of

Table 2. Soil test report (0-30 cm depth) before the application of fertilization treatments (Jan. 2010), and in May 2013, after the fertilizations of summer 2010, 2011 and 2012. Average of three sampled trees per treatment of 'Ataúlfo' mango in two orchards (El Divisadero and Las Palmas).

Analysis	El Divisadero			Las Palmas		
	Control 2010	Normal dose 2013	High dose 2013	Control 2010	Normal dose 2013	High dose 2013
pH (1:2 H_2O)	4.7 (VA)	4.3 (VA)	4.2 (VA)	6.6 (Ne)	5.3 (Ac)	5.0 (Ac)
Organic matter (%)	1.6 (L)	1.9 (L)	2.2 (L)	0.7 (VL)	2.5 (ML)	2.8 (ML)
CEC (meq 100 g^{-1})	1.81 (VL)	2.92 (VL)	3.32 (VL)	7.29 (L)	11.1 (L)	10.4 (L)
	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - mg kg^{-1}	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - -
Inorganic N	9.8 (ML)	11.5 (M)	16.7 (M)	11.2 (M)	15.2 (M)	19.9 (M)
P-Bray	0.4 (VL)	2.1 (VL)	5.6 (L)	10.2 (MB)	7.5 (L)	24.0 (M)
K	27.4 (VL)	52.5 (VL)	40.1 (VL)	290 (M)	434.9 (MH)	473.5 (MH)
Ca	130.0 (VL)	185.6 (VL)	181.1 (VL)	918 (MB)	1290.2 (ML)	1247.6 (ML)
Mg	10.6 (VL)	55.8 (L)	46.7 (VL)	231 (M)	421.4 (MH)	342.9 (M)
S	304.0 (MH)	199.9 (M)	217.2 (MH)	65 (VH)	94 (M)	92.2 (M)
Na	5.5 (VL)	5.9 (VL)	5.8 (VL)	17.2 VL)	0.3 (VL)	0.4 (VL)
Fe	1.0 (VL)	2.4 (VL)	3.7 (L)	6.5 (ML)	33.5 (M)	55.3 (MH)
Cu	0.03 (VL)	0.1 (VL)	0.1 (VL)	0.1 (VL)	0.3 (VL)	0.4 (VL)
Mn	1.2 (VL)	1.8 (MH)	1.3 (L)	3.6 (L)	97.1 (VH)	127.5 (VH)
Zn	0.1 (VL)	0.5 (VL)	1 (L)	0.4 (L)	2.5 (ML)	3.9 (ML)
B	0.2 (VL)	0.4 (L)	0.9 (ML)	0.2 (VL)	1.1 (M)	1.3 (M)
Al	76.5 (ML)	124.02 (M)	164.57 (MH)	N.D.	0.0 (VL)	10.7 (VL)

VA = very acid; Ac = acid; Ne = neutral; VH = very high; MH = moderately high; M = medium; ML = moderately low; L = low; VL = very low; N.D. = Not determined.

Table 3. Influence of the year and fertilization treatments on leaf nutrient concentrations in the 'Ataúlfo' mango. Fertilizations were done in summer 2010, 2011 and 2012. Leaves of the summer flush and were collected in Feb. 2011, 2012, and 2013 in Las Palmas and El Divisadero orchards.

	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn	B
	- - - - - - - - - - - - g 100 g^{-1}					- - - - - - - - - - - -	- - - - - - - - - - mg kg^{-1}				- - - - - - - - - - - -
					Years of evaluation						
2011	1.30 a†	0.11 b	0.52 c	2.05 a	0.26 a	0.07 b	48.93 a	7.07 b	437.23 b	12.25 b	19.18 b
2012	1.02 b	0.11 b	0.79 a	2.15 a	0.24 b	0.39 a	49.35 a	32.39 a	744.52 a	15.64 a	48.55 a
2013	1.1 b	0.16 a	0.67 b	2.2 a	0.22 b	0.02 c	39.1 b	23.7 b	710.8 a	14.6 b	21.4 b
Pr > F	0.0001	0.0001	0.0001	0.1723	0.0004	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
					Fertilization treatments (2013 sampling)						
Normal	1.1 a	0.17 a	0.72 a	2.3 a	0.26 a	0.02 a	38.8 ab	24.2 a	708.9 a	15.5 a	24.7 a
High	1.2 a	0.15 a	0.65 a	2.2 a	0.19 b	0.02 a	42.0 a	24.5 a	689.9 a	14.6 a	18.3 b
Control	1.1 a	0.14 a	0.63 a	1.9 a	0.23 ab	0.01 a	33.9 b	20.9 a	756.2 a	12.6 a	21.4 b
Pr > F	0.5751	0.1601	0.2355	0.4032	0.0068	07543	0.0461	0.5312	0.8836	0.1112	0.0002

† Mean separation in columns, for each section, by Waller-Duncan's multiple range test ($P \leq 0.05$).

fertilization (Salazar-García *et al.,* 2008; Cossio-Vargas *et al*., 2009[1]; Salazar-García *et al*., 2009).

