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# Compatibility and Physical Stability of Mixtures of Pre-Emergent Herbicides with the Insecticide-Nematicide Mocap® for the Control of Weeds, Symphylids and Nematodes in Pineapple (*Ananas comosus* cv MD-2)

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## A B S T R A C T

In Costa Rica, pineapple production is affected among other soil pests, by symphylids (*Scutigerella* spp., *Hanseniella* spp.) and nematodes (*Pratylenchus* ssp., *Helicotylenchus* spp.) that cause production losses. To prevent the presence of soil pests, insecticides-nematicides are applied. In addition, due to the high cost of labor and the reduced yield in manual weeding, it is common to apply pre-emergent herbicide before planting. Ideally, a single application targeting both approaches would be desirable to save water, reduce costs, and maximize labor. The present investigation studied the compatibility and physical stability of solutions that include pre-emergent herbicides (oxyfluorfen, hexazinone, ametrine, diuron) and the insecticide-nematicide Mocap® 72EC. Subsequently, the commercial application of a mixture of oxyfluorfen + Mocap® was carried out to verify if it prevents the initial presence of weeds and pests in the pineapple planting establishment (*Ananas comosus* cv MD-2). The results showed that the combination of the herbicides with Mocap® 72EC in a volume of 2400 liters per hectare was compatible and keep the spray solution stable in all cases. The field test, with the oxyfluorfen and Mocap® solution, confirmed the biological efficacy of the oxyfluorfen herbicide, where no weeds were found in the evaluation of 10 linear meters of bed 60 days after planting. Similarly, it was confirmed that Mocap® prevented symphylids infestation, finding 0% incidence and a 48% of the total phytoparasitic nematode population reduction (P= 0.0017) at 60 days of planting age, when compared to the untreated control. Therefore, the evaluated pre-emergent herbicides and the insecticide-nematicide Mocap® solutions can be applied given the common occurrence of symphylids, nematodes and weeds in the establishment of pineapple plantations.

**Keywords**

Nematode control, symphylids control, weed control, pre-emergent herbicides, insecticide-nematicides, soil pest control

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## Introduction

Pineapple (*Ananas comosus* cv MD-2) is grown in Costa Rica for export in fresh fruit and a small, processed quantity. The planted area is estimated at 40000 ha (Barquero, 2021; https://canapep.com/estadisticas/), giving a total income in 2021 of US$ 1014 million (https://canapep.com/estadisticas/), which it becomes the second crop that generates foreign currency for the country, after bananas. Despite being an annual or biannual crop, its commercial production is in continuous monoculture on the same soils.

This monoculture had favored the development of soil pests such as symphylids (*Scutigerella* spp., *Hanseniella* spp.) and nematodes (*Pratylenchus* spp., *Helicotylenchus* spp.), common pests in all pineapple areas of the country (Araya, 2019a; 2019b; Araya *et al.,* 2021).

These pests feed on the roots of the plant, which reduces its biomass and health, restricting the absorption of water and nutrients (Agrios, 2005), photosynthesis (Castillo *et al.,* 2021) and finally, the yield of the plantation (Rebolledo *et al.,* 1998, 2011; Rabie, 2017).

The presence of symphylids, nematodes and weeds are common in the establishment of plantations. Symphylids control is recommended since pre-planting (Rebolledo *et al.,* 2011), and in parallel, the best results in nematode control are reported with pre-planting and post-planting treatments (Rabie, 2017). Given the slow nature of manual weeding, which entails a high cost, the use of pre-emergent herbicides is indispensable.

The shortage of labor, the restriction in water availability, in agricultural machinery and the high production costs, a desirable practice would be the application of solutions that simultaneously include herbicides and insecticides-nematicides capable of exercising control over germination and development of weeds and soil pests that initially affect the pineapple crop.

