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Diagnosis and field management strategies to improve the size and uniformity of the mango fruit in Ecuador

- Final report of research project -

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Abstract: A research project was conducted to identify the main factors limiting fruit development and to evaluate agronomic strategies to enhance fruit size and uniformity in commercial mango orchards of 'Tommy Atkins' and 'Ataulfo' in Guayaquil, Ecuador. The project was structured in three phases: (1) diagnostic evaluation of climate, soil, plant nutrition, and orchard characteristics; (2) implementation of five distinct management strategies in the field; and (3) identification of the most effective practices based on fruit productivity and quality. In the first phase, limitations such as poor root development, high soil compaction, nutrient imbalances, and moderate oxidative stress were observed. Phosphorus, potassium, and boron were frequently limited, with high calcium and magnesium levels affecting nutrient uptake. The orchard also presented restricted irrigation coverage due to the use of a single micro-sprinkler per plant. Field trials compared five management strategies: T1 (traditional management), T2 (fertilization based on phenological demand + irrigation according to Kc), T3 (T2 + amino acids + phytoregulator), T4 (T3 + sunblock), and T5 (T4 with liquid fertilizers). T2 showed the highest increase in fruit number (+53.6% in 'Tommy Atkins'; +14.9% in 'Ataulfo') and was most effective in maximizing yield. T5 resulted in the highest fruit mass (+19.9% in 'Ataulfo'; +8.9% in 'Tommy Atkins') and improved commercial fruit size distribution but required adequate soil fertility. T3 offered a balanced result between fruit quantity and quality. It is recommended to adopt T2 as a baseline strategy or T5 depending on market goals and orchard conditions. Structural improvements such as installing a second micro-sprinkler and strategies to stimulate root growth and mitigate abiotic stress are also advised. The consistent application of these practices across production cycles is essential to improve mango fruit quality and competitiveness in Ecuador.
keywords: *Mangifera indica* L.; orchard management; fertilization strategies, biostimulation

Nutrient abbreviations used in this study:
N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; S – sulfur; B – boron; Zn – zinc; Cu – copper; Mn – manganese; Fe – iron; Mo – molybdenum.

1. Introduction

The mango tree (*Mangifera indica* L.) is extensively cultivated in Ecuador and stands out as one of the tropical fruits with high commercial value in the country. Despite favorable climatic conditions and the agricultural vocation of the producing regions, Ecuadorian mango production faces significant challenges, particularly related to low fruit uniformity and reduced fruit size. These limitations compromise the market value of the harvest, may restrict access to more demanding international markets, and directly affect the profitability of the production system.

The occurrence of undersized fruits is a multifactorial issue, involving both genetic aspects and the need for adjustments in agronomic management. Among the main determinants are nutritional imbalances, water deficits, low photosynthetic efficiency, abiotic stresses—especially those related to adverse environmental conditions—and inadequate or inefficient cultural practices (Torres, 2019; Lino et al., 2024). These factors, acting individually or synergistically, impair proper fruit development and increase the proportion of non-commercial grade fruits, particularly for the North American market, the main importer of Ecuadorian mangoes.

Given this scenario, the development and validation of more efficient management strategies become essential. Such strategies should consider the specific phenological stages of mango and the limiting factors for producing high-quality fruits. Among them, fertilization programs based on the crop's nutritional demands at each phenological phase are noteworthy (Carneiro et al., 2018; Oldoni et al., 2018), as well as the incorporation of technologies that enhance nutrient availability, such as fulvic acids (Torres, 2019). These practices should be integrated with rational irrigation management based on crop coefficient (Kc) values (Cotrim et al., 2017; Levin et al., 2018), promoting greater input use efficiency and supporting the effectiveness of bioactive products with biostimulant properties (Cavalcante et al., 2018; Lobo et al., 2019; Lino et al., 2023; Lino et al., 2024; Venancio et al., 2024).

Specifically regarding biostimulants, these inputs act on metabolic pathways associated with cell expansion, fruit filling, and stress tolerance, thereby contributing to increased fruit size and uniformity (Calvo et al., 2014; Taiz et al., 2017; Mudo et al., 2025). Biostimulants influence plants through various mechanisms, including the enhancement of carbohydrate availability that is essential for fruit development. The quantity of carbohydrates supplied to fruits, in turn, depends on the amount produced via leaf photosynthesis, the reduction in sink demand, and the availability of stored reserves (Léchaudel & Joas, 2007).

Given the prevailing climate, soil characteristics, and the current state of the orchard, agronomic management must be aligned with the desired fruit quality and size. This is because the competition among sinks for assimilates directly influences both the growth rate of the plant and fruit set. An increased fruit load on the plant promotes a greater partitioning of photoassimilates, which can limit the development of individual fruits (Andriolo & Falcão, 2000; Costa et al., 2017). When there are fewer competing sinks, the photosynthetic products can be more efficiently allocated to the remaining fruits during the fruiting phase (Gazzola, 1991). In this context, two alternatives arise: adopting management strategies tailored to local conditions to improve assimilate distribution or reducing fruit competition through thinning—though the feasibility and practicality of thinning in commercial settings remain debatable.

Based on these premises, the present study was conducted in a commercial mango production area in Ecuador, with the goal of identifying the main causes of small fruit formation and testing management practices to improve fruit size and uniformity.

2. Material and methods

The project was developed over three consecutive phases in commercial mango orchards selected from mango producers/exporters in Ecuador (Fundación Mango del Ecuador) initially with 'Tommy Atkins' mango but following the mango growers demand it also was developed with 'Ataulfo'.

The harvested fruit is a consequent characteristic of genetic factors, but influenced by different factors of climate, soil and orchard. This way, the project was developed in three different phases: First phase – Diagnosis; second phase: Conducting field; and third phase: Identification and recommendation of the best management strategy.

2.1 First phase – diagnosis

This phase involved gathering and analyzing climate variables, soil data, and the characteristics of the orchards chosen for the study.

Historical data for climatic variables were analyzed for air temperature, air humidity, cloudiness, rainfall and solar energy. Other variables were measured for orchard characterization, such as sun light intensity (Lux x100 x 50.000), leaf chlorophyll indexes (*a*, *b* and total), soil moisture (%), soil firmness (MPa) and leaf electrolyte leakage (µS/cm).

The 'Ataulfo' orchard studied was nearly 19 years old spaced 9.0 x 5.5 m and irrigated with one micro sprinkler per plant for a flow of 50.0 L/h. The 'Tommy Atkins' orchard studied was nearly 31 years old, spaced 9.0 x 6.0 m and irrigated with one micro sprinkler per plant for a flow of 36.0 L/h.

Thermal images were also captured from the orchard using a thermographic imaging system (Flir One®, Wilsonville, US) with wireless connectivity.

Sun light intensity was evaluated using a luximeter (Instrutherm®, Brazil) within mango tree rows. Leaf chlorophyll readings (*a*, *b* and total indexes) were measured using a chlorophyll meter reading (Falker®, Brazil) in four leaves in each plant from the canopy middle part at each cardinal point, following the instructions of El-Hendawy et al. (2005). Soil moisture was measured using a soil tester measurer (Falker®, Brazil) in the coverage area of the micro sprinkler. Leaf electrolyte leakage was performed following the methodology proposed by Lutts et al. (1996).

The measurements of leaf chlorophyll meter readings, soil moisture and sunlight intensity can be verified in Figure 1.

Figure 1: Measurements of leaf chlorophyll indexes (A), soil moisture (B) and sunlight intensity (C) in the experimental orchards during the characterization phase.

Still during the characterization phase soil and leaf samples were collected to diagnose the nutritional status of ‘Ataulfo’ and 'Tommy Atkins' mango trees separately. Leaves of the last mature flush were collected stored in paper bags, then sent to the Plant Soil Laboratories® (Petrolina, Brazil) for leaf analysis according to Tedesco et al. (1995) the diagnostic leaf nutritional status. Soil samples at 0-30 cm of soil depth were collected below the mango tree canopy in the coverage area of the micro sprinkler, stored in proper plastic bags, then sent to the Plant Soil Laboratories® (Petrolina, Brazil) for fertility analysis. Soil texture was assessed following Donagema et al. (2011). Such analyses were performed on two separate dates, both before treatment definition and application.

The root system was also evaluated by visual identification (soil excavation at root zone).

2.2 Second phase: conducting field experiments

With the guiding results obtained in the first phase of the project, specific experiments were carried out based on the main problems faced by orchards with a focus on better fruit for 'Ataulfo' and 'Tommy Atkins'.

These treatments were elaborated by the union of basic management factors associated with specific technological strategies for the mango crop, already used in other producing regions or results of scientific production already published.

The experiments (mango trees of cv. 'Ataulfo' and 'Tommy Atkins' separately) were arranged in randomized blocks with five treatments, four blocks and five plants per block. The treatments were defined as:

T1 - Control (traditional farm management, without alterations);

T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc);

T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc) + amino acids + phytoregulator;

T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc) + amino acids + phytoregulator + sunblock;

T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation adjustment (according to Kc) + amino acids + phytoregulator + sunblock.

The nutrient amounts applied in each treatment are in Table 1 specifically for each mango cultivar.

Table 1: Nutrient amounts applied in each treatment (kg/ha from flowering to fruit harvest) according to each mango cultivar.

Nutrient	Ataulfo			Tommy Atkins		
	T1	T2, T3 and T4	T5	T1	T2, T3 and T4	T5
N	58.32	15.0	5.26	57.36	23.6	5.65
P	28.43	18.0	8.18	26.97	29.0	8.77
K	42.22	19.0	6.52	40.39	28.0	6.99
Ca	33.94	-	1.26	28.84	-	1.35
Mg	1.37	4.75	0.92	1.66	6.65	0.99
Zn	1.47	2.2	0.04	1.02	1.10	0.05
B	0.20	7.41	0.00	0.22	9.14	0.00
Mn	0.0	8.96	0.01	-	8.96	0.01
Fe	0.0	3.0	0.01	-	1.04	0.01

T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc); T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc) + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation adjustment (according to Kc) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation adjustment (according to Kc) + amino acids + phytoregulator + sunblock.

While the fertilizing calendars from flowering to fruit harvest for each treatment (T2, T3, T4 and T5) are in Appendix 1 and 2, for T1 treatments the total of fertilizers were applied through fertigation: Tommy Atkins - 96.4 g/tree of ammonium nitrate, 27.0 g/tree of diammonium phosphate, 27.0 g/tree of monoammonium phosphate, 80.8 g/tree of potassium nitrate, 90.2 g/tree of calcium nitrate, 13.8 g/tree of magnesium sulfate, 4.4 g/tree of zinc sulfate, and 1.8 g/tree of boric acid; Ataulfo - 89.6 g/tree of ammonium nitrate, 28.4 g/tree of diammonium phosphate, 28.4 g/tree of monoammonium phosphate, 84.4 g/tree of potassium nitrate, 108.7 g/tree of calcium nitrate, 11.4 g/tree of zinc sulfate, and 1.6 g/tree of boric acid.

All fertilizers were applied via a fertigation system. The recommended doses of each nutrient used for T2, T3 and T4 were defined according to Gargantini (1999), personal recommendations of FRUTVASF (no published data criteria) and following the adequate ranges of supply defined by Rezende et al. (2022) and the nutrient exportation with fruit harvest properly defined by Torres (2019). Doses of T5 based on a lysimeter experiment performed in Brazil (non-published data).

The aminoamides source used in T3, T4, and T5 treatments was Biomax™, which presents 90% of free aminoacids, and was applied at flowering, once in the second physiological fruit fall and twice more every fifteen days through fertigation in a dose of 250 g/ha each application, reaching 1000 g/ha.

The phytoregulator used in T3, T4, and T5 treatments was Biotek™, which presents cytokinins (2197.95 mg/kg), gibberellins (33.50 mg/kg), auxins (34.70 mg/kg), in addition to nutrients (N, P, K, Ca, Mg, Fe, Zn, Mn, Cu, B, Co, S and Mo) and vitamins (folic acid, pantothenic acid, riboflavin, choline, niacin and thiamine), at flowering, once in the second physiological fruit fall and twice more every fifteen days through fertigation in a dose of 1 L/ha each application, reaching 4 L/ha.

The sunblocks used in treatments T4 and T5 based on the results of Silva et al. (2022a) with adaptations, i.e., foliar sprays with Humigel Plus A™ and Humigel Plus K™ in applications started 30 days after flowering and carried out as follows: 1st application (Humigel Plus A™ - 4.0 L/ha), 2nd application (Humigel Plus K™ - 1.0 L/ha), 3rd application (Humigel Plus A™ - 4.0 L/ha) and 4th application (Humigel Plus K™ - 1.0 L/ha), using 400 L/ha. Humigel Plus A™ acts as a protective barrier by forming a film (biodegradable film) also contains N (2%), CaO (4%), Zn (2.9%), SiO_2 (15%) and fulvic acids (12%); Humigel Plus K™ also acts as a protective barrier by forming a film (biodegradable film) and contains N (2%), K_2O (18%), CaO (2.8%), and fulvic acids (10%).

The irrigation recommendation (T2, T3, T4 and T5) was based on reference evapotranspiration (Eto) and followed the recommendations of Sousa (2015) cited by Cavalcante (2022), as can be seen in Appendix 3. The irrigation management for T1 consisted of: a) 'Tommy Atkins': when the orchard was at 30% flowering, 12 mm/week (4x 3.0 mm on alternate days) were supplied, gradually increasing until reaching 16 mm/week; From when the orchard reached the fruit filling phase, it remained between 20 and 25mm/week until harvest; and b)'Ataulfo': it started with a maximum of 5 mm/week at the beginning of flowering; from the fruit setting, the same water depths reported for 'Tommy Atkins' were practiced with an increase of 20%.

It is important to highlight that for the experiment with Ataulfo, it is the practice of the partner farm to carry out a light thinning of fruits, maintaining an average of four fruits per productive branch and excluding only those fruits that are really smaller than the general average of the orchard.

Evaluations

The evaluations for each experiment consisted of:

i) Soil fertility at 0-30 cm soil depth (Donagema et al., 2011);

ii) Leaf nutritional status (Tedesco, 1995);

iii) Fruit caliper according to distribution (Table 2) for 'Tommy Atkins'. For 'Ataulfo' the fruits were classified as: < 200 g, 200 – 250 g, 250 – 300 g and > 300 g.

Table 2: Fruit caliper classification according to US demand.

Fruit size (caliper)	Fruit mass (g)	
	Minimum	Maximum
5	799	899
6	667	799
7	572	667
8	490	572
9	450	490
10	380	450
12	320	380
14	270	320

iv) Fruit mass (g);

v) Number of fruits per plant and fruit yield (t/ha);

vi) Proportional distribution between number fruits per plant and fruit mass (g), which is a base for treatment efficiency.

Statistical analyses included analysis of variance (ANOVA) for the separation of treatments in each experiment using Tukey or Scott-Knott test. All calculations were performed using the 'R' software.

2.3 Third phase – Identification and recommendation of the best management strategy

In the third and final stage of the project, the most effective management strategies for producing larger fruits were identified, taking into account the specific conditions of the region. The factors influencing fruit size were analyzed, and a suitable management approach was proposed.

3. Results and discussion

3.1 Characterization of the orchards studied

The historical climatic conditions in Guayaquil (EC) throughout the year are in Table 3, including air temperature, cloudiness, rainfall, relative air humidity, and available solar energy. The maximum monthly air temperature ranged from 26.8 ºC (July) to 28.7 ºC (December), while the minimum ranged between 20.5 ºC (September) and 23.3 ºC (March and April). The average monthly temperature remained relatively stable, ranging from 23.0 ºC (August and September) to 25.3 ºC (March and April).

Table 3: Average historical data for average air temperature [maximum (Max), minimum Min) and average Ave), percentage of time spent in each cloud band (cloudiness), categorized by the percentage of sky covered by clouds (most cloudy and least cloudy), average rainfall and solar energy in Guayaquil (EQU).

Month	Air temperature (ºC)			Cloudiness (% of time)		Rainfall (mm)	Air humidity (%)	Solar energy (kWh/m^2 per day)
	Max	Min	Ave	Most	Least			
Jan	28.1	23.0	24.8	79	21	253	84	5.7
Feb	28.1	23.2	25.0	83	17	390	87	5.5
Mar	28.5	23.3	25.3	83	17	395	86	5.4
Apr	28.6	23.3	25.3	75	25	323	85	5.6
May	27.9	22.7	24.7	60	40	239	85	5.7
Jun	27.0	21.5	23.6	73	57	155	85	5.9
Jul	26.8	20.9	23.1	34	66	124	83	6.2
Aug	27.2	20.6	23.0	32	68	89	81	6.6
Sep	27.5	20.5	23.0	42	58	101	81	6.7
Oct	27.6	20.8	23.3	57	43	73	80	6.5
Nov	28.2	21.1	23.7	66	34	57	78	6.2
Dec	28.7	22.2	24.6	73	27	122	79	5.9

Historical data is available at Climate Data and Weather Spark.