Fertilization treatments did not change leaf concentrations of N, P, K, Ca, S, Cu, Mn and Zn (Table 3). Mg showed its lowest concentration in the High dose treatment. For Fe, the High dose reflected the highest concentration of Fe (42.0 mg kg^{-1}) compared to the Control (33.9 mg kg^{-1}), although it was similar to the Normal dose (38.8 mg kg^{-1}). B concentration was higher with the Normal dose (24.7 mg kg^{-1}) than with the other two treatments.

Total Cumulative Yield and Fruit Size

The highest cumulative yield was obtained in Las Palmas orchard (306.9 kg $tree^{-1}$), of which 89.6% was small-sized fruit (C22: 274.9 kg $tree^{-1}$) (Table 4). In El Divisadero, the cumulative yield was lower (179.4 kg $tree^{-1}$), but 74.5% of this yield (133.6 kg $tree^{-1}$) corresponded to the C22 size class. The lower yield (7.0 Mg ha^{-1} $year^{1}$) in El Divisadero orchard was possibly influenced by the high production of "baby" mango (parthenocarpic fruit). Salazar-García *et al*. (2016) evaluated the presence of such fruit in this orchard, reaching 91% at fruit-set (March) and 63.7% at harvest (May). In Las Palmas orchard, these proportions were lower, 72.2% (fruit-set) and 40.1% (harvest).

Our results provide evidence that fertilization treatments modified fruit yield and size. The Normal dose produced the highest cumulative yield (292.8 kg $tree^{-1}$), followed by the High dose (254.1 kg $tree^{-1}$) and the Control (184.4 kg $tree^{-1}$) (Table 4). The highest fruit yield was obtained with the Normal dose treatment (73.2 kg $tree^{-1}$).

The average yield 2011-2014 for cv. Ataúlfo in the municipalities of Compostela and San Blas, where the experimental orchards were located, was 8.3 Mg ha^{-1} (SIAP-SAGARPA, 2014); this is equivalent to 53.2 kg $tree^{-1}$ (with a plantation of 156 trees ha^{-1}). For both orchards, the Normal dose produced 11.4 Mg ha^{-1} (73.2 kg $tree^{-1}$), estimating a 38% increase.

Regardless the mango-producing region (China, Egypt, India, Mexico, Pakistan, Thailand, Taiwan, others), mango fertilization is commonly based on N, P and K (Suriyapananont, 1992; Sharma *et al*., 2000; Shu *et al*., 2000; Shakeel *et al*., 2001; Xiuchong *et al*., 2001; Vázquez-Valdivia *et al*., 2005) and sometimes only K (Taha *et al*., 2014). The applied doses of N, P and K per tree in these countries varied from 340 to 1500 g, 54.5 to 654 g and 249 to 623 g, respectively. For these same nutrients, doses that increased fruit yield in

[1] Cossio-Vargas, L. E., S. Salazar-García y J. L. González-Durán. 2009. Respuesta del aguacate 'Hass' a la fertilización con boro en huertos sin riego. 4-17 pp. *In*: Memorias III Congreso Latinoamericano del Aguacate. 11-13 noviembre 2009. Medellín, Colombia.

the present study were 509-608 g N, 21-206 g P, and 132-582 g K. The observed differences in relation to other producing regions support the use of the SSF approach to increase yield for mango in Nayarit. Besides, unlike the aforementioned reports, this study included applications of Ca, Mg, Fe, Mn, Zn and B. The addition of such nutrients could influence the results here reported; however, their specific effect was not the scope of this study.

In the fertilization treatments, the increased yield was accompanied by increased production of small fruit (C22) (Table 4). However, the sum of the intermediate (C20+C18+C16) and large (C14+C12) sizes was higher with the High (44.2 kg tree^{-1}) and Normal (43.6 kg tree^{-1}) doses, compared to the Control (28.8 kg tree^{-1}). For the 2011-2014 harvests, the ABI only showed differences between orchards (Table 4). Its values were 0.11 and 0.18 for Las Palmas and El Divisadero, respectively.

