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Determination of the Electrical Conductivity, pH and Fertilizer Concentration of Insecticide-Nematicide Solutions and Nutritional Cocktails Applied to Pineapple (*Ananas comosus* MD-2)

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A B S T R A C T

In commercial pineapple farms, the electrical conductivity (EC), pH, and fertilizer concentration of the insecticide-nematicide and nutrient solutions that are applied commercially were determined to analyze if they are related with the presence of toxicity symptoms in the pineapple foliage. Insecticide-nematicide and nutrient solutions were evaluated at one thousandth of the solution used commercially per hectare and correspondingly using one thousandth of the rate indicated per hectare of the product or of each fertilizer source. The EC of the solution was measured with a SevenGo DuoTM SG23 Mettler Toledo conductivity meter and the pH with a Hanna® Instruments model HI9811-5 electronic pH meter and in each fertilizer solution the concentration of macronutrients (N-P-K-Ca- Mg), micronutrients (Zn, Fe, B, Mn, Cu) and total fertilizer was estimated. The EC of the insecticide-nematicide solutions fluctuated between 0.14 and 0.43 mS cm^{-1} and the pH between 3.6 and 7.3. On farms that added citric acid to the insecticide-nematicide solutions, their pH was reduced to a very acidic condition that can favor the mineralization of the product and its corresponding loss of efficacy. In the nutrient solutions, the EC varied between 40.5 and 111.8 mS cm^{-1}, the pH between 2.7 and 4.7, and the fertilizer concentration between 2.6 and 13.09%. The fertilizer sources that most contributed to the EC were UAN (31-0-0), YaraMila™ Complex™, potassium chloride and potassium sulfate given their amounts included in the nutritional cocktails. Four independent factors or some of them together or a combination of all of them, could be associated or explain the phytotoxicity in the crop: nutritive solutions with EC greater than 40 mS cm^{-1}, very low pH of the solutions less than 4.7, fertilizer concentrations greater than 4, 5 and 9%, and over-application of the solutions. Although some nutrient solutions did not exceed 5% concentration, their EC exceeded 40 mS cm^{-1}. It seems then that to avoid leaf crop damage it would be more accurate to use the EC instead of the fertilizer concentration. To prevent foliage toxicity or burning due to foliar fertilization, it is suggested to apply low EC fertilizer cocktails of less than 40 mS cm^{-1}. This can be achieved by adding smaller amounts of the products that most contribute to EC. Another possibility is to incorporate sources that lead to a reduction in the EC of the fertilizer cocktails, for example, using potassium citrate (Greenplants® K) as a source of K. The pH of the solutions must be adjusted to the optimal range (5.5 to 6.5) of absorption suggested for the crops and over-application of the solutions must be eliminated. Therefore, the pressurization of the equipment must be carried out with the arms outside the terraces, in terraces that do not have the total number of beds, the arms of the boom must not be tilted and in the curves of the roads when it is necessary to go back to align the equipment and continue with the application, the nozzles should be closed to prevent over application of the nutrient solutions.

Introduction

In pineapple, up to 2-3 months after planting, the fertilization is carried out with granular formulas that are applied to the soil or in the axils of the oldest leaves due to the accumulation of rainwater and dew in these sites that facilitates the dissolution of the fertilizer. After 2-3 months of planting, plant growth limits and restricts said application. Knowing that pineapple leaves absorb all nutrients (Py *et al.,* 1987), N, P, K, Mg, Fe, Cu, Zn and B are commonly applied in solution via foliar spray (Swete, 1993; Molina, 2002a; Hepton, 2003; Palma and Zavala, 2020a) even from 30 days after planting. The morphological structure of the leaves and their phyllotaxy facilitates receiving foliar applications that, due to the volumes used between 2300 and 3800 L ha^{-1}, part of the solution is channeled to the axillary roots (Py *et al.,* 1987; Sinclair, 1993) that wrap the stem at the base of the old leaves, and when there is any runoff or leaching of the solution, it would be towards the root mass at the base of the plant, where the nutrients would also be used.

An exception is calcium (Ca) since most Ca salts are relatively insoluble or would make other nutrients in solution insoluble (Sinclair, 1993; Malézieux and Bartholomew, 2003). Additionally, Ca is relatively immobile in plants (Mengel and Kirkby, 2000; Molina, 2002a; White, 2012; Fernández *et al.,* 2013), so its foliar application means that it is not remobilized from the tissue where it is absorbed to the tissue where it is deficient (Malézieux and Bartholomew, 2003). Foliar applications of Ca are infrequent and when they are applied the nutrient goes alone in the solution.