As can be seen in Table 3, cloudiness showed significant seasonal variation, being higher between January and April, when the sky was predominantly overcast for 75 to 83% of the time. In contrast, the months of July to September recorded lower cloud covers, with only 32 to 42% of the time being cloudy. Total rainfall followed a typical seasonal pattern, with higher volumes in the first months of the year, reaching a peak of 395 mm in March. From May onwards, rainfall gradually decreased, reaching the lowest values between August (89 mm) and November (57 mm).

Relative air humidity varied little throughout the year, remaining between 78% (November) and 87% (February), with average values above 80% in most months.

Solar energy availability was inversely proportional to cloudiness, with the lowest values recorded in the rainiest months, such as March (5.4 kWh/m^2.day), and the highest between August and September (6.6–6.7 kWh/m^2.day), a period of clearer skies.

In Guayaquil (EC) the mango trees have been managed aiming to perform the flower induction in May, with full flowering in June – July and fruit harvest from October to December, depending on the farm calendar and the energy demand of the mango cultivar, i.e., cultivars with lower thermal demands are harvested earlier while cultivars with higher thermal demands are harvested later. In other words, in general, orchard management needs to be adequate to integrate climatic conditions with the demands of the mango tree, throughout the phenological cycle, but especially between the period from flowering to harvest, between the months of July and November-December for cv. Tommy Atkins.

Between July and December, climatic conditions in Guayaquil (EC) (Table 3) directly influence the growth and final size of mango fruits. During the early development stages, from July to September, average temperatures range between 23.0 and 23.1°C, which are relatively low to promote vigorous cell expansion (Mouco et al., 2019). Although solar radiation is relatively high during this period (6.2–6.7 kWh/m².day), favoring photosynthesis and the production of photoassimilates, the conversion of these assimilates into effective growth may be limited by suboptimal temperatures. Between October and December, when fruit filling occurs, there is a progressive increase in cloud cover (from 42% in September to 73% in December), accompanied by a reduction in solar radiation (from 6.7 to 5.9 kWh/m².day). This decrease in available energy may restrict carbohydrate translocation to fruits, negatively impacting their final size.

Additionally, the low precipitation recorded during this period (< 125 mm/month) may lead to water deficits if irrigation is not properly managed, further limiting fruit growth. The combination of these climatic factors may partially explain the historical trend of producing smaller mango fruits in Ecuador. To mitigate these effects, practices such as optimizing water and nutrient management, using biostimulants to promote cell division and expansion, and regulating fruit load can be adopted to improve fruit size. Strategies aimed at maximizing light interception, such as pruning adjustments, may also help minimize the impact of high cloud cover during the fruit-filling stage.

According to Silva (2000), Silva (2019), Santos (2021), Costa et al. (2008) and Galán-Saúco (2009) for optimal mango cultivation, it is recommended that temperatures remain below 33°C. The ideal relative humidity ranges between 60% and 80%, while solar radiation levels should be between 5 and 7 kWh/m².day. However, it is important to emphasize that climatic factors do not operate independently. When multiple conditions, even if individually close to critical limits, occur simultaneously and interact, they can considerably increase the risk of suboptimal vegetative growth and fruit production in mango trees.

In this scenario, Guayaquil (EC) presents certain unfavorable climatic conditions during the mango fruit development stage, indicating that these factors may limit and influence fruit size. Implementing orchard management strategies tailored to the crop's needs could significantly impact this aspect, especially if applied consistently over multiple production cycles. It is essential to highlight that the continuous adoption of appropriate agronomic practices tends to have a more pronounced effect on fruit yield and size over time.

Regarding the quality of irrigation water, the electrical conductivity of water was an average 381 µS/cm, which presents moderate risk of soil salinization according to the classification proposed by the U.S. Salinity Laboratory Staff – USDA Agriculture Handbook No. 60, the risk of soil salinization is categorized as follows: low (electrical conductivity between 0 and 250 µS/cm at 25°C), medium

(250–750 µS/cm at 25°C), high (750–2,250 µS/cm at 25°C), and very high (2,250–5,000 µS/cm at 25°C). The irrigation water also presented 191 ppm of salts (0.01%), and average pH 7.5.

The characterization data collected from the orchard (Table 4) indicate data aligned with historical climatic data, including numerical values when considering 2.4 kWh/m² ≈ 300.0 klux during, whose assessment was made during one of the periods of lowest historical light incidence.

Table 4: Soil moisture, soil firmness, sun light intensity, leaf chlorophyll *a* index, leaf chlorophyll *b* index, leaf total chlorophyll and leaf electrolyte leakage.

	Sun light intensity	Soil firmness	Soil moisture	Leaf chlorophyll index			Leaf electrolyte leakage
	Lux x 100 x 50.000	Mpa	%	*a*	*b*	Total	µ/cm
Ataulfo	300.1	3.1	15.0	26.1	9.0	35.1	65
Tommy Atkins	299.3	3.4	16.9	28.5	9.7	38.2	70

The chlorophyll indices are compatible with those found in the literature, especially for the Tommy Atkins cultivar, but particularly lower than those recorded by Santos et al. (2024) for both the chlorophyll *a* and chlorophyll *b* indexes. These differences may have resulted from a variety of factors, primarily related to farm management practices. Additionally, conditions such as moderate water deficit, temperature stress, or nutrient deficiencies can alter chlorophyll ratios as an adaptive strategy. Consequently, the plant may invest more in producing chlorophyll *b* to optimize light capture during periods of reduced photosynthetic efficiency, as proposed by Taiz et al. (2017), since chlorophyll *a* is responsible for transferring the absorbed light energy to the reaction center, where the conversion of light energy into biochemical energy occurs, which is a function not performed by chlorophyll *b;* thus, the increase in chlorophyll *a* index enhances the photosynthetic capacity of mango plants. These findings are supported by thermal images captured during the project's initial development phase (Figure 2).

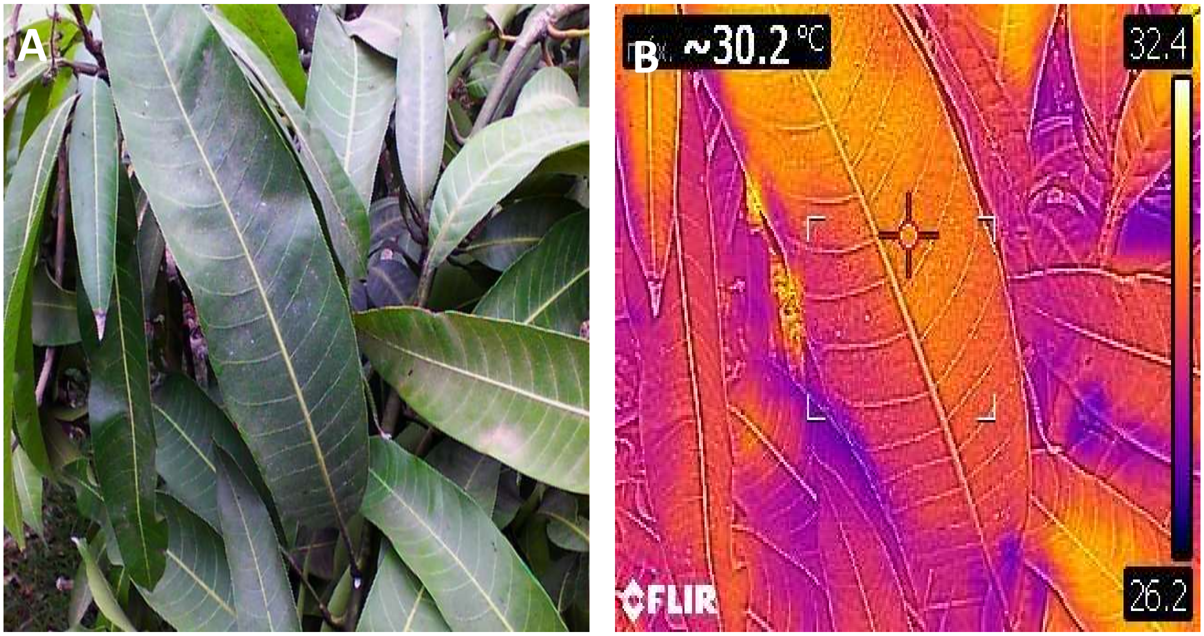


Figure 2: Usual (A) and thermic (B) photos of mango trees in Guayaquil, Ecuador.

The electrolyte leakage presented averages values of 65 µS/cm for 'Ataulfo' and 70 µS/cm for 'Tommy Atkins' (Table 3).

When compared to the electrolyte leakage classification suggested by Ferraz (n.d.) (unpublished data), it is evident that, in both cultivars during the characterization phase, the observed values were at the threshold for the onset of leaf yellowing. According to this classification for mango leaves, electrical conductivity (EC) values range from 40 to 45 µS/cm in green leaves, 65 to 70 µS/cm in leaves beginning to yellow, and exceed 100 µS/cm in leaves exhibiting sunburn symptoms. These values indicate the progressive impact of stress factors on leaf integrity, suggesting the need for monitoring and appropriate management practices to mitigate potential damage and maintain plant health.

Regarding soil moisture estimated under the plant canopy during the characterization phase of the project, both for 'Ataulfo' and 'Tommy Atkins' (Table 3), there were average values of 15.0% and 16.9% respectively. Such values indicate good water availability at that moment, but due to the drainage capacity of the soil, this moisture can decrease rapidly, requiring efficient irrigation management to prevent water stress in the mango tree, especially during the early fruit development stage. To address this, it is recommended to continuously monitor soil moisture, apply frequent irrigation in smaller amounts to minimize excessive losses, or use much to reduce evaporation and improve water retention. It should also be noted that the assessment was carried out in the micro-sprinkler action zone and that in the orchards evaluated there was only one sprinkler per plant, that is, the assessment carried out was restricted to only part of the area occupied by the mango root system.

Soil penetration resistance (soil firmness) also showed similar results in both orchards evaluated (Table 4), with average values of 3.1 MPa and 3.4 MPa, classifying them, according to Bowen (1981), in the range of very high resistance (>3 MPa), indicating an impediment to root growth. This level of compaction can limit root expansion, reduce water and nutrient uptake, and compromise plant development, especially during periods of water deficit. The presence of high resistance suggests the need for soil management practices, such as subsoiling or cover cropping, to reduce compaction and improve conditions for mango root growth. It is important to mention that the Bowen (1981) classification relates different values of penetration resistance with root development, and not a non-cultivated soil.

In both cultivations, the root system development was visually analyzed, revealing concerning conditions, as illustrated in Figure 3A. The identification of absorption roots was virtually impossible, emphasizing the need for management strategies aimed at stimulating root system growth.

Another issue that reinforces this poor root development is the use of only one micro-sprinkler per plant (Figure 3B). This irrigation setup restricts water distribution, failing to adequately cover the entire canopy area and, consequently, the root system. As a result, approximately 25% of the area that should be occupied by roots experiences root death, highlighting the need for improved irrigation practices.

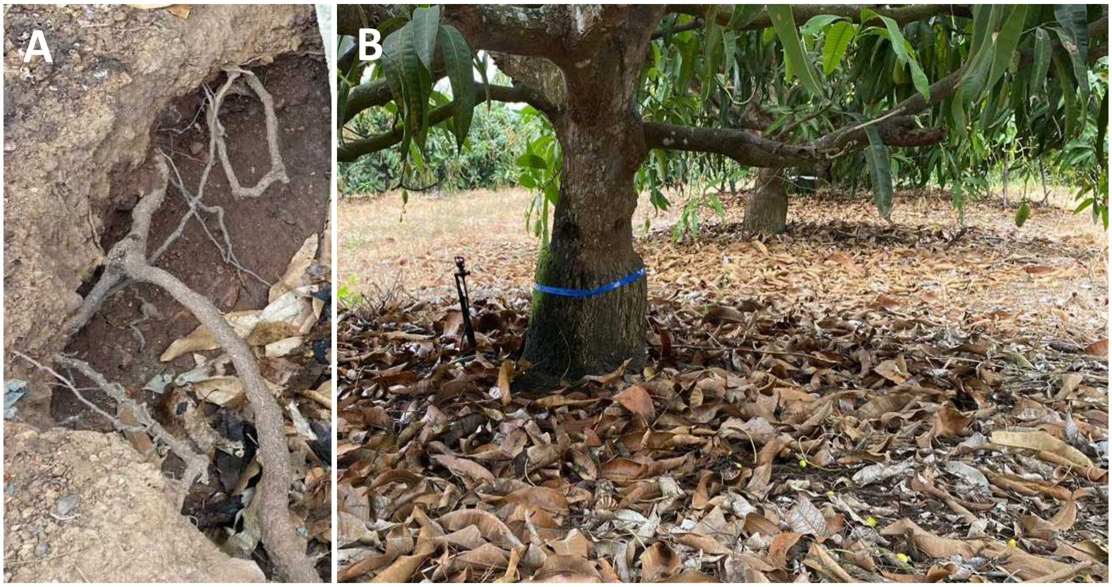


Figure 3: Visual root system evaluation (A) and just one micro-sprinkler (B) in mango orchard in Guayaquil (EC).

The physical and chemical properties of the orchard soils were analyzed, revealing distinct textural classes for 'Ataulfo' and 'Tommy Atkins' mango cultivars—sandy clay loam and sandy loam, respectively (Table 5). It is worth highlighting that the elevated silt content in the soil of 'Tommy Atkins' presents additional challenges for irrigation management, necessitating more precise cultural practices to maintain optimal soil conditions.

Table 5: Characterization of the soil texture (0-30 cm depth) the experimental areas of 'Ataulfo' and 'Tommy Atkins' mangoes before the application of treatments. *

Soil characteristics	Ataulfo	Tommy Atkins
Sand (%)	58	68
Silt (%)	16	22
Clay (%)	26	10
Soil classification	Sandy clay loam	Sandy loam

*Analis performed by the farm.

The characterization of soils for fertility and chemistry in Guayaquil (EC) for 'Ataulfo' and 'Tommy Atkins' indicated problems in both orchards (Table 6).

Table 6. Soil chemical analysis of the experimental areas of 'Ataulfo' and 'Tommy Atkins' mangoes before the application of treatments.

Cultivar	Soil depth	pH	M.O	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$(H^+ + Al^{3+})$	SB	V	Sat. Ca	Sat. Mg	Sat. K	Sat. Na
	cm	H_2O	g/kg	mg dm^{-3}	cmol$_c$ dm^{-3}							%				
								1st evaluation*								
Ataulfo	0-30	5.8	32.5	44.0	0.67	-	12.37	2.26	-	-	15.29	-	-	-	-	-
Tommy	0-30	6.2	38.4	174.0	0.49	-	12.37	1.86	-	-	14.72	-	-	-	-	-
								2nd evaluation								
Ataulfo	0-30	5.6	7.2	86.1	0.43	0.2	3.9	0.6	0.1	1.5	5.16	77.7	59.2	9.0	6.4	3.1
Tommy	0-30	6.3	7.7	20.0	0.46	0.4	14.4	6.9	0.0	1.3	22.2	23.5	61.3	29.6	1.9	1.8

*The first evaluation was performed by the farm. SB: sum of bases; Sat.: saturation. Extractors: P, K e Na: Resin ($HCl + H_2SO_4$); Ca, Mg e Al: KCl 1 M. Tommy: Tommy Atkins

Table 7. Soil chemical analysis for micronutrients (mg/dm^3) of the experimental areas of 'Ataulfo' and 'Tommy Atkins' mangoes before the application of treatments.

Location	Soil depth	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	B
			1st evaluation*			
Ataulfo	0-30	306	16.0	5.6	13.3	1.11
Tommy	0-30	29.0	47.0	12.3	52.0	0.9
			2nd evaluation			
Ataulfo	0-30	79.2	56.2	2.2	48.7	0.4
Tommy	0-30	57.9	19.4	2.4	2.1	0.78

*The first evaluation was performed by the farm. Tommy: Tommy Atkins

Whether comparing the values in Tables 6 and 7 with those considered ideal for mango cultivation (Cavalcante & Paiva Neto, 2024 – Appendix 4), the following considerations can be done.