Therefore, the compatibility and physical stability of solutions of pre-emergent herbicides (active ingredients: oxyfluorfen, hexazinone, ametrine and diuron-urea) in mixture with the insecticide-nematicide Mocap® 72EC were evaluated and subsequently, one of the solutions was applied after bed preparation and before planting in order to determine the presence of weeds and the incidence and population density of symphylids and nematodes in the initial stages of the plants.

## Materials and Methods

Herbicides with pre-emergent action alone or in a mixture with oxyfluorfen (Zeus® 24EC-Rainbow), hexazinone (Velpar® 75WG-Duwest), diuron-urea (Trombo® 80WG-Agricenter) and ametrine (Sellapax® 80WG-Agricenter) were evaluated and always in combination with the insecticide-nematicide Mocap® 72EC-AMVAC (ethoprofos) according to the rates indicated (1x) on their respective labels. A volume of 2400 L of solution per hectare was considered. For the compatibility and physical stability, the rates per hectare and the solution per hectare of the mixtures were evaluated in 500 ml of solution. The recommended rate of the products on the label per hectare and the corresponding quantities in 1 L and 500 ml of solution are found in Table 1. To prepare the solutions, groundwater from the LIFE-RID mixing laboratory (Muelle, San Carlos-Costa Rica) was used to which the pH measurement was carried out. The pH of the pure products was also measured with a Hanna® Instruments model HI9811-5 electronic peachimeter.

The solutions product mixing order was kept standard, first the herbicide(s): oxyfluorfen, followed by diuron-urea, ametrine and finally, the insecticide-nematicide: Mocap® 72EC. In the 500 ml beaker, 250 ml of water was initially added, subsequently the products were added individually, and the solution was stirred with a Cole-Parmer® electric stirrer at 1000 rpm for 3 minutes, then it was filled up to 500 ml and stirred again for 3 minutes. Example of solution 4: 250 ml of water was placed in the 500 ml beaker, 0.31 g of hexazinone was added, it was stirred for 3 minutes, 0.52 g of diuron-urea was added, it was stirred for 3 minutes, 0.52 g of ametrine was added, it was stirred for 3 minutes, the 2.08 ml of Mocap® was added, it was stirred for 3 minutes, then the beaker was filled up to 500 ml and the mixture was stirred again for 3 minutes. When the products were liquid, in preparing the solution, the volume of the liquid products was subtracted from the 500 ml of water. The extraction and measurement of the quantities of the products to be used were done with a spatula, an analytical balance scale or graduated pipette.

Once each solution was prepared, the 500 ml were transferred to 500 ml graduated cylinder and their physical behavior over time was evaluated, through visual observation of the compatibility and stability of the mixture, perception of odors and manual contact with the graduated cylinder to detect changes in the temperature of the solutions. For the physical stability of the solutions, the following visual scale was used: 1. Stable solution, where no phase separation is observed in the column of the graduated cylinder, 2. Unstable solution, where slight separation of the components is observed, which enter into solution again with slight stirring and 3. Solution with phases, where there is separation of components of the products that do not return to solution after stirring. If unstable solutions or solutions with phases are found, before stirring, the thickness or width of the phases is measured with a graduated ruler in centimeters. Visual evaluations of compatibility and stability, in addition to a photographic record, were carried out at the end of the preparation of each solution (0 minutes) and after 15, 30, 45 and 60 minutes. With the peachimeter, the pH of each solution was determined at the time it was made and then after 60 minutes.

At field level, in a sixth planting area of Ananas Export Company (ANEXCO), the application of the oxyfluorfen solution (Zeus® 24EC-Rainbow 3 L $ha^{-1}$) + Mocap® 72EC-AMVAC (ethoprofos) 10 L $ha^{-1}$was carried out in a volume of 2400 L of water, after the beds have been prepared and seven days before planting. At 60 days after planting, in 10 planting terraces applied with the solution and in the 10 terraces without application (control treatment), one linear meter of bed was randomly evaluated, and the presence of weeds recorded. On each terrace, a plant was randomly extracted from beds 3, 5, 7, 9 and 11, which were inspected for the presence of symphylids, and its roots were collected in an identified plastic bag with the respective treatment and repetition. These samples were sent to the CORBANA Nematology laboratory for nematode extraction by the maceration and sieving method (Araya, 2002).