Foliar applications are common in most crops (Gutiérrez, 2002; Segura, 2002; Molina, 2002a; Eichert and Fernández, 2012), with reduced concentrations of nutrients and their use is complementary to soil fertilization. In pineapple, foliar applications of nutrient solutions are effective and easy to mechanize as indicated by Hepton (2003) and are a substitute for soil applications, which entails high concentrations of nutrients. In Costa Rica, it is estimated that 80% or more of the crop's nutritional requirements are supplied via the foliar route (Herrera, 2001; Molina, 2002a; Palma and Zavala, 2020a). To greater growth and development of the plant, greater is the nutritional demands, requiring a higher concentration of nutrients in the solution. Although pineapple leaves tolerate nutrient solutions with high concentrations of salts (Molina, 2002a; Vásquez and Bartholomew, 2018), the basal white tissue of young growing leaves is very sensitive to fertilizer burning and nutrient solutions with high osmotic concentrations (Hepton, 2003; Garita, 2014).

In fertigation nutrient solutions, it is known that the total ionic concentration and subsequent osmotic pressure affects the absorption of water, nutrients, and crop yield (Preciado *et al.,* 2003; Parra *et al.,* 2008; Marschner, 2012; Urbina *et al.,* 2015). Nutrient solutions with high osmotic pressure decrease the free energy of water and restrict the absorption of water and some nutrients (Asher and Edwards, 1983; Ehret and Ho, 1986; Al-Harbi, 1994; Marschner, 1995; Kafkafi and Bernstein, 1996). Solutions with low osmotic pressure, having a deficiency of nutrients in the nutrient solution, can lead to nutritional deficiencies (Steiner, 1973; 1980; Ehret and Ho, 1986).

To prevent leaf burning or symptoms of toxicity in pineapple leaves with foliar applications of nutrient solutions, different concentrations of fertilizer are recommended. Rebolledo *et al.,* (1998) suggest that the fertilizer concentration does not exceed 5% (5 kg or L in 100 L water), later part of those same authors, Rebolledo *et al.,* (2011) indicated that it does not exceed 4% (4 kg or L in 100 L water), Vásquez (2015) under controlled conditions reported that the maximum concentration that can be used is 9% without damage to the leaves and Vásquez and Bartholomew (2018) mentioned a maximum of 5% in macronutrients and 1% in micronutrients in solutions between 2000 and 2500 L ha^{-1}.

For the application of phytosanitary products in agriculture, the quality of the water is determined by the concentration and composition of the constituents it contains. These constituents are generally mineral salts found in water dissociated as ions. The sum of all the minerals dissolved in a water sample is known as total dissolved solids (TDS). The higher the (TDS) value, the greater the electrical conductivity of the solution. Therefore, a measure of electrical conductivity (EC), in millisiemens cm^{-1} (mS cm^{-1}) at 25ºC, is used to estimate the total dissolved solids (TDS ppm) in water (Molina 2002b). Palma and Zavala (2020a) with sprays of nutrient solutions with specific EC values to the foliage found a greater incidence of plants with lesions-damage (symptoms of toxicity) in the leaves as the EC of the solution and the number of fertilizer cycles applied increased. Therefore, the objective of the present investigation was to determine the electrical conductivity (EC), pH and fertilizer concentration of insecticide-nematicide and nutritional solutions applied in commercial pineapple farms where symptoms of toxicity on leaves (Figure 1A-I) have occurred. Additionally, quantify the EC contribution made by each nutritional source.

Materials and Methods

The electrical conductivity (EC) and pH, the concentration of macronutrients (N, P, K, Ca, Mg), micronutrients (Zn, B, Fe, Mn, Cu) and total fertilizer was calculated from the commercially insecticide-nematicide solutions and nutritional mixtures that are applied in the production of pineapple (*Ananas comosus* MD-2). The insecticides-nematicides evaluated were Mocap® 72EC (ethoprofos-AMVAC) and Nemacur® 40EC (fenamiphos-AMVAC) at the rate indicated on the label. The fertilizer sources evaluated were YaraMila™ Complex™ 12-11-18-2.7-8-0.015-0.2-0.02-0.02 (N-P_2O_5-K_2O-MgO-S-B-Fe-Mn-Zn Yara), Soluble Mop (62% K_2O DISAGRO), zinc sulfate heptahydrate (10.5%S, Zn 21.5% ABOPAC), boric acid (17.5% B ABOPAC), potassium chloride (62% K, 47 % Cl ABOPAC), iron sulfate heptahydrate (20% Fe, 12% S DISAGRO), magnesium sulfate heptahydrate (16.3% Mg, 13% S ABOPAC), UAN (31-0-0 ABOPAC), CaTs (6 % CaO, 10% S- Tessenderlo Kerley) and citric acid (99.5% $C_6H_8O_7$ DISAGRO).