The chemical analysis of the soils in the 'Ataulfo' and 'Tommy Atkins' mango orchards revealed significant differences compared to the ideal values for mango cultivation. The soil pH was within the acceptable range for both cultivars, although 'Ataulfo' (5.6) was near the lower limit. However, organic matter was notably low in both soils (0.72% and 0.77%), potentially compromising fertility and moisture retention, indicating the need for practices to increase organic content. Phosphorus levels also showed significant discrepancies, being above the ideal range in 'Ataulfo' (86.1 mg/dm³), whereas 'Tommy Atkins' had a severe deficiency (20.0 mg/dm³), which could negatively affect root growth and early plant development. In terms of K, both orchards exhibited slightly elevated levels, with 'Ataulfo' (0.43 cmolc/dm³) and 'Tommy Atkins' (0.46 cmolc/dm³) surpassing the recommended range, which, while potentially beneficial for fruit quality, should be monitored to prevent imbalances with other cations. Sodium levels were within acceptable limits but showed elevated saturation (3.1% in 'Ataulfo' and 1.8% in 'Tommy Atkins'), which could negatively impact soil structure and nutrient absorption over time. Regarding Ca and Mg, 'Ataulfo' had appropriate Ca levels (3.9 cmolc/dm³) but a Mg deficiency (0.6 cmolc/dm³), whereas 'Tommy Atkins' exhibited severe imbalances, with excessive Ca (14.4 cmolc/dm³) and Mg (6.9 cmolc/dm³), potentially hindering K uptake and the availability of other essential nutrients. The base saturation values further highlight this imbalance: 'Ataulfo' had an adequate level (77.7%), whereas 'Tommy Atkins' was significantly below the ideal threshold (23.5%), suggesting lower availability of essential cations. Additionally, K saturation was optimal in 'Ataulfo' (6.4%) but extremely low in 'Tommy Atkins' (1.9%), reinforcing the need for K fertilization adjustments in this cultivar.

Overall, the soil in 'Ataulfo' displayed better chemical conditions, requiring only minor corrections in Mg and organic matter, while the soil in 'Tommy Atkins' showed more severe imbalances, necessitating urgent corrections in P, K, and base saturation, as well as strategies to reduce excessive Ca and Mg levels. Given this scenario, it is recommended to implement management strategies that include balanced fertilization, increased organic matter content, and close monitoring of sodium levels, ensuring optimal nutrition for both cultivars.

As can be seen in Table 8, the second evaluation of leaf nutrient analysis for 'Ataulfo' and 'Tommy Atkins' mango trees showed several imbalances compared to the optimal ranges suggested by Rezende et al. (2022). Nitrogen was adequate in 'Ataulfo' (16.4 g/kg) but slightly deficient in 'Tommy Atkins' (11.1 g/kg). P was below the ideal range in both cultivars, with 'Ataulfo' (1.1 g/kg) and 'Tommy Atkins' (0.8 g/kg) requiring supplementation. Potassium was also deficient, particularly in 'Ataulfo' (6.3 g/kg), while 'Tommy Atkins' (8.5 g/kg) was closer to adequacy. Calcium was slightly below the ideal range in 'Ataulfo' (23.9 g/kg) but adequate in 'Tommy Atkins' (32.3 g/kg). Sulfur exceeded the upper limit in 'Ataulfo' (2.2 g/kg), while 'Tommy Atkins' (1.3 g/kg) was below the ideal range, quoted in Table 9.

Table 8. Nutritional analysis of 'Ataulfo' and 'Tommy Atkins' mango leaves before the application of treatments.

Location	N	P	K^+	Ca^{2+}	Mg^{2+}	S	B	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Mo	Na	Si
	——— g kg^{-1} ———						——— mg kg^{-1} ———							
1st evaluation*														
Ataulfo	16.0	1.3	7.8	13.2	1.7	1.3	46.0	7.0	124.0	184.0	25.0	-	-	-
Tommy	15.0	1.1	9.7	21.6	1.7	1.3	67.0	5.0	122.0	211.0	55.0	-	-	-
2nd evaluation														
Ataulfo	16.4	1.1	6.3	23.9	2.0	2.2	78.0	5.6	112.2	793.4	29.1	2.91	260.9	704.7
Tommy	11.1	0.8	8.5	32.3	1.2	1.3	52.5	6.0	214.8	442.3	23.4	<LQ	329.7	550.7

*The first evaluation was performed by the farm. Nutrient of cells in red are below, nutrient of cells in blue are adequate and nutrient of cells in brown are above the adequate range of supply of Rezende et al. (2022). <LQ: above the method quantifier limit.

Table 9. Optimal leaf mineral concentration ranges for a minimum fruit yield of 'Tommy Atkins' (34 t ha^{-1}), suggested by (Rezende et al., 2022)*.

N	P	K^+	Ca^{2+}	Mg^{2+}	S	B	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Mo
——— g kg^{-1} ———						——— mg kg^{-1} ———					
11.9 –17.9	1.5 – 2.4	10.2 –15.9	24.3 –32.1	1.6 – 2.4	1.7 – 2.1	101.1-225.1	100.8-217.2	345.5-783.9	33.3-147.2	8.6-12	1.4-2.1

*For 'Ataulfo' mango still there is no specific range of supply in the scientific literature.

Among micronutrients, B was deficient in both 'Ataulfo' (78.0 mg/kg) and 'Tommy Atkins' (52.5 mg/kg). Iron was adequate in both cultivars, while Mn was excessive in 'Ataulfo' (793.4 mg/kg) but normal in 'Tommy Atkins' (442.3 mg/kg). Zinc and Cu were below optimal levels in both cultivars, with 'Ataulfo' at 29.1 mg/kg (Zn) and 5.6 mg/kg (Cu), and 'Tommy Atkins' at 23.4 mg/kg (Zn) and 6.0 mg/kg (Cu). Molybdenum was slightly above the recommended limit in 'Ataulfo' (2.91 mg/kg) but undetectable in 'Tommy Atkins' (<LQ), indicating a severe deficiency.

When comparing soil values with leaf values, it is observed that several nutrients were present in the soil in adequate or even excessive quantities but were not effectively absorbed by the plants. This phenomenon may be related to several factors, such as interactions between nutrients, actual availability for absorption, physical-chemical conditions of the soil, pH, presence of antagonisms between elements and even problems in the root system.

In a global evaluation, P was high in the soil of 'Ataulfo' (86.1 mg/dm^3, above the ideal 60–80 mg/dm^3), but leaves showed deficiency (1.1 g/kg, below the ideal 1.5–2.4 g/kg), suggesting possible fixation in the soil. Potassium was slightly above the ideal range in both soils but deficient in leaves, indicating that excess Ca and Mg in 'Tommy Atkins' may have inhibited its absorption, while in 'Ataulfo', leaching could be a factor due to the sandy soil texture. Calcium and Mg were excessively high in 'Tommy Atkins' soil (14.4 and 6.9 $cmolc/dm^3$, well above the ideal 3–5 and 0.75–1.25 $cmolc/dm^3$, respectively), likely limiting the uptake of K and micronutrients. Zinc was high in the soil of 'Ataulfo' but low in leaves, possibly due to interference from excess phosphorus. Boron, despite being close to the ideal range in the soil, was deficient in both cultivars' leaves, possibly due to Ca interactions. Manganese was high in both the soil and leaves of 'Ataulfo', indicating excessive uptake, likely influenced by soil pH. Molybdenum showed severe deficiency in the leaves of 'Tommy Atkins' (<LQ), suggesting low availability in the soil or antagonistic effects from other nutrients. These findings confirm that nutrient presence in the soil does not guarantee plant uptake, emphasizing the need for a nutritional management approach that considers nutrient interactions, balances cation ratios, and applies strategies to enhance nutrient availability, such as foliar applications or soil corrections.

Furthermore, several other factors may explain these discrepancies, as suggested by Gloser et al. (2020), Yan et al. (2020), and Hartemink & Barrow (2023). Variation in soil moisture can affect nutrient availability, as lower moisture levels hinder the diffusion of nutrients to the roots. Soil penetration resistance may also play a role by limiting root expansion and impairing Ca and K uptake. Additionally, uneven nutrient distribution in the soil may result in key elements being concentrated in layers beyond the reach of active roots. Reduced transpiration rates can limit the movement of mobile nutrients, such as Ca, through the xylem, while localized deficiencies may arise due to differences in nutrient mobility, favoring Mg (more mobile) over Ca (less mobile). The presence of sodium (Na) in the soil can further hinder K absorption by competing for the same uptake pathways. High pH or bicarbonates can reduce Ca and K availability, while excessive nitrogen fertilization may promote vegetative growth at the expense of a balanced Ca and K uptake. Lastly, the restricted development of the root system in the crop further exacerbates nutrient absorption limitations.

3.2 Second phase: conducting field experiments

3.2.1. Results for Ataulfo

The soil chemical analysis prior to treatment application indicated moderately acidic conditions (pH 5.65), low organic matter content (7.2 g/kg), and high P levels (86.1 mg/dm³), which may suggest either previous accumulation or low plant uptake (Table 10). Potassium and Ca concentrations were within acceptable ranges as established by Cavalcante & Paiva Neto (2024) (Appendix 4), whereas Mg content was relatively low (0.6 cmolc/dm³), potentially limiting the balanced uptake of other cations. Exchangeable aluminum (Al^{3+}) was low (0.1 cmolc/dm³), and both the sum of bases (SB = 5.16 cmolc/dm³) and base saturation (V = 77.7%) indicate moderate soil fertility.

Table 10. Comparison of the soil chemical analysis (at 30 cm soil depth) before and at the end of the experiment as a function of different management strategies for Ataulfo mango in Ecuador.

	pH	M.O	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$(H^+ + Al^{3+})$	SB	V	Sat. Ca	Sat. Mg	Sat. K	Sat. Na
	H_2O	g/kg	mg dm^{-3}	cmol$_c$ dm^{-3}							%				
Before	5.65	7.2	86.1	0.43	0.2	3.9	0.6	0.1	1.5	5.16	77.7	59.2	9.0	6.4	3.1
T1	6.16^a	9.9^c	37.1^c	0.45^c	0.3^a	21.6^b	10.8^a	0.0	1.9^a	33.2^a	94.6^a	61.6	30.7	1.3	1.0
T2	5.80^a	7.1^c	74.1^a	0.69^a	0.3^a	21.2^b	9.6^b	0.1	2.5^a	31.8^a	92.7^a	61.7	28.1	2.0	0.9
T3	6.41^a	15.2^b	60.2^b	0.65^a	0.3^a	27.9^a	11.3^a	0.0	1.9^a	40.2^a	95.5^a	66.3	26.8	1.5	0.8
T4	6.44^a	13.2^b	58.5^b	0.44^c	0.4^a	18.1^c	7.3^c	0.0	1.4^a	26.3^b	95.1^a	65.6	26.5	1.6	1.3
T5	6.51^a	19.0^a	43.9^c	0.51^b	0.4^a	17.8^c	7.4^c	0.0	1.7^a	26.1^b	93.9^a	64.0	26.7	1.8	1.4

SB: sum of bases; Sat.: saturation. Extractors: P, K e Na: Resin (HCl + H_2SO_4); Ca, Mg e Al: KCl 1 M. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

As shown in Table 10, following the application of different treatments, there was a significant increase in soil pH across all treatments, with the most notable effect observed in T5 (6.51), reflecting the influence of liquid fertilizers and the enhanced mobility of cations in solutions. Organic matter content increased substantially in treatments T3 (15.2 g/kg), T4 (13.2 g/kg), and particularly T5 (19.0 g/kg), indicating the positive effects of biostimulants and sun protectants, which also contain humic and fulvic acids.

Phosphorus levels decreased in all treatments, which may suggest greater plant uptake or redistribution within the soil profile, with T2 (74.1 mg/dm³) maintaining the most favorable P levels. Soil K increased notably in T2 (0.69 cmolc/dm³) and T3 (0.65 cmolc/dm³), reflecting improved performance of treatments with balanced fertilization.

Calcium and Mg contents increased markedly, especially in T3 (27.9 and 11.3 cmolc/dm³, respectively), suggesting a cumulative effect of nutrient application in combination with amino acids and plant growth regulators. As a result, the sum of bases (SB) was significantly higher in treatments T1 through T3, with T3 showing the greatest value (40.2 cmolc/dm³), and base saturation (V) exceeded 92% in all treatments, reinforcing the adequate supply of exchangeable cations.

Regarding specific cation saturation, a balanced proportion of Ca^{2+} and Mg^{2+} was observed in the treatments with the best performance (T3 and T4). However, K^+ saturation was higher in the soil prior to treatment (6.4%), suggesting possible leaching or competitive inhibition with other cations after treatment.

Micronutrient concentrations in the soil are presented in Table 11 and showed significant variation among treatments for Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}, and B, directly influenced by the type and efficiency of the applied management practices. Comparisons regarding mango crop requirements were based on Appendix 8 (Cavalcante & Paiva Neto, 2024).

Table 11. Comparison of the soil chemical analysis (at 30 cm soil depth) for micronutrients (mg dm^{-3}) before and at the end of the experiment as a function of different management strategies for Ataulfo mango in Ecuador.

	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	B
Before	79.2	56.2	2.2	48.7	0.4
T1	13.1^b	27.9^c	1.4^a	4.2^c	1.1^a
T2	22.9^a	33.8^c	0.5^c	4.9^c	0.9^a
T3	7.9^b	32.2^c	1.0^b	9.1^b	1.1^a
T4	11.8^b	42.5^b	1.0^b	4.8^c	1.4^a
T5	10.7^b	51.9^a	0.9^c	11.3^a	0.8^b

T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

The initial Fe concentration was high (79.2 mg/dm³), yet within the adequate range (4–100 mg/dm³). However, all treatments led to a drastic reduction in Fe levels, with T2 (22.9 mg/dm³) being the only treatment statistically superior to the others. This decline may be associated with the immobilization of Fe into less available forms, particularly in higher pH environments, as observed in T3–T5 (Zuo & Zhang, 2011). The superior performance of T2 may be attributed to the balanced application of solid nutrients and efficient irrigation management, which promoted Fe availability without disrupting its equilibrium with other cations.

For Mn, the initial soil level at the experimental site (56.2 mg/dm³) was slightly above the optimal range (4–50 mg/dm³). Treatment T5 showed the highest final Mn concentration (51.9 mg/dm³), maintaining it within the suitable range. In contrast, treatments T1–T4 presented significantly lower levels, suggesting possible leaching or fixation. The effectiveness of T5 is linked to the higher organic matter content observed (Table 10), which complexes Mn and helps retain it in plant-available forms (Li et al., 2021), in addition to the chelation effects promoted by fulvic acids present in the liquid fertilizers.

Regarding Cu, all treatments showed a decrease in soil levels. T1 retained the highest Cu content (1.4 mg/dm³), followed by T3 and T4 (~1.0 mg/dm³). T2 (0.5 mg/dm³) and T5 (0.9 mg/dm³) recorded the lowest concentrations. The generalized reduction may be explained by competitive inhibition from Zn^{2+} and by increases in cation exchange capacity (CEC) and pH, which promote Cu^{2+} precipitation (McBride & Blasiak, 1979). The higher retention observed in T1 may be due to the absence of pH-raising interventions; however, this does not represent an agronomic advantage, as Cu levels remained sufficient in all other treatments.

Soil Zn levels were initially very high (48.7 mg/dm³) but decreased significantly across all treatments. T5 had the highest final Zn concentration (11.3 mg/dm³), remaining within the ideal range (2–15 mg/dm³) and outperforming the other treatments. T3 also presented a considerable value (9.1 mg/dm³), while T1, T2, and T4 displayed lower levels (4.2–4.9 mg/dm³). The superior performance of T5 may be attributed to the use of liquid fertilizers containing micronutrients in chelated and highly bioavailable forms, as well as the role of humic and fulvic acids in mobilizing Zn in the soil (Boguta & Sokołowska, 2020).

Initially, soil B levels were below the optimal range (1–2 mg/dm³). Following treatment, T4 (1.4 mg/dm³), T1 and T3 (1.1 mg/dm³), and T2 (0.9 mg/dm³) reached adequate levels, whereas T5 remained below the threshold (0.8 mg/dm³). The lower efficiency of T5 in supplying B may be related to the absence of this element in the applied liquid fertilizers or to competitive uptake with Ca^{2+} and K^{+}, which were abundant in this treatment, as described by Hellal et al. (2015).

With regard to the nutritional status of macro- and micronutrients (Table 12), significant variations were observed for most of the evaluated elements.

Table 12. Comparison of the leaf nutritional status before and at the end of the experiment as a function of different management strategies for Ataulfo mango in Ecuador.