The SSF approach proved to increase fruit yield and size of ‘Ataúlfo’ mango. The highest total yield and C22 (196-220 g) and C20 (221-250 g) intermediate fruit sizes were obtained with the Normal fertilization dose. This treatment was based on the application per tree of 509-608 g N, 21-206 g P, 132-582 g K, 19-234 g Mg, 6.5-18 g Fe, 6-46 g Mn, 2-6 g Zn and 3-13 g B, depending on the orchard. We found that the High fertilization dose was beyond tree needs, resulting in lower production composed of smaller fruit size, compared to the Normal dose. The results herein are now available for ‘Ataúlfo’ mango growers in these regions and the SSF approach used are worth to be tested in other producing regions.

Economic Analysis

The most profitable fertilization treatment was the Normal dose (Table 5). In addition to improving the fruit size, this treatment increased yield by 4.3 Mg ha^{-1} and had a net economic benefit of US$ 537.7 per hectare, each year, compared to the Control. As we can see, yield and fruit size showed a significant response in the short term, confirming that fertilization trials in fruit trees should be conducted over several seasons. The short-term response is important to mango growers to convince them that they do not have to wait several years to have an economic benefit from proper fertilization management.

Table 4. Influence of the orchard and fertilization treatments (2010 to 2013) on cumulative yield, fruit size (2011 to 2014 harvests) and alternate bearing index (ABI) in the ‘Ataúlfo’ mango.

	Cumulative yield	ABI	Distribution of yield by size (kg tree^{-1})					
			C22	C20	C18	C16	C14	C12
			196-220	221-250	251-283	284-315	316-365	> 366
	kg tree^{-1}		- - - - - - - - - -	- - - - - - - - - -	- - - g - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - -
			Experimental orchards					
Las Palmas	306.9 a†	0.11 b	274.9 a	22.7 b	5.7 a	1.3 a	1.3 a	0.1 b
El Divisadero	179.4 b	0.18 a	133.6 b	33.0 a	8.8 a	1.9 a	1.1 a	0.9 a
Pr > F	0.0001	0.0001	0.0001	0.0009	0.1229	0.2750	0.7113	0.0144
			Fertilization treatments					
Normal	292.8 a	0.14 a	249.6 a	31.4 a	7.3 ab	1.9 a	2.2 a	0.4 a
High	254.1 b	0.16 a	210.3 b	31.0 a	10.2 a	1.7 a	0.2 b	0.6 a
Control	184.4 c	0.13 a	155.6 c	21.1 b	4.3 b	1.3 a	1.3 ab	0.6 a
Pr > F	0.0001	0.0504	0.0001	0.0088	0.0486	0.7464	0.0126	0.4890
			Distribution of yield by size (%)					
Normal	292.8 a		85.2	10.7	2.5	0.6	0.8	0.1
High	254.1 b		82.8	12.2	4.0	0.7	0.1	0.2
Control	184.4 c		84.4	11.4	2.3	0.7	0.7	0.3

† Mean separation in columns, for each table section, by Waller-Duncan’s multiple range test ($P \leq 0.05$).

Table 5. Economic analysis for fertilization treatments evaluated. Yield data are the average of the 2011-14 harvests.

Item	Treatments		
	Control	Normal dose	High dose
Total fruit yield (kg ha^{-1})	7191.6	11 419.2	9909.9
Yield (kg) fruit sizes C12 (> 366 g). C14 (316-365 g). C16 (284-315 g)	124.8	187.2	101.4
Price (US $ kg^{-1}) †	0.445	0.445	0.445
Gross income (US $/ha)	55.5	83.3	45.1
Yield (kg) fruit size C18 (251-283 g)	171.6	280.8	405.6
Price (US $ kg^{-1})	0.26	0.26	0.26
Gross income (US $ ha^{-1})	44.6	73	105.4
Yield (kg) fruit sizes C20 (221-250 g) and C22 (196-220 g)	6895.2	10 966.8	9422.4
Price (US $ kg^{-1})	0.148	0.148	0.148
Gross income (US $ ha^{-1})	1020.5	1623.1	1394.5
Gross income all fruit sizes (US $ ha^{-1})	1120.6	1779.4	1545
Fertilizer plus application cost	290	411	617
Net benefit per fertilization treatment (US $ ha^{-1}) ‡	830.7	1368.4	928

† US$ = 13.5 MXP (sept. 2014). ‡ Minus other production costs.

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