With those sources, the nutritional mixtures that are used commercially on the farms, which are indicated in each table, were proportionally prepared. The volume of solution per hectare that is used commercially was considered. The mixtures were evaluated in one thousandth of the commercially used solution per hectare and correspondingly using one thousandth of the indicated rate per hectare. In each table, the recommended product rate per hectare and its thousandth corresponding to the thousandth of the solution are presented and the fertilizer concentration (macronutrients and micronutrients) is indicated. To prepare the solutions, the same water source that is used to prepare the solutions on the farms was used and following the order of mixing of the farms. To a plastic container with a capacity of 5 L, 50% of the water required in the solution was added, then the defined amount of insecticide-nematicide or fertilizer source was added. After adding each source of insecticide-nematicide or fertilizer, the solution was stirred for 1 minute, and after adding the last source, it was stirred again, the volume of solution was completed with water, stirred again for 1 minute and the electrical conductivity (EC) of the solution was measured with a SevenGo DuoTM SG23 Mettler Toledo conductivity meter and the pH with a Hanna® Instruments electronic peachimeter model HI9811-5 (Figure 2A-B). The pH of the water source and of the pure products (Mocap® 72EC and Nemacur® 40EC) was measured with the same pH meter indicated for the fertilizer solutions.

In consecutive applications of the same nutritional mixture, it was determined whether the consecutive application of the same fertilizer cocktail leads to an increase in the EC in the application of the subsequent boom. To do this, after the preparation of each boom, a sample of the solution was taken directly from the nozzle (Figure 2C) at the beginning of the spray and another at the end of the application of each boom and its EC was measured.

Results and Discussion

The pH of the commercial insecticide-nematicide products was Mocap® 72EC 1.1 and Nemacur® 40EC 6.2. The electrical conductivities obtained in the solutions with insecticide-nematicide fluctuated between 0.14 and 0.43 mS cm^{-1} and the pH between 3.6 and 7.3 (Table 1). The addition of citric acid reduced the pH of the insecticide-nematicide solutions between 2.9 and 3.5 units, acidifying the solution. Although the commercial Mocap® 72EC product has an acidic pH of 1.1 when placed in solution with the volume of water, it only reduced the pH by 0.8 units, going from 7.5 to 6.7 in the solution. Nemacur® 40EC with pH 6.2 reduced the pH by 0.4 units, going from 7.5 to 7.1 in the solution.

In the nutrient solutions evaluated, the EC found ranged between 40.5 and 111.8 mS cm^{-1}, the pH between 2.7 and 4.7 and when estimating the concentration of fertilizer in the solution it was found that it varied between 2.6 and 13.09% (Table 2). In the solutions that included YaraMila™ Complex™, precipitation of this was observed and in the solution that included potassium sulfate, its low solubility was noted. When the evolution of the electrical conductivity was measured as each fertilizer source was added, it was found that potassium chloride and UAN (31-0-0) are the ones that increase the EC the most, reaching 144.3 and 109.3 mS cm^{-1}, being that, upon completing the final volume of solution, it closed at 132.7 mS cm^{-1} (Table 3). This indicates that

UAN increased the EC by 75.2 units and the addition of potassium chloride by 35 units. Citric acid and boric acid did not lead to a greater contribution in EC and the increase with magnesium sulfate was 10.6 mS cm^{-1}, which later when adding zinc sulfate and iron sulfate the increase was 1 and 2.6 units, respectively. After adding potassium sulfate, the EC changed to 34.1 mS cm^{-1}, adding 20.8 EC units.

When the evolution of the EC was measured in solutions that included the YaraMila™ Complex™, it was observed that this was the one that increased the EC the most, adding 46.6 units to the mixture (Table 4). Additionally, by adding said product, the pH of the solution was reduced by 1.2 units, moving it to a pH of 4.2. In this fertilizer mixture, the addition of zinc sulfate and iron sulfate did not increase the EC but did reduce the pH of the solution by 0.3 and 0.5 units, respectively.

When quantifying the EC contribution of specific fertilizer sources, it was observed that potassium sulfate at 40 kg ha^{-1} and potassium chloride at 50 and 57 kg ha^{-1} in 2400 L of solution added up to 22 (Table 5), 42 (Table 6) and 47 mS cm^{-1} of EC (Table 7), respectively. The addition of UAN (31-0-0) at 50 and 150 L ha^{-1} in 2400 L of solution added 29 (Table 6) and 78 mS cm^{-1} of EC (Table 8), respectively. The use of calcium sulfate at 11 L ha^{-1} in 1400 L of solution did not lead to a drastic change in the EC (0.16 to 2.7 mS cm-1) or of the pH from 7.1 to 6.7 (Table 9).

Contrary to was expected, the EC of booms prepared with the same nutrient solution decreased in solution 1 from 53 to 39.2 mS cm^{-1}. In the booms of solution 2, the EC was atypical, increasing until the initial evaluation of boom 2, then decreasing in the final evaluation of boom 2, rising again in the final evaluation of boom 3 and then decreasing from the final evaluation of boom 4 (Table 10). An atypical EC was also observed between its measurement at the beginning and end of each boom, especially in solution 2. In some cases, the EC at the end of the boom was lower and in other cases it was higher. The variations in pH were much smaller, ranging in solution 1 between 4.52 and 4.83 and in solution 2 between 4.47 and 4.83.