	N	P	K^+	Ca^{2+}	Mg^{2+}	S	B	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Mo
	g kg^{-1}						mg kg^{-1}					
Before	16.4	1.1	6.3	23.9	2.0	2.2	78.0	5.6	112.2	793.4	29.1	2.91
T1	16.1^a	1.0^a	6.8^a	21.7^a	1.3^b	1.5^a	87.5^a	5.0^a	56.6^b	737.3^a	15.4^b	2.74^a
T2	15.4^b	1.0^a	6.2^b	24.0^a	1.9^a	1.4^a	73.9^a	5.4^a	51.6^b	361.5^b	9.7^c	3.41^a
T3	15.4^b	1.0^a	6.9^a	23.9^a	2.1^a	1.4^a	66.4^a	6.4^a	62.3^b	265.3^c	15.5^b	4.15^a
T4	15.1^b	1.0^a	6.7^a	22.9^a	1.7^a	1.5^a	76.4^a	6.0^a	79.8^a	316.4^b	28.6^a	4.66^a
T5	15.4^b	1.1^a	6.2^b	23.7^a	2.0^a	1.5a	50.8^d	7.7^a	78.9^a	168.3^d	24.5^a	4.42^a

T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Average values followed by the same letter in columns do not differ among them ($p > 0.05$).

For N, values ranged from 15.1 to 16.4 g/kg, all within the sufficiency range (11.9–17.9 g/kg), although T1 exhibited the highest concentrations, with no statistical difference from T3 to T5, indicating that even the traditional management was sufficient for this nutrient. However, the slight reduction observed in treatments T2–T5 may be related to increased vegetative growth induced by biostimulants, resulting in a dilution effect of N concentration per unit leaf mass (non-measured visual observations).

Regarding P, all treatments maintained values below the ideal range (1.5–2.4 g/kg), despite specific fertilization practices. This supports the previously stated hypothesis of P fixation in the soil, especially under treatments with increased Ca and Zn, which may compete with P for uptake or promote phosphate precipitation, as reported by Prasad et al. (2016). In this case, management strategies aimed at strengthening the root system, including the use of alternative P sources or foliar applications, may be necessary to correct deficiencies.

Final K concentrations ranged from 6.2 to 6.9 g/kg, still below the sufficiency range (10.2–15.9 g/kg), confirming poor K uptake even when soil availability was not limiting. This may be due to high soil concentrations of Ca^{2+} and Mg^{2+} (Table 10), which compete with K^+ for root uptake sites (Marschner, 2012). T3 showed the highest K^+ content, suggesting that the application of amino acids and plant growth regulators facilitated absorption. This finding is consistent with Rouphael et al. (2015), who noted that amino acids act as complex and carrier agents, improving nutrient uptake and mobility within the plant's apoplast and symplast. Furthermore, growth regulators such as auxins, cytokinins, and gibberellins stimulate root development and the activity of transport proteins like the plasma membrane H^+-ATPase, which is essential for the active uptake of ions such as K^+ (Taiz et al., 2017; Tripathi et al., 2022).

Foliar Ca levels remained stable across treatments (21.7–24.0 g/kg), within or slightly below the sufficiency range (24.3–32.1 g/kg, Rezende et al., 2022). Treatments T2, T3, and T4 achieved satisfactory Ca^{2+} levels despite the absence of direct Ca supplementation, indicating that the adopted management practices effectively enhanced the absorption and utilization of native soil calcium.

In T2, the combination of N and K fertilization aligned with the crop's phenological stages and rational irrigation management (based on crop coefficient, Kc) favored the solubilization and transport of existing Ca^{2+} to the root zone. As Ca uptake occurs passively via mass flow, soil water availability and active transpiration are critical determinants (White & Broadley, 2003). In T3, which combined the same water-nutrient management with the use of amino acids and growth regulators, uptake efficiency was even more pronounced. Amino acids function as complexing agents, enhancing Ca^{2+} mobility in the rhizosphere and root absorption. Moreover, plant growth regulators such as auxins and cytokinins stimulate root system expansion, meristematic activity, and cell division, increasing physiological demand and internal Ca translocation, especially to developing leaves (Taiz et al., 2017; Colla et al., 2015).

The occurrence of adequate foliar Ca^{2+} levels in T4, even without direct Ca supplementation, further supports the positive role of physiological management and irrigation in optimizing the use of soil mineral resources. In contrast, T1 (conventional management), despite no apparent water or nutrient restrictions, exhibited the lowest foliar Ca^{2+} content (21.7 g/kg), highlighting the insufficiency of traditional practices to optimize nutrient absorption.

Foliar Mg levels ranged from 1.3 g/kg (T1) to 2.1 g/kg (T3). All treatments except T1 reached concentrations within the sufficiency range for mango (1.6–2.4 g/kg; Rezende et al., 2022). Although all treatments received some form of Mg fertilization, including T1, the lower performance of this treatment suggests that the applied dose or conventional management practices were insufficient for adequate nutrient uptake, especially considering the low available Mg in the soil (0.6 cmolc/dm³).

Treatment T3, which applied 0.92 kg/ha of Mg via fertigation along with amino acids and plant growth regulators, achieved the highest foliar Mg concentration, indicating that nutrient uptake was enhanced by additional biochemical and physiological mechanisms. Amino acids function as complexing agents, increasing Mg solubility in the soil solution, while growth regulators stimulate root expansion and metabolic demand, promoting greater nutrient assimilation (Calvo et al., 2014; Taiz et al., 2017). T5, which applied a higher Mg dose (1.66 kg/ha), reached 2.0 g/kg, confirming that both physiological efficiency and application rate/form play critical roles in the success of Mg fertilization.

Foliar S concentrations exceeded the adequate range (1.7–2.1 g/kg) only in the initial evaluation (2.2 g/kg); after treatment, values stabilized between 1.4 and 1.5 g/kg. The slight reduction may be attributed to dilution due to leaf growth. No statistically significant differences were observed.

Among the micronutrients evaluated (Table 12), notable reductions in foliar Fe and Mn were observed across all treatments compared to initial values. This reduction was most pronounced in T5, which presented 78.9 mg/kg of Fe and 168.3 mg/kg of Mn, compared to initial values of 112.2 mg/kg and 793.4 mg/kg, respectively. These results suggest a dilution effect associated with vegetative growth, and possibly the correction of initial excesses—particularly in the case of Mn^{2+}, which exceeded the ideal range (345.5–783.9 mg/kg, Rezende et al., 2022). The higher efficiency of T5 may be attributed to the application of liquid fertilizers containing organic complexing agents (e.g., fulvic acids), which enhance micronutrient availability while modulating uptake, reducing excessive accumulation, and promoting more balanced tissue distribution (Marschner, 2012; Rouphael & Colla, 2020).

For Cu, Zn, and B, results were more variable. Cu^{2+} concentrations remained within the recommended range (8.6–12 mg/kg) across all treatments, with only minor fluctuations. Zn^{2+} levels improved significantly in T5 (24.5 mg/kg) and T4 (28.6 mg/kg), consistent with the optimal range (33.3–147.2 mg/kg), reinforcing the superior efficiency of liquid fertilizers in delivering chelated, highly bioavailable micronutrients (Calvo et al., 2014). Regarding B, only T5 presented a deficient level (50.8 mg/kg), below the recommended range (101.1–225.1 mg/kg), likely due to the absence of B in the applied liquid fertilizers and competition with Ca^{2+} and K^{+} during xylem transport (White & Broadley, 2003). All other treatments maintained adequate B levels, demonstrating the beneficial effect of conventional management or biostimulant use on the retention and uptake of this mobile and leachable nutrient.

Fruit production (kg/plant) and fruit yield (t/ha) of 'Ataulfo' mango showed no statistically significant differences among treatments (Figures 4A and 4B). However, the highest average values were observed in T2 (solid fertilization adjusted to phenological demand + irrigation) and T1 (traditional management), both exceeding 70 kg/plant and 15 t/ha. This suggests that, although T1 reflects conventional management, the site already had favorable production conditions, and T2, even in the absence of biostimulants, demonstrated the potential to maintain or surpass productivity, due to effective irrigation management and synchronization of fertilization with crop phenology.

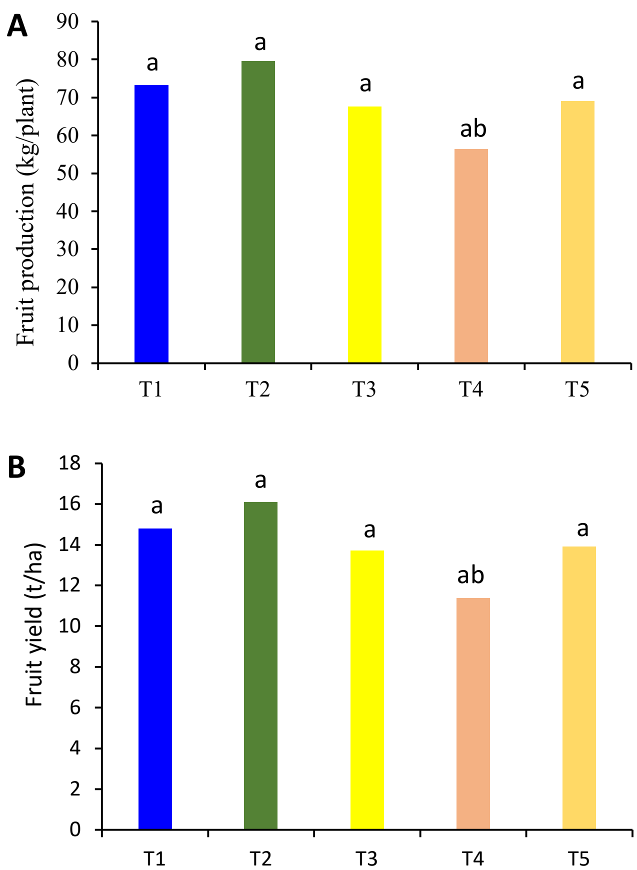
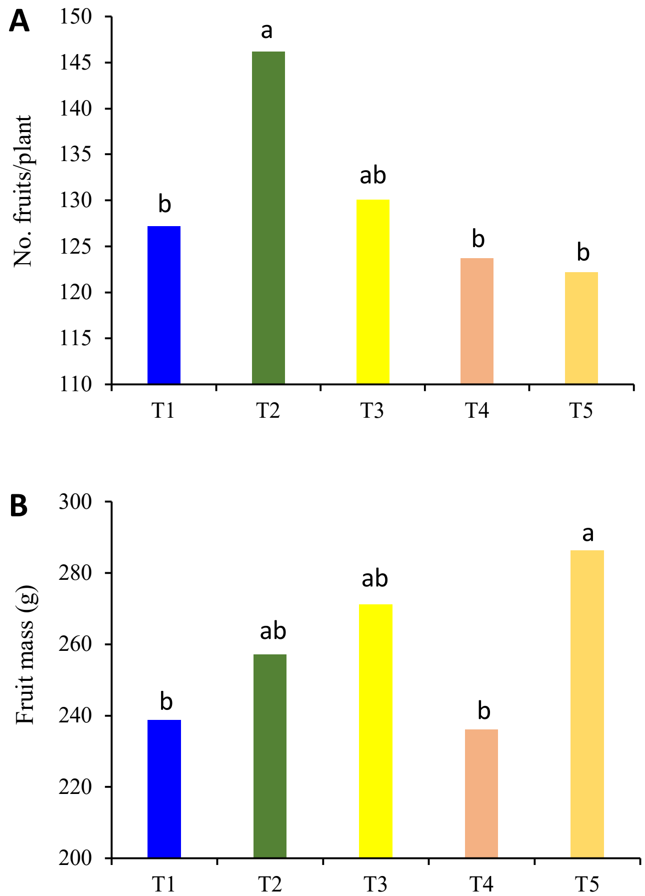


Figure 4: Fruit production (A) and fruit yield (B) of 'Ataulfo' as a function of different management strategies in Guayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

Although T3 and T5 demonstrated qualitative improvements in aspects such as foliar nutrition and fruit uniformity (as discussed previously), their average yield was slightly lower than that of T2 (Figure 4), which may be attributed to an increased number of small fruits or to a shift toward vegetative growth promoted by biostimulants and growth regulators, potentially compromising final fruit filling (Taiz et al., 2017). T4 exhibited the lowest yield (~57 kg/plant), although this was not statistically different from the other treatments. This lower performance may be associated with a negative response to the use of the sun protectant, possibly due to interference with net photosynthesis or light absorption, as reported by Silva et al. (2022a) under high solar radiation conditions.

As shown in Figure 5A, the number of fruits per plant was significantly influenced by the treatments. T2 recorded the highest value (~147 fruits/plant), representing a 14.9% increase compared to the control (T1), suggesting that fertilization tailored to the crop's nutritional demand, combined with irrigation management based on the crop coefficient (Kc), enhanced fruit retention. This management probably improved the physiological conditions required for flowering, fruit set, and fixation by mitigating limiting factors such as water stress or nutritional imbalances (Taiz et al., 2017). In contrast, treatments T4 and T5, which incorporated amino acids, plant growth regulators, and sun protectants, did not differ significantly from the control and exhibited the lowest number of fruits per plant (~123 and 122 fruits/plant, respectively), suggesting that the combination of biostimulants may have altered hormonal balance or redirected assimilates toward vegetative growth or fruit quality rather than increasing fruit set.



C

	Number of fruits per plant	Fruit mass
T1 => **T2**	**+14,9%**	**+7,7%**
T1 => **T3**	**+2,3%**	**+13,6%**
T1 => T4	**-2,8%**	**-1,1%**
T1 => T5	**-3,9%**	**+19,9%**

Figure 5: Number of fruits per plant (A), fruit mass (B) and fluctuations of such variables between the treatments studied of 'Ataulfo' as a function of different management strategies in Guayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

On the other hand, average fruit mass exhibited an opposite trend: T5 resulted in the highest mean fruit mass (~287 g), significantly surpassing all other treatments and representing an increase of nearly 20% compared to T1. T3 also yielded a high value (~273 g), indicating that the use of biostimulants (amino acids + plant growth regulators) promoted the growth and filling of the remaining fruits, likely by enhancing the transport and assimilation of essential nutrients such as K, Ca, and Mg (Calvo et al., 2014; Rouphael & Colla, 2020) (Figure 5B). This demonstrates the compensatory effect commonly observed in practices that reduce fruit load but enhance individual fruit quality—an advantage from a commercial perspective for cultivars such as ‘Ataulfo’ which are highly dependent on fruit size for market acceptance. In contrast, T4, despite utilizing similar technologies, showed the lowest performance in both fruit number and mass, possibly due to adverse effects of the sun protectant on net photosynthesis and the plants' energy efficiency (Silva et al., 2022a).

The percentage comparison between treatments and the control (T1), shown in Figure 5C, reveals two distinct agronomic response patterns to the management strategies. T2 demonstrated the best combined performance, with a 14.9% increase in fruit number and a 7.7% increase in average fruit mass, consistent with the physiologically balanced strategy employed: solid fertilization aligned with phenological demand and irrigation based on the crop coefficient (Kc). This approach appears to have supported both fruit set and fruit filling without inducing excessive competition for assimilates—an ideal outcome in high-yield production systems (Taiz et al., 2017).

In contrast, T3 and T5 exhibited compensation strategies: they showed modest or even negative changes in fruit number (+2.3% and –3.9%, respectively), but substantial gains in average fruit mass (+13.6% for T3 and +19.9% for T5). These findings suggest that the application of biostimulants and growth regulators (in T3) and liquid fertilizers in combination with these inputs (in T5) prioritized individual fruit growth over fruit quantity—a common physiological outcome when hormonal stimulation enhances cell division and expansion (Calvo et al., 2014; Rouphael & Colla, 2020). These results underscore the importance of tailoring physiological management strategies according to the production goal—whether prioritizing fruit quantity or size - depending on the cultivar’s commercial requirements.

Figure 6 highlights marked differences in fruit size distribution as a function of the applied management practices. T5 showed the best qualitative performance, with 38.2% of fruits exceeding 300 g and 41.2% ranging from 250–300 g, totaling nearly 80% of fruits in the most commercially valuable size categories. The complete absence of fruits below 200 g in this treatment demonstrates the effectiveness of the management strategy combining liquid fertilizers, amino acids, plant growth regulators, and sun protectant in promoting fruit growth and filling—likely through improved uptake of key nutrients (K, Ca, Mg) and stimulation of physiological pathways associated with biomass accumulation in fruit tissues (Calvo et al., 2014; Taiz et al., 2017).