Root weight data were subjected to ANOVA by Proc GLM of SAS. With the nematode data, the population composition was determined. The nematode data were analyzed with generalized linear models, using the logarithmic transformation as a link function and negative binomial distribution of the errors.

## Results and Discussion

The preparation of the solutions was carried out in groundwater with a pH of 7.2 and the pure products had the following pH: hexazinone 7.1; oxyfluorfen 8.1; diuron-urea 7.1; ametrin 7.1; and ethoprophos 1.8. Once the preparation of the mixtures was completed, no changes in temperature or presence of odors were detected, which are usually related to the decomposition of the products. No phase separation was observed in any of the solutions throughout the evaluation times (Figure 1 and 2). The mixture with Mocap® 72EC at the evaluated rate of 10 L (1x) in 2400 L of solution per hectare was compatible and did not destabilize the herbicide-insecticide-nematicide solutions (Table 2).

The initial and final pH values of the solutions were close to neutral with a range between 7.1 and 7.4 and without variation when it was measured at the time of preparation and 60 minutes after preparation. If these solutions are applied soon after their preparation, degradation or hydrolysis of said products would not be expected to occur.

The field application of the oxyfluorfen solution (Zeus® 24EC-Rainbow) 3 L $ha^{-1}$ + Mocap® 72EC-AMVAC (ethoprofos) at 10 L $ha^{-1}$ allowed the biological effectiveness of both products to be verified. At 60 days after planting, the presence of 6 weeds (*Cyperus odoratus*, *Digitaria* spp., *Mimosa* spp., *Ochoroma* spp., *Spermacoce* spp. and *Asystasia gangética*) was detected in the terraces of the control treatment (Plate 1A-B), while in the terraces applied with the solution, no germination or development was observed (Plate 1C-D). In none of the plants evaluated in the control treatment or in those treated with the solution, the presence of symphylids was observed. Although the plants in the beds treated with the Zeus® 24EC + Mocap® 72EC solution contained 38% more roots (27.6 vs. 20 g per plant), the difference was not large enough to be significant (P= 0.1794, Figure 3A). Of the phytoparasitic nematodes detected, 88% corresponded to *Pratylenchus* spp. and 12% to *Helicotylenchus* spp. (Figure 4). In the terraces treated with the Zeus® 24EC + Mocap® 72EC solution, the total population of phytoparasitic nematodes was 48% lower (P= 0.0017) than that of the control terraces (Figure 3B).

The application of solutions that include herbicides and nematicides is not new in agriculture and has been used successfully in the cultivation of soybeans (Okora *et al.,* 1988), potatoes (Thornton *et al.,* 2010). The mixture of phytosanitary products (fungicides, nematicides) in tobacco is also reported, where the mixture of Methalaxyl with fenamiphos (Nemacur) has been effective for the simultaneous control of *Phythophtora parasitica* and *Meloidogyne incognita* (Csinos and Minton, 1983; Csinos *et al.,* 1986).

**Table.1** Pre-emergent herbicide solutions (oxyfluorfen-Zeus® 24EC, hexazinone-Velpar® 75WG, diuron-urea-Trombo® 80WG and ametrine-Sellapax® 80WG) in mixture with the insecticide-nematicide (Mocap® 72EC-ethoprofos) proposed for weeds, symphylids and nematodes control in pre-planting of the pineapple crop (*Ananas comosus* cv MD-2) with rates per hectare, liter and 500 ml of solution.