The EC of the water sources varied between 0.15 and 0.16 mS cm^{-1}, being slightly lower than the water sources in the country (Vargas *et al.,* 2001) where it varied between 0.22 and 0.55 mmohs cm^{-1} (0.22 and 0.55 mS cm^{-1}), also lower than that reported by Solís *et al.,* (2018) who indicates EC between 50 and 549 µS cm^{-1} (0.05 and 0.54 mS cm^{-1}) for groundwater-wells and between 20 and 499 µS cm^{-1} (0.02 and 0.49 mS cm^{-1}) for spring water in Costa Rica, and of irrigation water in parts of Mexico where it varied between 0.12 and 1.29 dS m^{-1} or 0.12 and 1.29 mS cm^{-1} (Castellón *et al.,* 2015). According to Van der Lugt (2016), when the EC of water is < 0.5 mS cm^{-1}, its use is appropriate for any crop. In waters for irrigation, Benton (2003) indicates that when the EC value is less than 2.0 dS m^{-1} (2 mS cm^{-1}) they are not saline. Similarly, Paull and Duarte (2011) indicate that when the EC of the solution is less than 0.25 dS m^{-1} (0.25 mS cm^{-1}) there are no negative effects on the crop and the magazine El Jornalero (2014) reported that when the content is less than 0.5 dS m^{-1} (0.5 mS cm^{-1}) the water for irrigation is practically free of salts. Marinho *et al.,* (1998) with salinity levels in irrigation water between 0 and 7 dS m^{-1} (0 and 7 mS cm^{-1}) found that the establishment and growth of pineapple plants was reduced at salinity levels greater than 3 dS m^{-1} (3 mS cm^{-1}). According to Molina (2002b), water suitable for irrigation in all crops is that with EC less than 0.75 mS cm^{-1}.

The applications of the insecticide-nematicide solutions did not represent any risk of toxicity for the crop since the EC was always less than 1 mS cm^{-1} and according to Palma and Zavala (2020a) for the foliar solutions to generate lesions or phytotoxicity in pineapple leaves must have an EC equal to or greater than 40 mS cm^{-1}. Regarding the pH of the insecticide-nematicide solutions, the incorporation of citric acid acidified the Mocap® and Nemacur® solution.

Farms that add citric acid to the solution may compromise the performance and biological effectiveness of both products. It is known that at acidic pH, mineralization (decomposition) of the products can occur, losing their effectiveness. On the labels of both insecticide-nematicides, none of them indicate that the solution must have a specific pH and the manufacturer is the best source to optimize the biological effectiveness of the product. However, as indicated by Gómez *et al.,* (2006), it is common for technicians to recommend the use of solution pH modifiers, often without justification. According to Whitford *et al.,* (1986); Fishel (2002); McKie and Johnson (2002) and Schilder (2008) for this type of agrochemicals an ideal pH of the solution is between 5.5 and 6.5.

Mocap® 72EC is recommended in pineapple cultivation for the control of symphylids (Araya, 2019a) and nematodes (Sipes and Schmitt, 1995; Rebolledo *et al.*, 2011; Araya *et al.*, 2021) and Nemacur® 40EC for the control of mealybugs (Araya, 2019b) and nematodes (Sipes and Schmitt, 1995; Rebolledo *et al.*, 2011; Araya *et al.*, 2021). The evaluated rate of Mocap® 72EC was 8 and 10 L ha^{-1}, which in a 2400 L solution results in concentrations of 2400 and 3000 ppm, and Nemacur® at 8 and 10 L ha^{-1} in a 2400 L solution results in a concentration of 1333 and 1666 ppm, respectively, and it is known that concentrations of 100 ppm in drench applications of 100 ml of solution per pot significantly reduced nematodes (Chávez *et al.*, 2018). Bunt (1987) reported that Mocap® is absorbed by the roots but without moving to the aerial part of the plants and Van Gundy and McKenry (1977); McKenry (1981, 1994) and Chitwood (2003) indicate that the Nemacur® is a systemic product via xylem (basipetal) and phloem (acropetal). When Nemacur® is applied to the foliage in pineapple crops, the tissue absorbs it and translocate it (acropetal phloem) to the rest of the plant (Zeck, 1971; Flint, 1977) and when it is applied to the soil or drains from the foliage to the soil, it is absorbed by the roots and translocated (basipetal xylem) to the foliage (Zeck, 1971; Flint, 1977). Both Mocap® and Nemacur® are organophosphate insecticide-nematicides whose mode of action is to inhibit acetylcholinesterase (Roberts and Hutson, 1999; Devine *et al.*, 2008) in the nervous system of the pest. This means that the application of any of these solutions is appropriate, because in commercial pineapple plantations the presence of nematodes and pests (mealybug, ant, weevil, *Phyllophaga*) at the same time is common. So, with a single application, its attack is controlled and prevented.