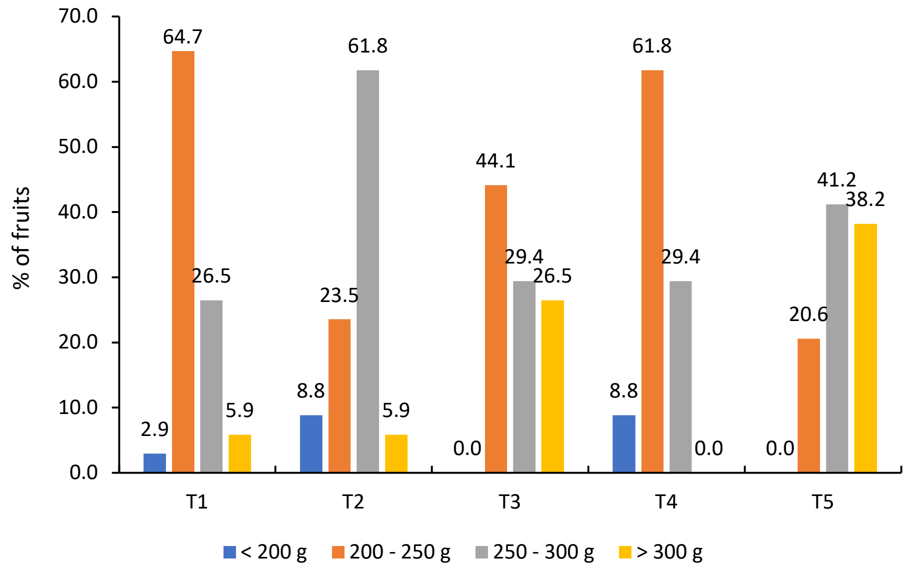


Figure 6: Distribution of fruit caliper classes of 'Ataulfo' as a function of different management strategies in Gayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock.

Still regarding Figure 6, T1 (control) concentrated 64.7% of fruits in the 200–250 g category and only 5.9% above 250 g, with 2.9% of fruits weighing less than 200 g, indicating low uniformity and inferior performance in terms of commercial quality. Treatments T2 and T4, even when applying solid fertilization adjusted to crop demand and biostimulants, retained over 60% of fruits in the 250–300 g range. However, they showed a lower proportion of fruits above 300 g, and in the case of T4, 8.8% of fruits were below 200 g, representing a qualitative setback.

In contrast, T3—employing physiological management without the sun protectant—displayed a more balanced distribution, with 26.5% of fruits >300 g, 29.4% between 250–300 g, and a complete elimination of the lower mass classes. These results indicate that although the total fruit number may be reduced with the use of biostimulants (as observed in T3 and T5), fruit quality and the commercial value of the harvest increase, enhancing grower returns in markets that demand larger fruit calibers.

3.2.2. Results for Tommy Atkins

Before treatment application, the soil exhibited a pH of 6.3, organic matter (OM) content of 7.7 g/kg, low available P (20 mg/dm³), and a chemical composition dominated by high levels of Ca^{2+} (14.4 cmolc/dm³) and Mg^{2+} (6.9 cmolc/dm³), yet with base saturation still below the ideal threshold (Table

13). When compared with the reference values listed in Appendix 8, initial deficiencies were observed particularly in P, organic matter, and base saturation balance (ideal: V > 65%; Ca saturation: 65–70%; Mg saturation: 15–20%; K saturation: 5–10%).

Following the treatments, changes in chemical attributes varied markedly among treatment groups. T3 stood out as the most effective in nutrient replenishment and availability, showing significant increases in P (96.4 mg/dm^3), K (0.83 cmolc/dm^3), Ca (24.2 cmolc/dm^3), and Mg (7.1 cmolc/dm^3), along with the highest sum of bases (SB = 32.6 cmolc/dm^3) and the highest base saturation (V = 96.5%). The use of biostimulants and plant growth regulators in this treatment likely enhanced microbial activity, organic matter mineralization, and nutrient mobilization in the rhizosphere, thereby optimizing nutrient uptake and recycling (Calvo et al., 2014; Rouphael & Colla, 2020).

Treatments T2 and T4, which also exhibited high organic matter contents (29.5 and 29.0 g/kg, respectively), showed P accumulation and considerable improvements in attributes such as pH, V, and SB, but did not reach the same levels of Ca^{2+}, Mg^{2+}, or K^+ saturation observed in T3. T4 had the highest P content among all treatments (145.5 mg/dm^3), exceeding the ideal range (60–80 mg/dm^3), which may indicate a risk of fixation or nutritional imbalance. T2, in contrast, achieved a better balance among V, pH, and macronutrients, representing an agronomically safe and efficient strategy.

Treatments T1 and T5 exhibited poorer chemical performance. T1 maintained low levels of exchangeable bases, particularly Ca^{2+} and Mg^{2+}, and a more acidic pH (6.0), while T5, despite the use of liquid fertilizers and biostimulants, did not result in significant increases in nutrient concentrations or organic matter content (5.4 g/kg). This suggests that, despite the use of more advanced technologies, their effectiveness depends on the formulation, application rate, and the initial chemical condition of the soil.

Table 13. Comparison of the soil chemical analysis (at 30 cm soil depth) before and at the end of the experiment as a function of different management strategies for Tommy Atkins mango in Ecuador.

	pH	M.O	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$(H^+ + Al^{3+})$	SB	V	Sat. Ca	Sat. Mg	Sat. K	Sat. Na
	H_2O	g/kg	mg dm^{-3}	$cmol_c\ dm^{-3}$							%				
Before	6.3	7.7	20.0	0.46	0.4	14.4	6.9	0.0	1.3	22.2	23.5	61.3	29.6	1.9	1.8
T1	6.0^b	7.6^b	78.6^b	0.40^b	0.1^a	4.2^d	0.6^b	0.0	1.6^a	5.3^b	77.1^b	61.5	9.0	5.4	1.2
T2	7.0^a	29.5^a	86.1^b	0.55^b	0.3^a	12.9^b	1.1^b	0.0	1.1^a	14.9^b	93.1^a	81.2	6.6	3.4	1.9
T3	6.9^a	3.9^c	96.4^b	0.83^a	0.4^a	24.2^a	7.1^a	0.0	1.2^a	32.6^a	96.5^a	71.6	21.2	2.5	1.2
T4	6.4^a	29.0^a	145.5^a	0.90^a	0.2^a	10.9^c	1.6^b	0.0	2.6^a	13.5^b	84.1^a	67.4	9.7	5.6	1.4
T5	6.6^a	5.4^b	95.7^b	0.40^b	0.1^a	4.7^d	0.9^b	0.0	0.7^a	6.1^b	89.4^a	69.3	13.0	5.8	1.4

SB: sum of bases; Sat.: saturation. Extractors: P, K e Na: Resin ($HCl + H_2SO_4$); Ca, Mg e Al: KCl 1 M. Average values followed by the same letter in columns do not differ among them ($p > 0.05$). T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock.

The dynamics of soil micronutrients (Table 14) were strongly influenced by the evaluated treatments, with notable variations in the levels of Fe, manganese, Zn, Zn, and B. Regarding Fe, treatment T5 exhibited the highest concentration (123.2 mg/dm³), exceeding the ideal range (4–100 mg/dm³), followed by T1 (81.2 mg/dm³), suggesting possible accumulation or limited plant uptake. In contrast, T2, T3, and T4 showed the lowest Fe^{2+} levels, due to higher plant absorption or complexation into less available forms under near-neutral soil pH conditions (White & Broadley, 2003). The excess Fe^{2+} observed in T5, combined with the low Zn^{2+} concentration in the same treatment, may indicate antagonistic interactions between these two nutrients (Marschner, 2012).

Table 14. Comparison of the soil chemical analysis (at 30 cm soil depth) for micronutrients (mg dm^{-3}) before and at the end of the experiment as a function of different management strategies for Tommy Atkins mango in Ecuador.

	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	B
	mg/dm³				
Before	57.9	19.4	2.4	2.1	0.78
T1	81.2^{b}	48.3^{c}	2.4^{a}	19.9^{d}	0.56^{a}
T2	13.3^{d}	119.9^{a}	0.2^{c}	73.3^{b}	0.63^{a}
T3	19.0^{c}	25.0^{d}	1.7^{b}	22.7^{c}	0.90^{a}
T4	12.3^{d}	111.4^{b}	0.6^{c}	124.5^{a}	0.94^{a}
T5	123.2^{a}	23.2^{d}	2.0^{b}	10.1^{e}	0.43^{b}

Average values followed by the same letter in columns do not differ among them ($p > 0.05$). T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock.

Still in relation to Table 14, Mn levels ranged from 23.2 mg/dm³ (T5) to 119.9 mg/dm³ (T2), with notably high values in T2 and T4. T2 reached the highest absolute concentration (119.9 mg/dm³), falling within the upper limit of the adequate range (4–50 mg/dm³), suggesting potential accumulation through redox processes in moister conditions, a result of controlled irrigation management (based on Kc). Conversely, treatments T3 and T5 showed low Mn^{2+} levels (<25 mg/dm³), indicating that the use of biostimulants may have enhanced Mn^{2+} uptake and translocation, thereby reducing its residual concentration in the soil.

Regarding Cu, all treatments remained within the ideal range (0.3–10 mg/dm³), with higher values observed in T1 and T5 (2.4 and 2.0 mg/dm³, respectively). T2 and T4 showed lower concentrations (0.2 and 0.6 mg/dm³), which may be attributed to higher plant uptake or soil fixation, particularly in soils with elevated organic matter content, as observed in these two treatments.

Zinc was the most responsive micronutrient to the different treatments (Table 14), with T4 exhibiting the highest value (124.5 mg/dm³), far above the adequate range (2–15 mg/dm³), likely due to the presence of chelated forms in its formulation or reduced plant uptake. In contrast, T5 showed the lowest value (10.1 mg/dm³), still within the ideal range, reflecting greater absorption and more efficient use of the nutrient. T2 and T3 maintained intermediate levels (22.7–73.3 mg/dm³), reinforcing the influence of nutritional management on Zn availability in the soil.

Finally, B levels were low in all treatments, except for T4 (0.94 mg/dm³) and T3 (0.90 mg/dm³), which were closest to the ideal range (1–2 mg/dm³). T5 presented the lowest value (0.43 mg/dm³), below the sufficiency threshold, indicating potential deficiency due to the absence of B in the liquid fertilizers applied. These results highlight the need for special attention in managing B, given its high mobility in soil and sensitivity to leaching (Kohli et al., 2023).

The nutritional status of 'Tommy Atkins' mango trees before the experiment and following the treatments is in Table 15.

Foliar N concentrations increased in all treatments compared to the initial condition (11.1 g/kg) but remained below the ideal range (11.9–17.9 g/kg) required for a minimum yield of 34 t/ha. The highest values were observed in treatments T3, T4, and T5 (13.3–13.6 g/kg), which were statistically superior to the control, highlighting the positive effects of biostimulants and liquid fertigation on N metabolism and vegetative growth. Nevertheless, the values indicate that N supply or uptake was not fully optimized, possibly due to root system limitations or N losses via volatilization.

Table 15. Comparison of the leaf nutritional status before and at the end of the experiment as a function of different management strategies for Tommy Atkins mango in Ecuador.

	N	P	K^+	Ca^{2+}	Mg^{2+}	S	B	Cu^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Mo
	g kg^{-1}						mg kg^{-1}					
Before	11.1	0.8	8.5	32.3	1.2	1.3	52.5	6.0	214.8	442.3	23.4	<LQ
T1	12.2[b]	0,8[a]	6.2[a]	32.4[b]	1.2[b]	1.0[a]	109.6[a]	4.7[b]	62.9[b]	360.5[c]	40.9[a]	0.10
T2	12.7[b]	0.9[a]	5.1[b]	32.4[b]	1.8[a]	1.0[a]	73.8[b]	5.3[a]	102.7[a]	433.5[b]	13.0[b]	<LQ
T3	13.3[a]	0.9[a]	5.1[b]	35.1[a]	1.3[b]	1.0[a]	107.7[a]	4.0[b]	68.7[a]	468.2[b]	10.2[c]	<LQ
T4	13.6[a]	0.8[a]	5.9[a]	29.6[c]	1.7[a]	1.0[a]	62.4[b]	4.8[b]	65.8[b]	358.7[c]	14.2[b]	0.14
T5	13.6[a]	0.9[a]	6.5[a]	29.0[c]	1.2[b]	1.0[a]	122.9[a]	8.5[a]	65.1[b]	551.3[a]	13.1[b]	<LQ

Average values followed by the same letter in columns do not differ among them ($p > 0.05$). T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock.

Despite the significant increase in available soil P following the application of different treatments (Table 13), particularly in T2 to T4, foliar P concentrations remained low across all treatments, ranging from 0.8 to 0.9 g/kg—below the recommended sufficiency range (1.5–2.4 g/kg).

This discrepancy between soil availability and foliar accumulation highlights the presence of limitations in P uptake or translocation which were not overcome by the management strategies used. One of the main factors may be the fixation of P into unavailable forms, especially in soils with high Ca levels, as observed in T3 and T2. Under near neutral to slightly alkaline pH conditions ($pH > 6.5$), P tends to precipitate as Ca, Mg, or Fe phosphates, thereby reducing its availability to plants (Marschner, 2012).

Additionally, the limited mobility of P in the soil and within the plant contributes to its poor redistribution to expanding tissues, particularly under conditions of dense root systems and intense competition with other anions. Elevated Zn levels in some treatments may also exert antagonistic effects on P uptake by interfering with alkaline phosphatase activity and membrane transporter function (Alloway, 2008).

Another important consideration is that although P was applied to the soil, its uptake is highly dependent on biological activity in the rhizosphere. Treatments such as T3 and T5, which included amino acids and plant growth regulators, could theoretically enhance root growth and the exudation of organic compounds, thus improving P uptake. However, these practices were insufficient to overcome chemical limitations. This suggests the need for more targeted strategies, including the use of highly soluble phosphate sources, localized applications, or foliar supplementation, especially during key phenological stages such as flowering and fruit filling.

Foliar K^+ concentrations in 'Tommy Atkins' mango trees (Table 15) ranged from 5.1 to 6.5 g/kg, all below the sufficiency range (10.2–15.9 g/kg) established in Table 9. The most striking result was from T1, which had a foliar K^+ level of 6.2 g/kg—similar or even slightly higher than other treatments—despite receiving the highest fertigation K dose (40.39 kg/ha), substantially greater than the other treatments, which ranged from 28.0 kg/ha (T2, T3, T4) to 6.99 kg/ha (Table 1). This outcome suggests inefficient absorption and utilization of K of T1 trees, probably due to a lack of synchronization with phenological demand and the absence of physiological practices to stimulate root function or ion transport activity. Moreover, competition with high Ca^{2+} and Mg^{2+} levels in the soil, especially in T1 and T3, may have restricted K^+ transport through root uptake, as these cations compete for the same absorption channels (Marschner, 2012). Hence, the low foliar K^+ accumulation—even under high soil availability—reinforces that nutrient form, balance, and physiological stimulation are more decisive than the applied quantity alone.

Although all treatments showed foliar Ca^{2+} concentrations within or near the sufficiency range, their responses varied according to the management strategy. T3 had the highest foliar Ca^{2+} level (35.1 g/kg), exceeding the upper limit of the ideal range, likely due to high soil Ca availability (24.2 cmolc/dm^3; Table 13) and the synergistic effect of growth regulators in mobilizing and allocating the nutrient, especially in actively growing tissues. This response may also be attributed to the expansion of the functional root area promoted by biostimulants, which improves the uptake of low-mobility nutrients like Ca (White & Broadley, 2003). In contrast, T4 and T5, despite high soil Ca levels, presented lower foliar concentrations (29.6 and 29.0 g/kg, respectively), suggesting that physiological or competitive factors may have limited effective assimilation. These include competition with elevated Mg^{2+} and K^+ levels, and possible disruptions in xylem transport, as Ca is not redistributed via the phloem and its uptake depends heavily on transpiration flow (Taiz et al., 2017). These findings reinforce the importance of balancing soil availability, cationic interactions, and physiological stimuli to ensure efficient Ca^{2+} nutrition.

Thus, the superior performance of T2, T3, and T4 in maintaining adequate foliar Ca levels—despite the absence of specific Ca fertilization—emphasizes the relevance of integrated strategies combining irrigation adjustment, physiological stimulation, and efficient use of existing soil resources, all of which promote balanced plant nutrition and contribute to the structural quality of vegetative tissues.

Foliar Mg^{2+} concentrations ranged from 1.2 to 1.8 g/kg, with T2 (1.8 g/kg) and T4 (1.7 g/kg) showing the best results—both within the recommended sufficiency range (1.6–2.4 g/kg). These two treatments, along with T3 (1.3 g/kg), received the highest Mg dose via fertigation (6.65 kg/ha), indicating that adequate nutrient supply, combined with effective practices such as Kc-adjusted irrigation and biostimulant use, favored Mg uptake and translocation. The better performance of T2 and T4 compared to T3, despite receiving the same Mg dose, may be due to more favorable ionic balance, pH, and reduced competition with other cations during uptake (Marschner, 2012).