| Solution / treatment | Recommended rate $ha^{-1}$ | Product rate / liter of solution | Product rate in 500 ml of solution |
|---|---|---|---|
| **1. 1x Zeus® 24EC 3 L $ha^{-1}$ +<br>1x Mocap® 72EC 10 L $ha^{-1}$<br>2400 L solution $ha^{-1}$** | 3 L<br>10 L | 1.25 ml<br>4.17 ml | 0.63 ml<br>2.08 ml |
| **2. 1x Zeus® 24EC 3 L $ha^{-1}$+<br>1x Velpar® 70WP 1.5 kg $ha^{-1}$ +<br>1x Mocap® 72EC 10 L $ha^{-1}$ +<br>2400 L solution $ha^{-1}$** | 3 L<br>1.5 kg<br>10 L | 1.25 ml<br>0.63g<br>4.17 ml | 0.63 ml<br>0.31 g<br>2.08 ml |
| **3. 1x Zeus® 24EC 3 L $ha^{-1}$ +<br>1x Trombo® 80WG2.5 kg $ha^{-1}$ +<br>1x Sellapax® 80WG 2.5 kg $ha^{-1}$ +<br>1x Mocap® 72EC 10 L $ha^{-1}$<br>2400 L solution $ha^{-1}$** | 3 L<br>2.5 kg<br>2.5 kg<br>10 L | 1.25 ml<br>1.04 g<br>1.04 g<br>4.17 ml | 0.63 ml<br>0.52 g<br>0.52 g<br>2.08 ml |
| **4. 1x Velpar® 75WP 1.5 kg $ha^{-1}$ +<br>1x Trombo® 80WG 2.5 kg $ha^{-1}$+<br>1x Sellapax® 80WG 2.5 kg $ha^{-1}$ +<br>1x Mocap® 72EC 10 L $ha^{-1}$<br>2400 L solution $ha^{-1}$** | 1.5kg<br>2.5 kg<br>2.5 kg<br>10 L | 0.63 g<br>1.04g<br>1.04 g<br>4.17 ml | 0.31 g<br>0.52 g<br>0.52 g<br>2.08 ml |

**Table.2** Visual evaluation of the pre-emergent herbicide solutions (oxyfluorfen-Zeus® 24EC, hexazinone-Velpar® 75WG, diuron-urea-Trombo® 80WG and ametrine-Sellapax® 80WG) with the insecticide-nematicide (Mocap® 72EC) proposed for weeds, symphylids and nematodes control pre-planting in pineapple cultivation (*Ananas comosus* cv MD-2). Visual evaluation times: 0, 15, 30, 45 and 60 minutes after preparation. Measurement of initial (0 minutes) and final (60 minutes) pH of the solutions.

| Solution / treatment | Eval 0 | Eval 15 | Eval 30 | Eval 45 | Eval 60 | pH i 0 | pH f 60 |
|---|---|---|---|---|---|---|---|
| **1. 1x Zeus® 24EC 3 L $ha^{-1}$ + 1x Mocap® 72EC 10 L $ha^{-1}$ 2400 L solution $ha^{-1}$** | 1 | 1 | 1 | 1 | 1 | 7.1 | 7.1 |
| **2. 1x Zeus® 24EC 3 L $ha^{-1}$ + 1x Velpar® 70WP 1.5 kg $ha^{-1}$ + 1x Mocap® 72EC 10 L $ha^{-1}$ 2400 L solution $ha^{-1}$** | 1 | 1 | 1 | 1 | 1 | 7.3 | 7.3 |
| **3. 1x Zeus® 24EC 3 L $ha^{-1}$ + 1x Trombo® 80WG 2.5 kg $ha^{-1}$ + 1x Sellapax® 80WG 2.5 kg $ha^{-1}$ + 1x Mocap® 72EC 10 L $ha^{-1}$ + 2400 L solution $ha^{-1}$** | 1 | 1 | 1 | 1 | 1 | 7.4 | 7.4 |
| **4.1x Velpar®70WP 1.5 kg $ha^{-1}$ + 1x Trombo® 80WG 2.5 kg $ha^{-1}$ + 1x Sellapax® 80WG 2.5 kg $ha^{-1}$ + 1x Mocap® 72EC 10 L $ha^{-1}$ 2400 L solution $ha^{-1}$** | 1 | 1 | 1 | 1 | 1 | 7.3 | 7.3 |

**Figure.1** Physical stability of herbicide + insecticide-nematicide solutions every 15 minutes up to 60 minutes after preparation. Solution 2400 L ha$^{-1}$.