With respect to the nutrient solutions evaluated, EC higher than 40 mS cm^{-1} was found in all of them. Palma and Zavala (2020a) reported the incidence of plants with lesions-damage (toxicity symptoms) on the leaves after the first two applications, with an interval of 15 days, of nutrient solutions with EC of 50 mS cm^{-1}. The same authors found symptoms of toxicity when they carried out 3 consecutive cycles, every 15 days of nutrient solutions with EC of 40 mS cm^{-1} inclusive, suggesting that the osmotic capacity of the solution to cause plasmolysis of plant cells may be cumulative.

Table.1 pH and electrical conductivity (EC mS cm^{-1}) of solutions of Mocap® 72EC and Nemacur® 40EC used for pest control in the pineapple crop (*Ananas comosus* cv MD-2) with rates per hectare in 2400 L of water solutions.

Solution-product	Rate ha^{-1} L o kg	Rates 2.4 L^{-1} solution*	pH	Electrical conductivity CE mS cm^{-1}
Farm water source			7.5	0.15
Mocap® 72EC	8	8 ml	6.7	0.15
Mocap® 72EC + citric acid	8 + 0.76	8 ml + 0.76 g	3.8	0.23
Mocap® 72EC	10	10 ml	6.8	0.14
Mocap® 72EC + citric acid	10 + 0.76	10 ml + 0.76 g	3.6	0.27
Nemacur® 40EC	8	8 ml	7.1	0.18
Nemacur® 40EC + citric acid	8 + 0.76	8 ml + 0.76 g	3.8	0.22
Nemacur® 40EC	10	10 ml	7.3	0.21
Nemacur® 40EC + citric acid	10 + 0.76	10 ml + 0.76 g	3.8	0.29
Mocap® 72EC + Nemacur® 40EC	5 + 5	5 ml + 5 ml	6.9	0.34
Mocap® 72EC + Nemacur® 40EC + citric acid	5 + 5 + 0.76	5 ml + 5 ml + 0.76 g	3.7	0.43

*one thousandth of 2400 L of water solution ha^{-1} (2.4 L)

Table.2 pH and electrical conductivity (EC mS cm^{-1}) of fertilizer solutions used in the nutrition of the pineapple crop (*Ananas comosus* cv MD-2).

Number of solution	pH	EC (mS cm^{-1})	Fertilizer concentration estimation (%)	Observation of the solution
Farm water source	7.5	0.15		
1	4.5	69.5	7.5	YaraMila™precipitated
2	4.7	50.3	5.2	YaraMila™precipitated
3	2.9	67.4	8.86	Stable
4	3.8	40.5	2.6	YaraMila™ precipitated
5	2.9	84.5	8.23	Stable
6	2.7	103.4	9.63	Stable
7	2.7	111.8	13.09	Stable, but potassium sulfate with low solubility

Solutions

1:YaraMila™ Complex™12-11-18-2.7-8-0.015-0.2-0.02-0.02 (N-P_2O_5-K_2O-MgO-S-B-Fe-Mn-Zn) 180 kg ha^{-1} in 2400 L solution (180 g in 2.4 L one thousandth of solution), **2:**YaraMila™ Complex™12-11-18-2.7-8-0.015-0.2-0.02-0.02 (N-P_2O_5-K_2O-MgO-S-B-Fe-Mn-Zn), 125 kg in 2400 L of solution (125 g in 2.4 L one thousandth of solution), **3:** citric acid 0.65 kg (0.65 g) + boric acid 1.7 kg (1.7 g) + magnesium sulfate 26.4 kg (26.4 g) + zinc sulfate 2.5 kg (2.5 g) + iron sulfate 6.3 kg (6.3 g) + potassium chloride 41 kg (41 g) + UAN 31-0-0, 81 L (81 ml) all in 1800 L of solution. The values in parentheses correspond to the thousandths of each product used in the thousandth of the 1.8 L solution, 4**:** YaraMila™ Complex™ 12-11-18-2.7-8-0.015-0.2-0.02-0.02 (N-P_2O_5-K_2O-MgO-S-B-Fe-Mn-Zn) 100 kg ha^{-1} in 3800 L solution (1 g in 3.8 L one thousandth of solution), **5:** citric acid 0.65 kg (0.65 g) + boric acid 3.3 kg (3.3 g) + magnesium sulfate 24.2 kg (24.2 g) + zinc sulfate 2.8 kg (2.8 g) + iron sulfate 6.6 kg (6.6 g) + potassium chloride 50 kg (50 g) + UAM 31-0-0, 110 L (110 ml) all in 2400 L of solution. The values in parentheses correspond to the thousandths of each product used in the thousandth of the 2.4 L solution, **6:** citric acid 0.65 kg (0.65 g) + boric acid 4.4 kg (4.4 g) + magnesium sulfate 33 kg (33 g) + zinc sulfate 3.6 kg (3.6 g) + iron sulfate 7.5 kg (7.5 g) + potassium chloride 72 kg (72 g) + UAN 31-0-0, 110 L (100 ml) all in 2400 L of solution. The values in parentheses correspond to the thousandths of each product used in the thousandth of the 2.4 L solution. **7:** citric acid 0.72 kg (0.72 g) + boric acid 6 kg (6 g) + magnesium sulfate 43 kg (43 g) + zinc sulfate 5.4 kg (5.4 g) + iron sulfate 11 kg (11 g) + potassium sulfate 40 kg (40 g) + potassium chloride 57 kg (57 g) + UAN 31-0-0, 151 L (151 ml) all in 2400 L of solution. The values in parentheses correspond to the thousandths of each product used in the thousandth of the 2.4 L solution.