T5, which received the lowest Mg dose (0.99 kg/ha), presented the same foliar level as T1 (1.2 g/kg), which had received 1.66 kg/ha. These values were below the sufficiency threshold, reinforcing that, beyond application rate, competition with Ca^{2+} and K^+, pH conditions, and the liquid form of application may all affect Mg dynamics in the soil. The low performance of T5 also suggests that, even with biostimulants and liquid fertigation, Mg supply was either insufficient or poorly utilized physiologically. Thus, foliar Mg responses were directly associated with application dose and uptake conditions, such as transpiration flow, nutritional balance, and irrigation management.

Sulfur levels were uniform (1.0 g/kg) and consistently below the sufficiency range (1.7–2.1 g/kg) across all treatments, indicating a possible generalized deficiency. It is worth noting that the fruit development stage is not necessarily the phenological phase with the highest S demand, and thus fertilization strategies may not have been focused on this nutrient.

Foliar B concentrations (Table 15) ranged from 62.4 to 122.9 mg/kg, but only treatments T1, T3, and T5 fell within the sufficiency range (101.1–225.1 mg/kg). This is particularly notable as T5 received no B fertilization, unlike T2 and T4, which received 9.14 kg/ha but failed to achieve sufficient foliar levels. This suggests that T5's performance may be related to efficient use of native soil B and the physiological action of biostimulants, which can improve transpiration and root activity, thereby enhancing uptake. The low efficiency of the other treatments, despite high application rates, may be due to leaching, Ca^{2+} antagonism, and suboptimal pH, all of which reduce B availability (Dordas & Brown, 2005).

As shown in Table 15, only treatment T5 (8.5 mg/kg) approached the lower threshold of the sufficiency range for Cu (8.6–12 mg/kg), while all other treatments were clearly deficient. T5's efficiency may be associated with Cu present in liquid formulations or complex biostimulants, which enhance solubility and uptake. Cu is easily complexed by organic matter and precipitated in soils with higher pH, requiring soluble forms and precise synchronization with plant demand to reach sufficient foliar concentrations (Alloway, 2008; Broadley et al., 2012).

For Fe, only T2 reached the lower limit of the sufficiency range (100.8–217.2 mg/kg). Even in treatments with high Fe availability in the soil (e.g., T5), foliar levels remained below the ideal range, probably due to Fe precipitation into insoluble forms (oxides and hydroxides) under near-neutral pH. Moreover, Fe has low phloem mobility, and its uptake is highly dependent on root activity and the reduction of Fe^{3+} to Fe^{2+} in the rhizosphere (Li et al., 2023).

All treatments showed foliar Mn levels within the sufficiency range (345.5–783.9 mg/kg; Rezende et al., 2022), indicating that Mn^{2+} was adequately available in the soil and efficiently absorbed, regardless of the management strategy applied. T5 stood out with the highest foliar Mn content, which may be attributed to improved root system efficiency stimulated by biostimulants and liquid fertigation, both of which enhance micronutrient uptake even under lower soil concentrations. Mn^{2+} uptake is highly dependent on root activity and soil redox conditions, responding well to aerated soils, slightly acidic pH, and elevated metabolic demand as promoted by physiologically active treatments (Millaleo et al., 2010; Rout & Sahoo, 2015).

As for Zn, only T1 (40.9 mg/kg) achieved a foliar level within the sufficiency range (33.3–147.2 mg/kg), despite receiving only 1.02 kg/ha of Zn. Treatments T2 to T4, even with similar application rates, exhibited deficient levels. This suggests poor Zn^{2+} uptake efficiency, maybe due to immobilization caused by excess P and Ca^{2+} in the soil or precipitation into insoluble forms.

Additionally, more vigorous vegetative growth in biostimulated treatments may have caused nutrient dilution in foliar tissues, reducing Zn concentration (Kirkby & Pilbeam, 1984).

For Mo, all treatments were well below the sufficiency range (1.4–2.1 mg/kg), with <LQ values recorded in T2, T3, and T5, and up to 0.14 mg/kg in T4. The absence of Mo fertilization, combined with near-neutral pH and possible competition with sulfate and phosphate, severely limited its uptake. Molybdenum is essential for nitrate reductase activity and N metabolism, and its deficiency may impair plant growth even when N levels are adequate (Kaiser et al., 2005; Shukla et al., 2018). At the end of the phenological cycle, it is relatively common for mango trees to exhibit reduced Mo levels due to the intensified N metabolism, which can negatively affect postharvest fruit quality.

As shown in Figures 7A and 7B, the superior performance of treatment T2 in both yield-related variables is directly associated with the synchronization of fertilization with the plant's phenological demand and irrigation management based on the crop coefficient (Kc). This strategy enabled nutrient supply at critical developmental stages, optimizing assimilation, fruit set, and filling. As demonstrated by Torres (2019) and Cavalcante et al. (2024), phenology-driven and balanced fertilization is essential to maximize fruit retention and biomass accumulation, particularly in long-cycle cultivars such as 'Tommy Atkins'. In this context, as noted by Calvo et al. (2014) and Rouphael & Colla (2020), biostimulants such as amino acids and growth regulators can enhance plant physiology, but their effectiveness depends on a solid nutritional base and favorable water and environmental conditions.

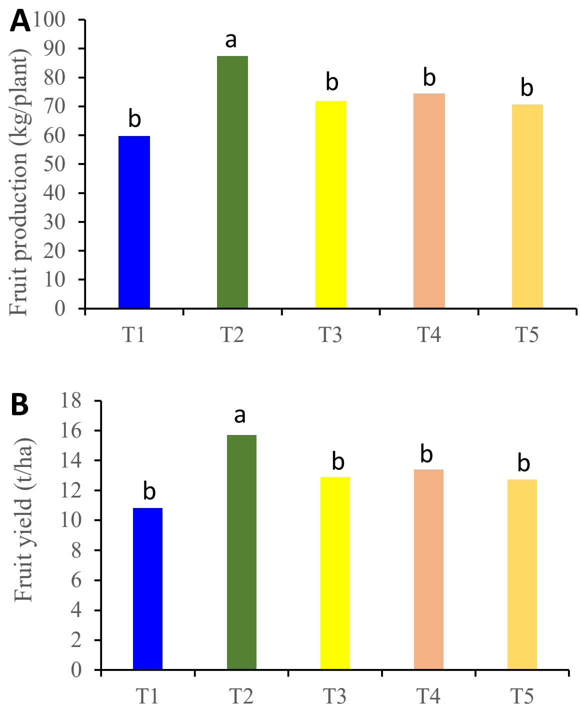
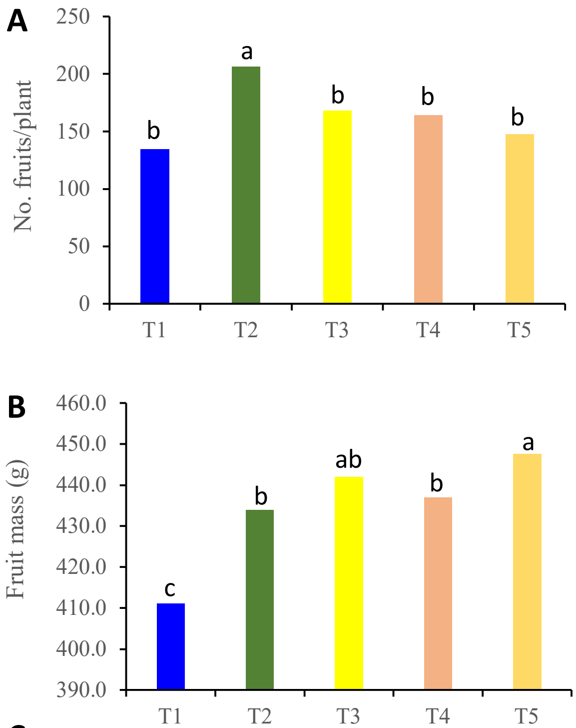


Figure 7: Fruit production (A) and fruit yield (B) of 'Tommy Atkins' as a function of different management strategies in Guayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

Additionally, the lower productive performance of treatment T1 (Figure 7) reinforces the limitations of conventional management, which lacks nutritional and irrigation adjustments, resulting in reduced physiological and productive efficiency of the plant. Furthermore, the lack of superiority observed in T5—despite the combination of biostimulants, liquid fertilizers, and sun protection—may be attributed to interference with photosynthesis or hormonal imbalance, as reported by Silva et al. (2022a), particularly under high radiation conditions.

Treatment T2 (Figure 8A) recorded the highest average number of fruits per plant (approximately 210 fruits/plant), being statistically superior to the other treatments ($p < 0.05$). This outcome can be attributed to the efficiency of nutritional and irrigation management synchronized with the phenological cycle, which favored flowering, fruit set, and retention. Treatments T1, T3, T4, and T5 showed similar values, ranging from 140 to 170 fruits/plant, with no significant differences among them.



C

	Number of fruits per plant	Fruit mass
T1 => **T2**	**+53,6%**	**+5,5%**
T1 => **T3**	**+25,0%**	**+7,5%**
T1 => **T4**	**+22,0%**	**+6,3%**
T1 => **T5**	**+9,8%**	**+8,9%**

Figure 8: Number of fruits per plant (A), fruit mass (B) and fluctuations of such variables between the treatments studied of 'Tommy Atkins' as a function of different management strategies in Guayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock. Bars with the same letter do not differ among them ($p > 0.05$).

Regarding average fruit mass, T5 recorded the highest average value (~450 g), significantly greater than both T1 and T2, while T3 presented an intermediate value, with no statistical difference compared to T5 and T2 (Figure 8B).

The control treatment (T1) showed the lowest values for both variables, highlighting the limitations of traditional management without adjustments to fertilization and irrigation (Figure 8B). This treatment resulted in lower fruit set, lighter fruits, and reduced productive efficiency, probably due to nutritional deficiencies—particularly of P, K, and micronutrients—as previously discussed in the foliar analysis.

The percentage comparison between treatments (Figure 8C) reveals distinct physiological response patterns to the adopted management strategies. Treatment T2 exhibited the greatest relative increase in fruit number (+53.6%), with a moderate improvement in average fruit mass (+5.5%). This indicates that nutrient applications aligned with plant demand, combined with Kc-based irrigation, strongly promoted fruit set and retention without significantly compromising fruit filling. Such strategies ensure adequate nutrient and water supply during critical fruiting stages, preventing flower abortion and supporting early cell division (Silva et al., 2022b).

In contrast, treatments T3 and T4, which incorporated biostimulants, demonstrated intermediate gains in fruit number (+25.0% and +22.0%, respectively) and slightly greater increases in fruit mass (+7.5% and +6.3%). This suggests that bio-inputs may have contributed to improved nutrient use efficiency, stimulation of hormonal pathways (e.g., auxins and cytokinin), and expansion of the functional leaf area, thereby supporting both vegetative growth and fruit filling (Calvo et al., 2014; Rouphael & Colla, 2020).

Treatment T5 (Figure 8C), which combined liquid fertilizers, biostimulants, and sun protection, showed the highest relative increase in average fruit mass (+8.9%), but only a modest gain in fruit number (+9.8%). This reflects a typical compensatory effect, in which a reduced fruit load leads to lower competition for assimilates and greater individual fruit growth. This response is advantageous in production systems focused on fruit quality and size uniformity, as demanded by international markets (Taiz et al., 2017). The use of liquid formulations may also have enhanced foliar nutrient absorption and contributed to more uniform mineral nutrition.

Although treatment T5 produced larger-sized fruits (Figure 9), its total number of fruits per plant was lower than that of T3, as shown previously (Figure 8A). This difference indicates that T5 experienced a reduced fruit load, which decreased competition among remaining fruits and promoted their expansion and filling. In contrast, T3, with a higher number of fruits per plant, experienced greater intra-plant competition, potentially limiting the development of larger calibers even under biostimulant application. These results are consistent with the physiological principle that the balance between source and sink is a key determinant of final fruit size, and that fruit thinning—whether natural or induced—can be an effective strategy to concentrate assimilates in commercially valuable fruits (Taiz et al., 2017; Bodh & Verma, 2025).

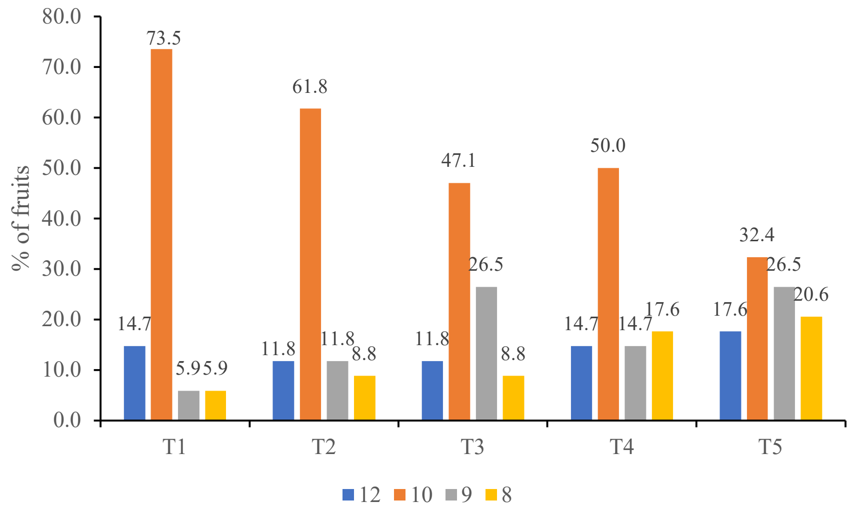


Figure 9: Distribution of fruit caliper classes of 'Tommy Atkins' as a function of different management strategies in Gayaquil, Ecuador. T1 - Control (traditional farm management, without alterations); T2 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc; T3 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to Kc + amino acids + phytoregulator; T4 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar + irrigation according to K) + amino acids + phytoregulator + sunblock; T5 - Fertilization recommendations according to nutrient plant demand in quantity and following a phenological calendar using liquid fertilizers + irrigation according to Kc + amino acids + phytoregulator + sunblock.

Based on the observed variations, it can be concluded that each management strategy distinctly influenced the components of mango production. Treatment T2 stood out for its pronounced effect on increasing fruit number, while T5 promoted the highest individual fruit mass. These results demonstrate that adopting nutrient management practices aligned with the crop's phenological stages is effective for maximizing fruit set and total yield, whereas the use of biostimulants and liquid fertilizers enhances fruit filling and quality. Therefore, the choice of the optimal management strategy should be guided by the specific production goals - whether focused on quantity or quality - and the target market profile.

3.3 Third phase – Identification and recommendation of the best management strategy

Based on the integrated results from the diagnostic phase, experimental trials, and the assessment of nutritional, productive, and fruit-quality effects in 'Tommy Atkins' and 'Ataulfo' mango orchards in Ecuador, it is possible to identify and recommend the most suitable management strategies to maximize yield and fruit quality, including

- ✓ The root system of the plants is not well-developed and is believed to be insufficient for absorbing the soil solution at the rate required by the plant for proper fruit growth.

- ✓ There is a need for the use of technologies to mitigate oxidative stress, as stress is present during certain parts of the year, particularly when light intensity is more aggressive, and temperatures are extremely high.
- ✓ The irrigation system, with only one micro-sprinkler per plant, partially meets the crop's water demand, as although there are no mechanical impediments, only part of the root system is supplied with water by the system. This situation limits the plants' ability to provide optimal conditions for proper fruit development.
- ✓ Fertilization recommendations require adjustments not only in the quantities applied but also in the timing and method of fertilizer distribution throughout fruit development, as evidenced by the results generated in this study.
- ✓ The current orchard conditions and management practices are not sufficient for the adequate development of fruits aimed at achieving larger calibers. Adjustments in the production system are necessary.

Below are specific recommendations for each mango cultivar evaluated in the project.

3.3.1 Ataulfo

In general, T2 (fertilization according to crop nutritional demand + irrigation adjusted based on crop coefficient, Kc) stood out by promoting the highest number of fruits per plant (~147 fruits), as well as the highest yield per plant and productivity per hectare. This performance is attributed to the balanced nutrient supply during critical phenological stages, particularly flowering and fruit set, and to proper water management, which enhances fruit retention (Rezende et al., 2023). However, the higher fruit load resulted in smaller fruit sizes, with 61.8% of fruits classified in size category 10—associated with lower commercial value.

In contrast, T5 (liquid fertilization + amino acids + plant growth regulators + sun protectant) produced fewer fruits per plant compared to T3 and T2 but resulted in the highest fruit sizes, with 38.2% in category 8 and 26.5% in category 9. It was the only treatment with a dominant distribution in the most commercially valuable fruit size categories, indicating a physiological compensatory effect in which reduced assimilate competition favors fruit filling. The localized application of liquid nutrients, combined with biostimulants, may have enhanced the absorption and transport of K, Ca, and B—nutrients essential for fruit expansion and skin quality (Calvo et al., 2014; Taiz et al., 2017; Tenreiro et al., 2023).