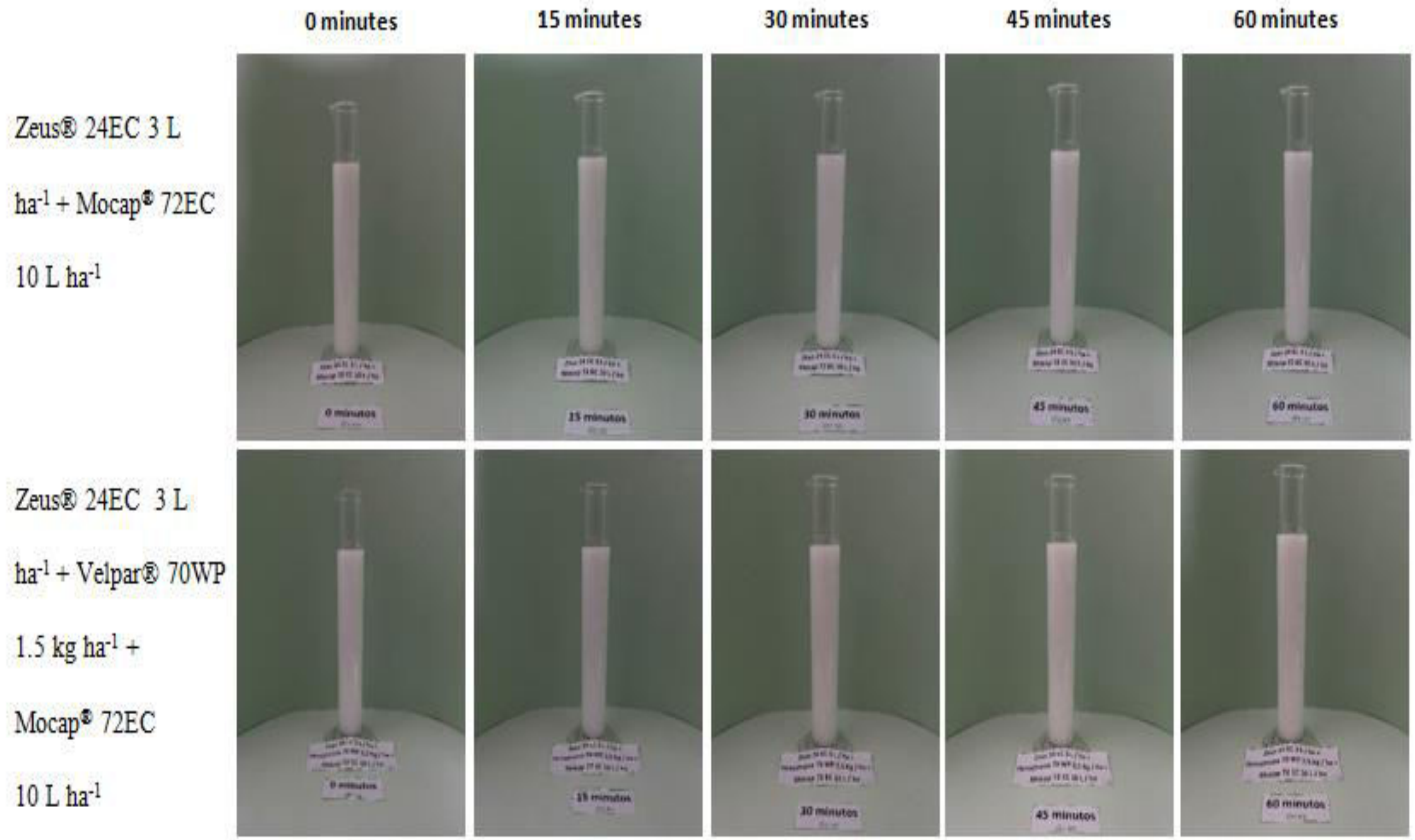


**Figure.2** Physical stability of herbicide + insecticide-nematicide solutions every 15 minutes up to 60 minutes after preparation. Solution 2400 L ha$^{-1}$.