Table.3 Effect of the addition of each fertilizer source on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1}	Electrical conductivity (EC mS cm^{-1})
Farm water source		0.15
Citric acid	720 g	0.23
Boric acid	610 g	0.48
Magnesium sulfate	44 kg	10.65
Zinc sulfate	5.4 kg	11.6
Iron sulfate	11 kg	13.3
Potassium sulfate	40 kg	34.1
UAN 31-0-0	150 L	109.3
Potassium chloride KCl	57 kg	144.3
Final 2400 L solution		132.7

*Fertilizer concentration= 12.86%

Table.4 Effect of the addition of each fertilizer source on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 3800 L	Electrical conductivity (EC mS cm^{-1})	pH
Farm water source		0.16	7.1
Potassium chloride	14.3 kg	8.71	6.7
Citric acid	0.65 g	8.85	5.4
Boric acid	4.4 g	8.85	5.4
UAN 31-0-0	54 L	26.8	5.4
YaraMila™complex™	192.5 kg	73.4	4.2
Zinc sulfate	3.5 kg	73.7	3.9
Iron sulfate	7.5 kg	73.7	3.7
Final		59.0	3.7

*Fertilizer concentration 11.51%

Table.5 Effect of the addition of potassium sulfate on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 2400 L	Electrical conductivity (EC mS cm^{-1})
Farm water source		0.16
Potassium sulfate	40 kg	22.2

*Fertilizer concentration 1.6%

Table.6 Effect of the equivalent addition of UAN (31-0-0) or potassium chloride (KCl) on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 2400 L	Electrical conductivity (EC mS cm^{-1})
Farm water source		0.16
UAN 31-0-0	50 L	29
Farm water source		0.17
Potassium chloride	50 kg	42.2

*UAN concentration 2.08% and KCL concentration 2.08%

Table.7 Effect of the addition of potassium chloride (KCl) on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 2400 L	Electrical conductivity (EC mS cm^{-1})
Farm water source		0.16
Potassium chloride	57 kg	47.2

*Potassium chloride (KCl) concentration 2.37%

Table.8 Effect of the addition of UAN (31-0-0) ammonium nitrate + urea on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 2400 L	Electrical conductivity (EC mS cm^{-1})
Farm water source		0.16
UAN (31-0-0)	150 L	78.1

*UAN concentration 6.2%

Table.9 Effect of the addition of calcium sulfate on the electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2).

Source	Rate ha^{-1} in 1400 L	Electrical conductivity (EC mS cm^{-1})	Solution pH
Farmwater source		0.16	7.1
Calcium sulfate	11 L	2.7	6.7

*Calcium sulfate ($CaSO_4$) concentration 0.78%

Table.10 Electrical conductivity (EC mS cm^{-1}) of the fertilizer solution for application in the pineapple crop (*Ananas comosus* cv MD-2) at the beginning (I) and end (F) of the application of each boom of two fertilizer solutions.

Boom and solution	Electrical conductivity EC mS cm^{-1})	pH
Boom-1-I solución 1	52.7	4.73
Boom-1-F solución 1	52.5	4.76
Boom-2-I solución 1	53.0	4.83
Boom-2-F solución 1	44.1	4.82
Boom-3-I solución 1	44.8	4.52
Boom-3-F solución 1	39.2	4.62
Boom-1-I solución 2	39.0	4.75
Boom-1-F solución 2	51.9	4.77
Boom-2-I solución 2	53.7	4.66
Boom-2-F solución 2	49.4	4.73
Boom-3-I solución 2	49.9	4.71
Boom-3-F solución 2	71.7	4.83
Boom-4-I solución 2	75.2	4.67
Boom-4-F solución 2	54.8	4.82
Boom-5-I solución 2	53.6	4.67
Boom-5-F solución 2	53.9	4.72
Boom-6-I solución 2	50.6	4.47
Boom-6-F solución 2	52.1	4.65

Solution 1: YaraMila™ Complex™12-11-18-3-0-8 (N-P_2O_5-K_2O-MgO-B-S) 185 kg ha^{-1} in 2400 L of water with 7.7% of fertilizer concentration, solución **2**: citric acid 0.6 kg ha^{-1} + boric acid 4.4 kg ha^{-1} + zinc sulfate 3.6 kg ha^{-1} + iron sulfate 7.5 kg ha^{-1} + potassium chloride 14 kg ha^{-1} + YaraMila™ Complex™ 192 kg ha^{-1} + UAN 31-0-0 54 L ha^{-1}all in 3800 L of water with a fertilizer concentration of 7.26%.