From a nutritional point of view, ‘Ataulfo’ presented adequate foliar levels of macro- and micronutrients in most treatments, except for P, K, S, and Mo, which remained below sufficiency thresholds despite soil application. Phosphorus limitation was particularly evident across all treatments, probably due to poor availability caused by fixation in insoluble forms in soils with high Ca^{2+} levels and near-neutral pH. Boron reached adequate levels only in treatments that included complexed sources (such as Biotek™), emphasizing the importance of nutrient chemical form and root activity in the absorption process (Bassirirad, 2000).

Treatments T3 and T4 showed intermediate performance in both fruit number and size, representing promising strategies for production systems aiming to balance yield and quality. In contrast, the control treatment (T1) displayed low productivity and an unfavorable fruit size distribution, reaffirming the limitations of conventional management without technical intervention.

3.3.2 Tommy Atkins

The results obtained throughout the experiment demonstrate that the management strategies had distinct effects on nutritional status, productive performance, and fruit mass and size. Treatment T2, based on fertilization according to plant nutritional demand and irrigation adjusted to the crop coefficient (Kc), stood out in several parameters: it resulted in the highest foliar concentrations of Fe and Mg, the greatest yield per plant and per hectare, and the highest number of fruits per plant (+53.6% compared to the control). However, the fruit size distribution was unfavorable, with more than 60% of fruits concentrated in size category 10—associated with lower commercial value. This result reflects a physiological dilution effect, whereby increased fruit load compromises fruit filling and reduces average fruit size.

In contrast, T5, which combined liquid fertilizers, amino acids, plant growth regulators, and sun protectant, produced the highest average fruit mass (~450 g), as well as a more balanced size distribution, with 26.5% of fruits in category 9 and 20.6% in category 8—both highly valued in export markets. However, the total number of fruits was lower than in T3, suggesting that this strategy favored fruit quality over quantity.

Soil and leaf analyses reinforce that nutrient absorption efficiency depends not only on the amount applied but also on the form, timing, and interaction with water management. For instance, despite high B applications in T2, T3, and T4, only T5 reached sufficient foliar levels—without direct B application—highlighting the importance of soluble nutrient forms and root system health in effective mineral nutrition. Furthermore, all treatments exhibited deficiencies in P and Mo, underscoring the need for specific adjustments in these sources, whether through localized fertigation or foliar application. Additional efforts should be directed toward strengthening the root system, which, based on visual assessment, showed suboptimal conditions for maximizing the benefits of the applied fertilizers and technologies.

Thus, the findings indicate that T2 is recommended when the goal is to maximize productivity in kg/ha, making it ideal for markets that accept medium-sized fruit. Conversely, T5 is the best alternative for producers targeting high-value markets with strict size requirements, such as exports to Europe or the United States, even if it results in a lower number of fruits per plant. T3 offers a balanced approach, with simultaneous gains in both fruit number and size, and appears promising for systems seeking equilibrium between yield and quality.

It is also important to note that liquid fertilization is not universally applicable, especially in orchards where the soil lacks minimum fertility conditions to support the crop's demands. The use of liquid fertilizers as applied in T5 depends on a baseline level of soil quality - particularly in terms of organic matter, pH, P availability, and cation exchange capacity (both in quantity and cationic balance) - which, in this study, was at least minimally met.

4. Final recommendations

Based on the conclusions from all phases of the project and the comprehensive analysis of the data generated throughout the implementation period, the following recommendations are proposed:

- ✓ It is recommended to install a second microsprinkler per plant to improve the uniformity of irrigation water distribution.
- ✓ Adopt strategies to stimulate root system development, such as the use of biofertilizers - especially after pruning, during flowering, and in the initial stages of fruit development. The installation of rhizotrons in the orchard is also advised to enable continuous monitoring of root growth.
- ✓ Implement technologies aimed at mitigating abiotic stress, with a focus on stimulating flowering and supporting fruit growth, in accordance with the management practices described in the appendices.
- ✓ Considering that fertilization adjustments targeting fruit growth allowed plants with high fruit loads to also produce heavier fruits, it is recommended to conduct pre-planting soil analysis and regular foliar diagnostics to support the formulation of nutrient management strategies specifically aimed at fruit filling.

The continued application of these practices over successive production cycles is expected to positively impact fruit development, particularly by inducing structural improvements in orchard systems. Therefore, maintaining these practices is essential to consistently enhance fruit size in mango orchards in Ecuador.

Based on the results from the second phase of the project, the following technical recommendations are proposed for both cultivars evaluated:

- ✓ For maximum productivity: apply Treatment T2 — fertilization according to phenological nutritional demand + irrigation based on the crop coefficient (Kc).
- ✓ For larger fruit size and improved commercial grade: apply Treatment T5 — liquid fertilization + biostimulants + sun protectant.
- ✓ For systems aiming at a balance between yield and fruit size: apply Treatment T3 — solid fertilization + amino acids + plant growth regulators.

It is important to emphasize, however, that liquid fertilizers, although more efficient than conventional ones (Asghar et al., 2022; Divya et al., 2022), require soils with minimum fertility conditions to meet crop demands. This includes adequate levels of organic matter, pH, P, and cation exchange capacity—all of which were addressed in the present study.

Thus, a promising alternative consists of using the T2 protocol as a technical baseline, with adaptations toward T5 depending on the orchard's commercial objectives (volume vs. quality). This approach promotes efficient, sustainable, and economically viable nutritional and physiological management, and—having been validated experimentally—emerges as an excellent strategy for mango production in Ecuador under future practical applications.

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6. Declaration of interest statement

The authors report there are no competing interests to declare.

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8. Appendix

Below are the appendixes 1, 2, 3 and 4 of this report.

Appendix 1: Fertilizing planning performed for 'Ataulfo' mangoes for treatments T2, T3, T4 and T5.

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Ataulfo)																
Investigador:	Dr. Ítalo Cavalcante		Parcero:	Ing. Roni Oliveira		Área:			ATAULFO - ROJO T2							
Total de plantas:	160		Espaçamento:													
Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													Total
			Florada	Enchimento de frutos											Colheita	
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,161	25,8	3,68	3,68	3,68	3,68	3,68	3,68	3,68	0,00	0,00	0,00	0,00	0,00	0,00	25,79
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,186	29,8	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	0,00	0,00	0,00	29,76
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,196	31,4	2,82	2,82	2,82	2,82	2,82	2,82	2,82	3,14	3,14	3,14	2,20	0,00	0,00	31,36
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,261	41,8	2,51	2,51	2,51	2,51	2,51	4,18	5,01	5,01	5,01	5,01	5,01	0,00	0,00	41,76
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,054	8,6	0,52	1,04	1,04	1,04	1,04	1,04	0,69	0,69	0,69	0,52	0,35	0,00	0,00	8,64
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,216	34,6	4,15	4,15	4,15	2,76	2,76	2,76	2,76	2,76	2,76	2,76	2,76	0,00	0,00	34,56
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,171	27,4	1,64	1,92	1,92	2,19	2,19	2,74	2,74	3,28	3,28	2,74	2,74	0,00	0,00	27,36
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,078	12,5	1,12	1,12	1,12	1,12	1,12	1,25	1,25	1,25	1,12	1,00	1,00	0,00	0,00	12,48
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Ataulfo)															
Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		ATAULFO - AMARILLO T3									
Total de plantas:	160	Espaçamento:		Mango frutvasf											
			Semanas												
Fertilizante	kg/planta fertilizante	kg total fertilizante	Florada	Enchimento de frutos										Colheita	Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,161	25,8	3,68	3,68	3,68	3,68	3,68	3,68	3,68	0,00	0,00	0,00	0,00	0,00	0,00	25,79
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,186	29,8	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	0,00	0,00	0,00	29,76
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,196	31,4	2,82	2,82	2,82	2,82	2,82	2,82	2,82	3,14	3,14	3,14	2,20	0,00	0,00	31,36
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,261	41,8	2,51	2,51	2,51	2,51	2,51	4,18	5,01	5,01	5,01	5,01	5,01	0,00	0,00	41,76
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,054	8,6	0,52	1,04	1,04	1,04	1,04	1,04	0,69	0,69	0,69	0,52	0,35	0,00	0,00	8,64
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,216	34,6	4,15	4,15	4,15	2,76	2,76	2,76	2,76	2,76	2,76	2,76	2,76	0,00	0,00	34,56
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,171	27,4	1,64	1,92	1,92	2,19	2,19	2,74	2,74	3,28	3,28	2,74	2,74	0,00	0,00	27,36
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,078	12,5	1,12	1,12	1,12	1,12	1,12	1,25	1,25	1,25	1,12	1,00	1,00	0,00	0,00	12,48
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Ataulfo)

Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		ATAULFO - BLANCO T4	
Total de plantas:	160	Espaçamento:					

Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													Total
			Florada	Enchimento de frutos											Colheita	
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,161	25,8	3,68	3,68	3,68	3,68	3,68	3,68	3,68	0,00	0,00	0,00	0,00	0,00	0,00	25,79
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,186	29,8	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	2,98	0,00	0,00	0,00	29,76
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,196	31,4	2,82	2,82	2,82	2,82	2,82	2,82	2,82	3,14	3,14	3,14	2,20	0,00	0,00	31,36
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,261	41,8	2,51	2,51	2,51	2,51	2,51	4,18	5,01	5,01	5,01	5,01	5,01	0,00	0,00	41,76
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,054	8,6	0,52	1,04	1,04	1,04	1,04	1,04	0,69	0,69	0,69	0,52	0,35	0,00	0,00	8,64
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,216	34,6	4,15	4,15	4,15	2,76	2,76	2,76	2,76	2,76	2,76	2,76	2,76	0,00	0,00	34,56
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,171	27,4	1,64	1,92	1,92	2,19	2,19	2,74	2,74	3,28	3,28	2,74	2,74	0,00	0,00	27,36
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,078	12,5	1,12	1,12	1,12	1,12	1,12	1,25	1,25	1,25	1,12	1,00	1,00	0,00	0,00	12,48
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Ataulfo)

Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		ATAULFO - AZUL T5	
Total de plantas:	160	Espaçamento:					

Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													
			Florada	Enchimento de frutos											Colheita	Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (Nitrogel Z)	0,047	7,5	1,08	1,08	1,08	1,08	1,08	1,08	1,08	0,00	0,00	0,00	0,00	0,00	0,00	7,53
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (H28)	0,129	20,6	2,06	2,06	2,06	2,06	2,06	2,06	2,06	2,06	2,06	2,06	0,00	0,00	0,00	20,64
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (H2)	0,248	39,7	3,57	3,57	3,57	3,57	3,57	3,57	3,57	3,97	3,97	3,97	2,78	0,00	0,00	39,68
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca + Mg (Nitrato de cálcio +	0,059	9,4	9,44	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	9,44
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Micronutrientes (Micron)	0,024	3,8	0,23	0,23	0,23	0,23	0,23	0,38	0,46	0,46	0,46	0,46	0,46	0,00	0,00	3,84
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%

Appendix 2: Fertilizing planning performed for ‘Tommy Atkins’ mangoes for treatments T2, T3, T4 and T5.

Proyecto: Diagnostico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Tommy)						
Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		TOMMY ROJO T2
Total de plantas:	384	Espaçamento:				

Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													Total
			Florada	Enchimento de frutos											Colheita	
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,324	124,4	17,79	17,79	17,79	17,79	17,79	17,79	17,79	0,00	0,00	0,00	0,00	0,00	0,00	124,54
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,382	146,7	14,67	14,67	14,67	14,67	14,67	14,67	14,67	14,67	14,67	14,67	0,00	0,00	0,00	146,69
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,369	141,7	12,75	12,75	12,75	12,75	12,75	12,75	12,75	14,17	14,17	14,17	9,92	0,00	0,00	141,696
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,468	179,7	10,78	10,78	10,78	10,78	10,78	17,97	21,57	21,57	21,57	21,57	21,57	0,00	0,00	179,712
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,035	13,4	0,81	1,61	1,61	1,61	1,61	1,61	1,08	1,08	1,08	0,81	0,54	0,00	0,00	13,44
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,340	130,6	15,67	15,67	15,67	10,44	10,44	10,44	10,44	10,44	10,44	10,44	10,44	0,00	0,00	130,56
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,218	83,7	5,02	5,86	5,86	6,70	6,70	8,37	8,37	10,05	10,05	8,37	8,37	0,00	0,00	83,712
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,035	13,4	1,21	1,21	1,21	1,21	1,21	1,34	1,34	1,34	1,21	1,08	1,08	0,00	0,00	13,44
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Tommy)

Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		TOMMY - AMARILLO T3	
Total de plantas:	354	Espaçamento:					

Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													Total
			Florada	Enchimento de frutos											Colheita	
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,324	114,7	16,40	16,40	16,40	16,40	16,40	16,40	16,40	0,00	0,00	0,00	0,00	0,00	0,00	114,81
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,382	135,2	13,52	13,52	13,52	13,52	13,52	13,52	13,52	13,52	13,52	13,52	0,00	0,00	0,00	135,23
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,369	130,6	11,76	11,76	11,76	11,76	11,76	11,76	11,76	13,06	13,06	13,06	9,14	0,00	0,00	130,626
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,468	165,7	9,94	9,94	9,94	9,94	9,94	16,57	19,88	19,88	19,88	19,88	19,88	0,00	0,00	165,672
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,035	12,4	0,74	1,49	1,49	1,49	1,49	1,49	0,99	0,99	0,99	0,74	0,50	0,00	0,00	12,39
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,340	120,4	14,44	14,44	14,44	9,63	9,63	9,63	9,63	9,63	9,63	9,63	9,63	0,00	0,00	120,36
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,218	77,2	4,63	5,40	5,40	6,17	6,17	7,72	7,72	9,26	9,26	7,72	7,72	0,00	0,00	77,172
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,035	12,4	1,12	1,12	1,12	1,12	1,12	1,24	1,24	1,24	1,12	0,99	0,99	0,00	0,00	12,39
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Tommy)

Investigador:	Dr. Ítalo Cavalcante	Parcero:	Ing. Roni Oliveira	Área:		TOMMY - BLANCO T4	
Total de plantas:	176	Espaçamento:					

Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													
			Florada	Enchimento de frutos											Colheita	Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (UREIA)	0,324	57,0	8,15	8,15	8,15	8,15	8,15	8,15	8,15	0,00	0,00	0,00	0,00	0,00	0,00	57,08
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (MAP)	0,382	67,2	6,72	6,72	6,72	6,72	6,72	6,72	6,72	6,72	6,72	6,72	0,00	0,00	0,00	67,23
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (Sulf. K)	0,369	64,9	5,84	5,84	5,84	5,84	5,84	5,84	5,84	6,49	6,49	6,49	4,55	0,00	0,00	64,944
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca	0,000	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Mg (Sulf. Mg)	0,468	82,4	4,94	4,94	4,94	4,94	4,94	8,24	9,88	9,88	9,88	9,88	9,88	0,00	0,00	82,368
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%
Zn (Sulf. Zn)	0,035	6,2	0,37	0,74	0,74	0,74	0,74	0,74	0,49	0,49	0,49	0,37	0,25	0,00	0,00	6,16
			6,00%	12,0%	12,0%	12,0%	12,0%	12,0%	8,00%	8,00%	8,00%	6,00%	4,00%	0,00%	0,00%	100%
B (Acd. Bórico)	0,340	59,8	7,18	7,18	7,18	4,79	4,79	4,79	4,79	4,79	4,79	4,79	4,79	0,00	0,00	59,84
			12,00%	12,0%	12,0%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	8,00%	0,00%	0,00%	100%
Mn (Sulf. Mn)	0,218	38,4	2,30	2,69	2,69	3,07	3,07	3,84	3,84	4,60	4,60	3,84	3,84	0,00	0,00	38,368
			6,00%	7,00%	7,00%	8,00%	8,00%	10,0%	10,0%	12,0%	12,0%	10,0%	10,0%	0,00%	0,00%	100%
Fe (Sulf. Fe)	0,035	6,2	0,55	0,55	0,55	0,55	0,55	0,62	0,62	0,62	0,55	0,49	0,49	0,00	0,00	6,16
			9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	9,00%	8,00%	8,00%	0,00%	0,00%	100%