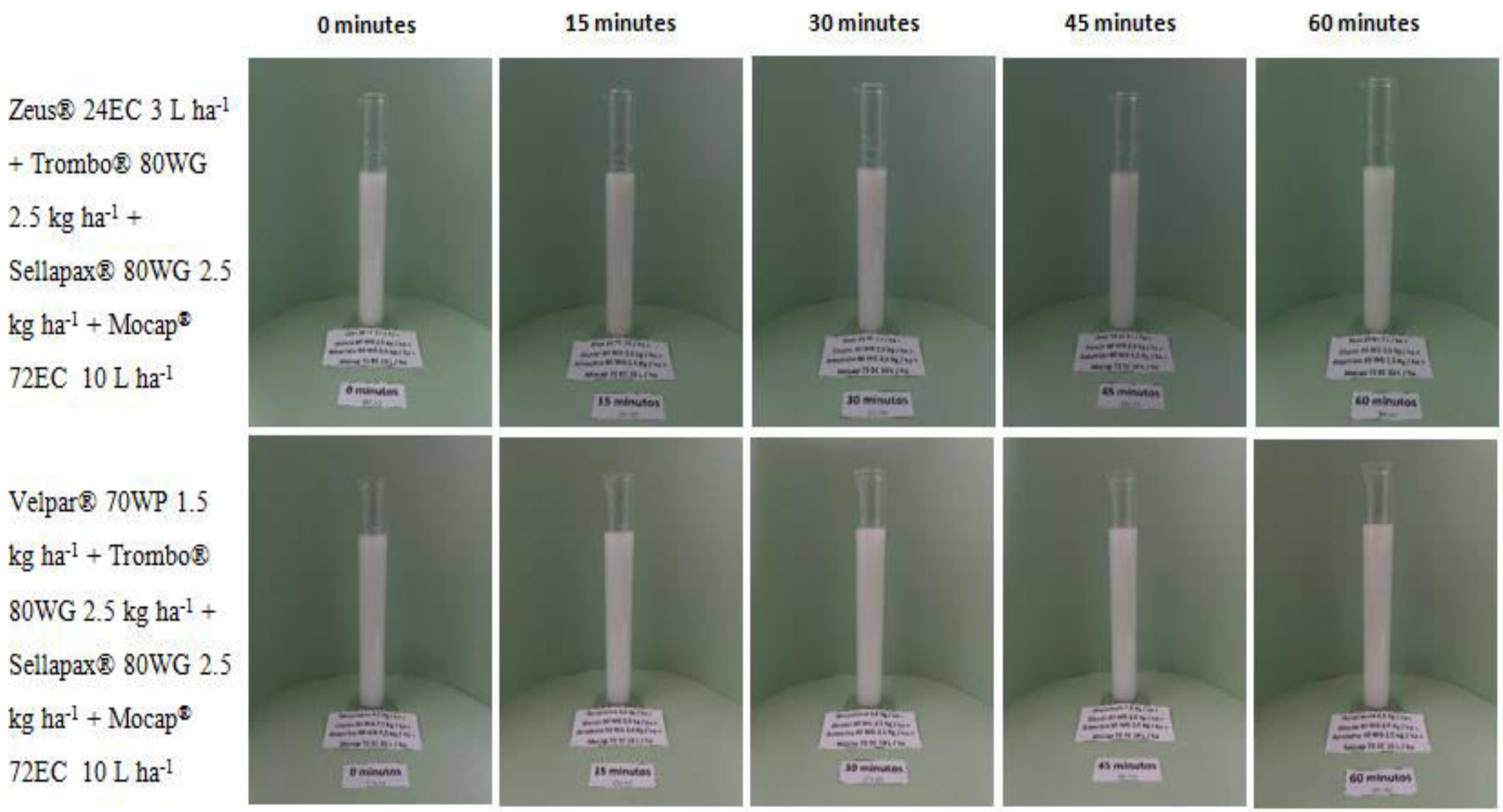


**Plate 1A-D** Determination of the presence of weeds 60 days after planting of pineapple (*Ananas comosus* cv MD-2) stem shoots, in one linear meter of bed on the terraces of the control treatment (A-B) and those applied with the oxyfluorfen solution (Zeus ® 24EC-Rainbow) 3 L $ha^{-1}$ + the insecticide-nematicide Mocap® 72EC-AMVAC (ethoprofos) 10 L $ha^{-1}$ in 2400 L of water (C-D).