Figure.1A-I Symptoms of toxicity within the blue rings on pineapple (*Ananas comosus* MD-2) leaves within commercial plantations.

Figure.2A-C Measurement of the electrical conductivity of insecticide-nematicide solutions and nutritional cocktails. In both photos A and B, the device on the left is the conductivity meter and the one on the right is the peachimeter. C: the red rectangle shows the collection of the solution sample taken directly from the boom nozzle at the beginning and end of the application of each boom with a nutritional cocktail.

From the fertilizer sources, the products that contributed the most to the EC were UAN (31-0-0), YaraMila™ Complex™, potassium chloride and potassium sulfate, mainly due to their quantities that are added to the solution. This agrees with what was indicated by Palma and Zavala (2020a), who reported that KCl, NO_3NH_4, Urea, $CaNO_3$ and K_2SO_4 are responsible for 80% of the EC in nutrient solutions. However, when the contribution of equal amounts of the products was compared, 50 kg of potassium chloride resulted in 42.2 mS cm^{-1} of EC while 50 L of UAN brought the EC to 29 mS cm^{-1}. In this sense, the same authors (Palma and Zavala, 2020a, 2020b) evaluated another source of K, Greenplants® K (potassium citrate) which, when equalizing the K contribution, resulted in an EC of less than 2 mS cm^{-1} without detriment to productivity.

The variations in EC of the same nutritional cocktail according to the number of booms applied are associated with factors in the operators, due to small changes in the preparation of the solutions. Any of the following, such as adding more product, loading less water into the tank, filling the tank with leftover from the previous boom and the lack of agitation, are variables that may have influenced the EC of the solutions.

Other authors such as Rebolledo *et al.,* (1998) to prevent possible leaf burning damage with foliar fertilization in pineapple suggest concentrations between 3 and 5% (3 to 5 kg or L in 100 L water) and later part of those same authors, Rebolledo *et al.,* (2011) indicated that it should not exceed 4% (4 kg or L in 100 L water). Vásquez (2015) under controlled conditions, carried out 6 consecutive cycles with an interval of 14 days and reported that the maximum concentration that can be used is 9% without damage to the leaves and Vásquez and Bartholomew (2018) mentioned a maximum of 5% in macronutrients and 1% micronutrients in solutions of 2000 to 2500 L ha^{-1}. When calculating the concentrations of macro and micronutrients in the nutrient solutions evaluated, it was found that they varied between 6.8 and 14.3% and between 0.42 and 0.93%, respectively, and of the total fertilizers between 7.26 and 15.01%.

Vásquez and Bartholomew (2018) recommend concentrations of up to 20% (20 kg per 100 L of water) of macronutrients, but with very low solution volumes of 350 to 500 L per hectare so that only the green part of the leaves be bathed preventing it from flowing into the white tissue, which it is very susceptible to burns. Nitrogen is one of the elements that is applied the most and according to Swete (1993) its foliar application is very efficient and concentrations of up to 10% of urea can be sprayed on the plants without problem, while if ammonium nitrate is applied, concentrations higher than 3% cause severe foliage burns.

The pH of the nutrient solutions evaluated were very acidic (Dubaniewicz, 2022), varying between 2.7 and 4.7, which could affect nutrient absorption. Molina

(2002b); Fernández *et al.,* (2013); Santos and Ríos (2016) indicate that the pH should be regulated in a slightly acidic environment that ranges between 5.5 and 6.5, which presents the best general conditions for the absorption of nutrients.

This pH also agrees with the optimal pH in the root zone of most crops grown in hydroponics, which is 5.5 to 6.5 (Singh *et al.,* 2019). According to Fageria *et al.,* (2011) and Van der Lugt (2016) a pH of around 5.5 in the nutrient solution is appropriate for all crops. Alam (1984) found higher dry matter production in rice plants grown in a nutrient solution at a slightly acidic pH between 5 and 6. Roosta and Rezaei (2014) evaluated the growth and development of roses in Hoagland nutrient solutions at pH 4.5; 5.5; 6.5 and 8 and found that the pH of 6.5 was optimal with the highest nutrient absorption and best vegetative and reproductive growth and quality of the roses. Alexopoulos *et al.,* (2021) compared the effect of pH (4.0, 5.5 and 7.0) of the nutrient solution on the growth, chemical composition, and nutritional quality of *Taraxacum officinale* and *Reichardia picroides* and reported that both plants had the best response to pH of 5.5. On the contrary, solutions with very low pH can cause phytotoxicity (Schilder, 2008).

Returning to the fact that pH is measured on a logarithmic scale (Whitford *et al.,* 1986; Deer and Beard, 2001; Fishel, 2002; Fishel and Ferrell, 2019) and considering a pH of 5.5 as optimal, the pH found in the solutions evaluated which ranged between 2.7 and 4.7 would be between 8 (pH 4.7) and 800 (pH 2.7) times more acidic than the pH of 5.5 and if the pH of 6.5 is taken as optimal, the solutions would be between 80 (pH 4.7) and 8000 (2.7) times more acidic than pH 6.5.