Proyecto: Diagnóstico y estrategias de manejo de campo para mejorar el tamaño y la uniformidad del fruto del mango (Tommy)																
Investigador:	Dr. Ítalo Cavalcante		Parcero:	Ing. Roni Oliveira		Área:			TOMMY - AZUL T5							
Total de plantas:	444	Espaçamento:														
Fertilizante	kg/planta fertilizante	kg total fertilizante	Semanas													Total
			Florada	Enchimento de frutos											Colheita	
			1	2	3	4	5	6	7	8	9	10	11	12	13	
N (Nitrogel Z)	0,059	26,2	3,75	3,75	3,75	3,75	3,75	3,75	3,75	0,00	0,00	0,00	0,00	0,00	0,00	26,22
			14,30%	14,3%	14,3%	14,3%	14,3%	14,3%	14,3%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
P (H28)	0,165	73,3	7,33	7,33	7,33	7,33	7,33	7,33	7,33	7,33	7,33	7,33	0,00	0,00	0,00	73,26
			10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	0,00%	0,00%	0,00%	100%
K (H2)	0,316	140,3	12,63	12,63	12,63	12,63	12,63	12,63	12,63	14,03	14,03	14,03	9,82	0,00	0,00	140,304
			9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	9,00%	10,0%	10,0%	10,0%	7,00%	0,00%	0,00%	100%
Ca + Mg (Nitrato de cálcio +	0,076	33,7	33,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	33,74
			100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
Micronutrientes (Micron)	0,030	13,3	0,80	0,80	0,80	0,80	0,80	1,33	1,60	1,60	1,60	1,60	1,60	0,00	0,00	13,32
			6,00%	6,00%	6,00%	6,00%	6,00%	10,0%	12,0%	12,0%	12,0%	12,0%	12,0%	0,00%	0,00%	100%

Appendix 3: Irrigation management planning during the second phase of the project (experimental phase)

PLANILHA PARA MANEJO DA IRRIGAÇÃO
BASEADO NO BALANÇO HÍDRICO DA CULTURA
Autor: José Sebastião Costa de Sousa
Doutor em Engenharia Agrícola - Irrigação e Drenagem
Prof. do Campus Petrolina Zona Rural, IFSERTÃO-PE

Outras planilhas: *Clique aqui para acessa o manual do usuário*
Clique aqui para consultar tabelas de kc e duração das fases fenológicas
Clique aqui para acessa planilha de cálculo de kc (fazer após consultar ta
Clique aqui para acessar planilha p/determinação da Eficiência do sistem
Clique aqui para acessar planilha p/determinação da percentagem de solo molhado

∑ Pe (mm) =	0,00
∑ LLI (mm) =	67,445
∑ LBI (mm) =	66,452
TF (h:min) =	0:00

Tommy Atkins
90 a 95 from flowering to harvest

Floração plena 15/07/2024
Previsão de colheita 14 a 18/10/2024

Número de casas decimais pretendidos para os arredondamentos → 3 Escolha o sistema aqui

DADOS DO SOLO E DA ÁGUA DE IRRIGAÇÃO						PLANTIO OU EMISSOR			DADOS DO DO SISTEMA			Localizado (Gotej., Micro.,	
Cc	13,00	% peso	Uini 1º dia	10,00	% peso	EP ou EE	9,00	m	Vazão	36,00	L/h	AUP (m2)	63,00
PMP	6,50	% peso	CEa	0,00	dS/m	EF1 ou EF	7,00	m	Eficiência	75,00	%	KL	0,26
Dg	2,20	g/cm3	CEes	6,50	dS/m	EF2		m	Pm	6,80	%	Eficiência x N	0,75

Nº -	Data -	Pe mm	ETo mm	kc adm.	f adm.	Zr cm	CTA mm	CRA mm	U crit mm	ETc mm	Ks -	ETR mm	U ini. mm	U intr. mm	LLI mm	U fin. mm	LBI mm	Volume L	TF h	TF h:min
1	05/08/24		5,42	0,700	0,30	50,00	4,86	1,46	3,40	0,99	0,73	0,72	2,62	1,90	2,96	4,86	3,95	248,98	6,92	6:55
2	06/08/24		5,39	0,700	0,30	50,00	4,86	1,46	3,40	0,99	1,00	0,99	4,86	3,88	0,00	3,88	0,00	0,00	0,00	0:00
3	07/08/24		5,16	0,700	0,30	50,00	4,86	1,46	3,40	0,94	0,90	0,85	3,88	3,03	1,83	4,86	2,44	153,78	4,27	4:16
4	08/08/24		5,23	0,700	0,30	50,00	4,86	1,46	3,40	0,96	1,00	0,96	4,86	3,91	0,00	3,91	0,00	0,00	0,00	0:00
5	09/08/24		5,14	0,700	0,30	50,00	4,86	1,46	3,40	0,94	0,90	0,85	3,91	3,06	1,80	4,86	2,40	151,20	4,20	4:12
6	10/08/24		5,44	0,700	0,30	50,00	4,86	1,46	3,40	1,00	1,00	1,00	4,86	3,87	0,00	3,87	0,00	0,00	0,00	0:00
7	11/08/24		5,19	0,700	0,30	50,00	4,86	1,46	3,40	0,95	0,90	0,85	3,87	3,02	1,84	4,86	2,46	154,79	4,30	4:18
8	12/08/24		5,38	0,700	0,30	50,00	4,86	1,46	3,40	0,98	1,00	0,98	4,86	3,88	0,00	3,88	0,00	0,00	0,00	0:00
9	13/08/24		5,55	0,700	0,30	50,00	4,86	1,46	3,40	1,01	0,90	0,91	3,88	2,97	1,89	4,86	2,52	158,82	4,41	4:25
10	14/08/24		5,47	0,700	0,30	50,00	4,86	1,46	3,40	1,00	1,00	1,00	4,86	3,86	0,00	3,86	0,00	0,00	0,00	0:00
11	15/08/24		5,37	0,700	0,30	50,00	4,86	1,46	3,40	0,98	0,89	0,88	3,86	2,99	1,88	4,86	2,50	157,56	4,38	4:23
12	16/08/24		5,79	0,700	0,30	50,00	4,86	1,46	3,40	1,06	1,00	1,06	4,86	3,81	0,00	3,81	0,00	0,00	0,00	0:00
13	17/08/24		5,60	0,700	0,30	50,00	4,86	1,46	3,40	1,02	0,89	0,91	3,81	2,90	1,97	4,86	2,62	165,06	4,59	4:35
14	18/08/24		5,18	0,700	0,30	50,00	4,86	1,46	3,40	0,95	1,00	0,95	4,86	3,92	0,00	3,92	0,00	0,00	0,00	0:00
15	19/08/24		5,43	0,700	0,30	50,00	4,86	1,46	3,40	0,99	0,90	0,89	3,92	3,02	1,84	4,86	2,45	154,48	4,29	4:17
16	20/08/24		5,43	0,700	0,30	50,00	4,86	1,46	3,40	0,99	1,00	0,99	4,86	3,87	0,00	3,87	0,00	0,00	0,00	0:00
17	21/08/24		5,01	0,700	0,30	50,00	4,86	1,46	3,40	0,92	0,90	0,82	3,87	3,05	1,81	4,86	2,42	152,15	4,23	4:14
18	22/08/24		4,97	0,700	0,30	50,00	4,86	1,46	3,40	0,91	1,00	0,91	4,86	3,95	0,00	3,95	0,00	0,00	0,00	0:00
19	23/08/24		5,25	0,700	0,30	50,00	4,86	1,46	3,40	0,96	0,91	0,87	3,95	3,08	1,78	4,86	2,37	149,37	4,15	4:09
20	24/08/24		5,19	0,700	0,30	50,00	4,86	1,46	3,40	0,95	1,00	0,95	4,86	3,91	0,00	3,91	0,00	0,00	0,00	0:00
21	25/08/24		5,23	0,700	0,30	50,00	4,86	1,46	3,40	0,96	0,90	0,86	3,91	3,05	1,81	4,86	2,41	151,96	4,22	4:13
22	26/08/24		5,38	0,700	0,30	50,00	4,86	1,46	3,40	0,98	1,00	0,98	4,86	3,88	0,00	3,88	0,00	0,00	0,00	0:00
23	27/08/24		5,24	0,700	0,30	50,00	4,86	1,46	3,40	0,96	0,90	0,86	3,88	3,02	1,84	4,86	2,46	154,67	4,30	4:18
24	28/08/24		5,26	0,700	0,30	50,00	4,86	1,46	3,40	0,96	1,00	0,96	4,86	3,90	0,00	3,90	0,00	0,00	0,00	0:00
25	29/08/24		5,54	0,700	0,30	50,00	4,86	1,46	3,40	1,01	0,90	0,91	3,90	2,99	1,87	4,86	2,50	157,19	4,37	4:22
26	30/08/24		5,10	0,700	0,30	50,00	4,86	1,46	3,40	0,93	1,00	0,93	4,86	3,93	0,00	3,93	0,00	0,00	0,00	0:00
27	31/08/24		5,53	0,700	0,30	50,00	4,86	1,46	3,40	1,01	0,90	0,91	3,93	3,02	1,84	4,86	2,46	154,92	4,30	4:18

28	01/09/24		4,96	0,900	0,30	50,00	4,86	1,46	3,40	1,17	1,00	1,17	4,86	3,70	0.00	3,70	0.00	0.00	0.00	0.00
29	02/09/24		4,86	0,900	0,30	50,00	4,86	1,46	3,40	1,14	0,88	1,00	3,70	2,70	2,16	4,86	2,89	181,76	5,05	5:03
30	03/09/24		4,68	0,900	0,30	50,00	4,86	1,46	3,40	1,10	1,00	1,10	4,86	3,76	0.00	3,76	0.00	0.00	0.00	0.00
31	04/09/24		5,07	0,900	0,30	50,00	4,86	1,46	3,40	1,19	0,88	1,05	3,76	2,71	2,15	4,86	2,87	180,62	5,02	5:01
32	05/09/24		4,89	0,900	0,30	50,00	4,86	1,46	3,40	1,15	1,00	1,15	4,86	3,71	0.00	3,71	0.00	0.00	0.00	0.00
33	06/09/24		5,01	0,900	0,30	50,00	4,86	1,46	3,40	1,18	0,88	1,03	3,71	2,68	2,18	4,86	2,91	183,14	5,09	5:05
34	07/09/24		4,75	0,900	0,30	50,00	4,86	1,46	3,40	1,12	1,00	1,12	4,86	3,75	0.00	3,75	0.00	0.00	0.00	0.00
35	08/09/24		4,82	0,900	0,30	50,00	4,86	1,46	3,40	1,13	0,88	1,00	3,75	2,75	2,11	4,86	2,82	177,41	4,93	4:56
36	09/09/24		4,74	0,900	0,30	50,00	4,86	1,46	3,40	1,11	1,00	1,11	4,86	3,75	0.00	3,75	0.00	0.00	0.00	0.00
37	10/09/24		5,01	0,900	0,30	50,00	4,86	1,46	3,40	1,18	0,88	1,04	3,75	2,71	2,15	4,86	2,87	180,68	5,02	5:01
38	11/09/24		4,90	0,900	0,30	50,00	4,86	1,46	3,40	1,15	1,00	1,15	4,86	3,71	0.00	3,71	0.00	0.00	0.00	0.00
39	12/09/24		5,11	0,900	0,30	50,00	4,86	1,46	3,40	1,20	0,88	1,05	3,71	2,66	2,20	4,86	2,94	184,97	5,14	5:08
40	13/09/24		4,83	0,900	0,30	50,00	4,86	1,46	3,40	1,13	1,00	1,13	4,86	3,73	0.00	3,73	0.00	0.00	0.00	0.00
41	14/09/24		4,97	0,900	0,30	50,00	4,86	1,46	3,40	1,17	0,88	1,03	3,73	2,70	2,16	4,86	2,88	181,44	5,04	5:02
42	15/09/24		4,94	0,900	0,30	50,00	4,86	1,46	3,40	1,16	1,00	1,16	4,86	3,70	0.00	3,70	0.00	0.00	0.00	0.00
43	16/09/24		5,09	0,900	0,30	50,00	4,86	1,46	3,40	1,20	0,88	1,05	3,70	2,66	2,21	4,86	2,94	185,28	5,15	5:09
44	17/09/24		4,65	0,900	0,30	50,00	4,86	1,46	3,40	1,09	1,00	1,09	4,86	3,77	0.00	3,77	0.00	0.00	0.00	0.00
45	18/09/24		5,16	0,900	0,30	50,00	4,86	1,46	3,40	1,21	0,88	1,07	3,77	2,70	2,16	4,86	2,88	181,69	5,05	5:03
46	19/09/24		5,13	0,900	0,30	50,00	4,86	1,46	3,40	1,21	1,00	1,21	4,86	3,66	0.00	3,66	0.00	0.00	0.00	0.00
47	20/09/24		5,40	0,900	0,30	50,00	4,86	1,46	3,40	1,27	0,87	1,10	3,66	2,55	2,31	4,86	3,08	194,04	5,39	5:23
48	21/09/24		5,19	0,900	0,30	50,00	4,86	1,46	3,40	1,22	1,00	1,22	4,86	3,64	0.00	3,64	0.00	0.00	0.00	0.00
49	22/09/24		4,88	0,900	0,30	50,00	4,86	1,46	3,40	1,15	0,87	1,00	3,64	2,65	2,22	4,86	2,95	186,04	5,17	5:10
50	23/09/24		4,93	0,900	0,30	50,00	4,86	1,46	3,40	1,16	1,00	1,16	4,86	3,71	0.00	3,71	0.00	0.00	0.00	0.00
51	24/09/24		4,89	0,900	0,30	50,00	4,86	1,46	3,40	1,15	0,88	1,01	3,71	2,70	2,16	4,86	2,89	181,76	5,05	5:03
52	25/09/24		5,04	0,900	0,30	50,00	4,86	1,46	3,40	1,18	1,00	1,18	4,86	3,68	0.00	3,68	0.00	0.00	0.00	0.00
53	26/09/24		4,89	0,900	0,30	50,00	4,86	1,46	3,40	1,15	0,87	1,00	3,68	2,68	2,19	4,86	2,92	183,65	5,10	5:06
54	27/09/24		5,05	0,900	0,30	50,00	4,86	1,46	3,40	1,19	1,00	1,19	4,86	3,68	0.00	3,68	0.00	0.00	0.00	0.00
55	28/09/24		5,19	0,900	0,30	50,00	4,86	1,46	3,40	1,22	0,87	1,06	3,68	2,61	2,25	4,86	3,00	189,00	5,25	5:15
56	29/09/24		5,14	0,900	0,30	50,00	4,86	1,46	3,40	1,21	1,00	1,21	4,86	3,65	0.00	3,65	0.00	0.00	0.00	0.00
57	30/09/24		5,02	0,700	0,30	50,00	4,86	1,46	3,40	0,92	0,87	0,80	3,65	2,86	2,01	4,86	2,68	168,53	4,68	4:41
58	01/10/24		4,91	0,700	0,30	50,00	4,86	1,46	3,40	0,90	1,00	0,90	4,86	3,97	0.00	3,97	0.00	0.00	0.00	0.00
59	02/10/24		5,08	0,700	0,30	50,00	4,86	1,46	3,40	0,93	0,91	0,84	3,97	3,13	1,74	4,86	2,32	145,91	4,05	4:03
60	03/10/24		4,84	0,700	0,30	50,00	4,86	1,46	3,40	0,88	1,00	0,88	4,86	3,98	0.00	3,98	0.00	0.00	0.00	0.00
61	04/10/24		4,82	0,700	0,30	50,00	4,86	1,46	3,40	0,88	0,91	0,80	3,98	3,18	1,68	4,86	2,25	141,44	3,93	3:56
62	05/10/24		5,11	0,700	0,30	50,00	4,86	1,46	3,40	0,93	1,00	0,93	4,86	3,93	0.00	3,93	0.00	0.00	0.00	0.00
63	06/10/24		5,06	0,700	0,30	50,00	4,86	1,46	3,40	0,93	0,90	0,83	3,93	3,09	1,77	4,86	2,36	148,49	4,13	4:08

Appendix 4: Soil characteristics considered as adequate for growing high yield mango orchards according to Cavalcante & Paiva Neto (2024).

Soil characteristics	Adequate values
pH	5.5 – 6.5
Organic Carbon	1-3 %
Electrical onductivity	< 0.2 dSm
Phosphorus	60 – 80 mg/dm^3
Potassium	0.25 – 0.4 meq/100 g
Sulphur	> 12 mg/kg
Sodium	<1.0 meq/100 g
Calcium	3 - 5 meq/100 g
Magnesium	0.75 – 1.25 meq/100 g
Cation Exchange	~5
% Sodium	< 1%
% Potassium	5 – 10 %
% Calcium	65 – 70%
% Magnesium	15 - 20 %
Copper	0.3 – 10 mg/kg
Zinc	2 – 15 mg/kg
Manganese	4 – 50 mg/kg
Iron	4 - 100 mg/kg
Boron	1 - 2 mg/kg