During the preparation of the solutions, the practice of filling the boom container halfway with water and then adding the fertilizers one by one, but without any established order, was observed. Knowing that water sources vary between neutral and alkaline, and that the optimal pH of the nutrient solution is between 5.5 and 6.5 (Molina, 2002b; Fernández *et al.,* 2013; Singh, 2019), the first thing to do is lower the pH of the water source (Whitford *et al.,* 1986; Deer and Beard, 2001; Schilder, 2008; Tharp and Sigler, 2013) with the addition of the required amount of citric acid. Then in the case of nutrient solutions, Molina (2002b) suggests adding the fertilizers one by one, starting with the liquids, then adding the solids one by one slowly and always with constant stirring.

In addition, he indicates that it is not advisable to mix sources that have sulfates with sources that contain calcium, for example, ammonium, potassium or magnesium sulfate with calcium nitrate and if it is required to include sources of phosphorus with products that contain calcium, first verify their compatibility. In some nutrient solutions, the inclusion of zinc sulfate, iron sulfate and a source of boron was observed, which should be reviewed because according to Swete (1993), these sources are incompatible with boron. In the case of phytosanitary products, after acidifying the water, Whitford *et al.,* (1986), recommend the following order; add wetting powders, dispersible granules, liquid products, floable products, emulsifiable concentrates, microencapsulated and lastly the surfactants, always stirring constantly.

Nutrient solutions are generally applied during the day with low environmental humidity and high temperature, which accelerates most of the water to evaporate and increases the concentration of salts, which are known to have a risk of causing burning or phytotoxicity in the foliage (Molina, 2002c; Rebolledo *et al.,* 2011; Eichert and Fernández, 2012). A greater performance of these applications would be if they are carried out at night, when pineapple, being a CAM crop, carries out photosynthesis (Sinclair, 1993; Malézieux *et al.,* 2003; Prigge and Gutiérrez, 2014; Sipes and Chinnasri, 2018; Castillo *et al.,* 2021). During the night, evaporation is reduced, the stomatal opening and plasma extensions or excites are activated, which favors the absorption of nutrients (Rebolledo *et al.,* 2011).

Toxicity symptoms on leaves were frequently observed in plants on the edges, bottoms of the terraces, and terraces found at the edge of road curves. In these cases, the symptoms of toxicity are associated with over application of the solution. At the beginning of the application of each boom, the equipment is pressurized, and in order not to waste the solution, the operators carry out the pressurization on the edges of the terraces, near the channel, which results in over-application of the solution on said plants. The same thing was observed in the terrace bottoms that do not have full beds, the operator tilts the boom arm so as not to waste solution, which results in over-application of the solution. Similarly, on road curves, when the tractor needs to go back to accommodate the equipment and continue, the nozzles do not close, which again leads to over-application of the solutions.

From what was analyzed there are four variables, which alone, or together some of them, or all of them, could be associated with or explain the phytotoxicity in the crop: nutrient solution with electrical EC greater than 40 mS cm^{-1}, very low pH of the solutions less than 4.7, fertilizer concentrations greater than 4, 5 and 9%, and over-application of the solutions. Although some nutrient solutions did not exceed 5% concentration, their electrical conductivity (EC) exceeded 40 mS cm^{-1}. It would seem then that to prevent damage to the crop it would be more accurate to use EC than fertilizer concentration. To prevent toxicity or burning due to fertilization, it is suggested to apply fertilizer cocktails with low EC less than 40 mS cm^{-1}. This can be achieved by adding smaller quantities of the products that contribute the most to the EC. Another possibility is to incorporate sources that lead to a reduction in the EC of the fertilizer cocktails, as demonstrated by Palma and Zavala (2020b) with the use of potassium citrate (Greenplants® K) as a source of K. The pH of the solutions must be adjusted to the optimal (between 5.5 and 6.5) absorption rate suggested for crops. In the over application of the solutions, the pressurization of the equipment must be carried out with the arms outside the terraces, on terraces that do not have the total number of beds, the arms of the boom must not be tilted and on the curves of the roads when if required to go back to align the equipment and continue with the application, the nozzles should be closed to prevent over-application of nutrient solutions.

Here we did not check in this research the rotation with other phytosanitary products like as fungicides and herbicides that are also applied on the crop. Would be advisable to determine the EC and pH of the fungicides and herbicides solutions and check if such mixtures predispose the pineapple foliage to burn when following a foliar fertilizer cocktail. Another line of research that need to be evaluated is the time between applications among all the phytosanitary products and the nutritional cocktails.

Author Contributions

Oscar Cortes: Investigation, formal analysis, writing—original draft. Juan Delgado: Validation, methodology, writing—reviewing. César Guillén:—Formal analysis, writing—review and editing. Eduardo Salas: Investigation, writing—reviewing. M. Araya: Resources, investigation writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

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