**Figure.3A-B** Root weight (A) per plant and total number of phytoparasitic nematodes (B) per 100 g of pineapple (*Ananas comosus* cv MD-2) roots by plant grown in beds applied or not applied with an oxyfluorfen solution (Zeus® 24EC- Rainbow) 3 L ha$^{-1}$+ Mocap® 72EC 10 L ha$^{-1}$in 2400 L of water. Each bar is the mean ± standard error of 10 replicates and each replicate included the roots of 5 plants.

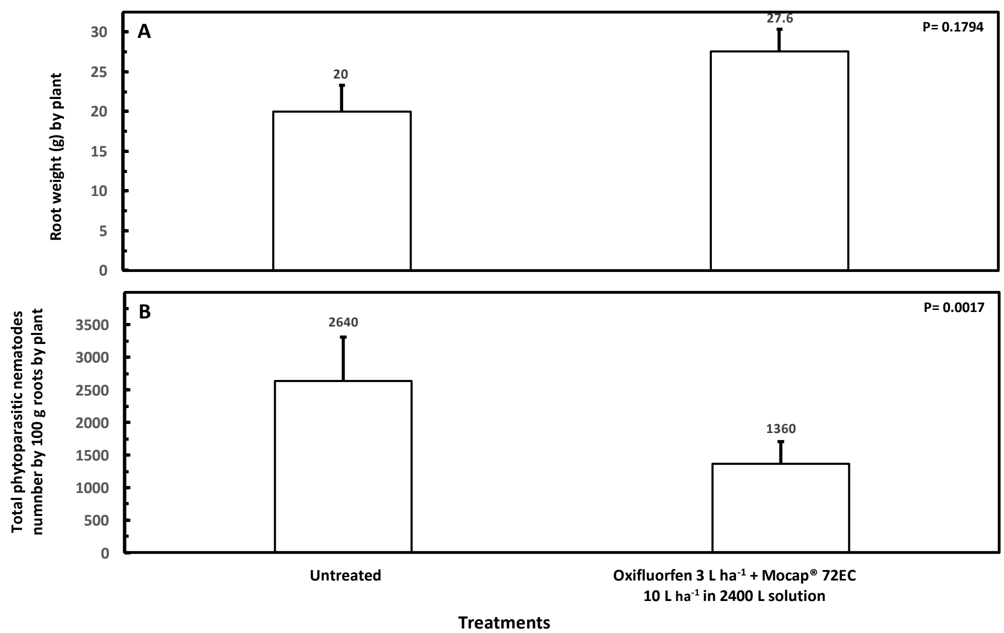
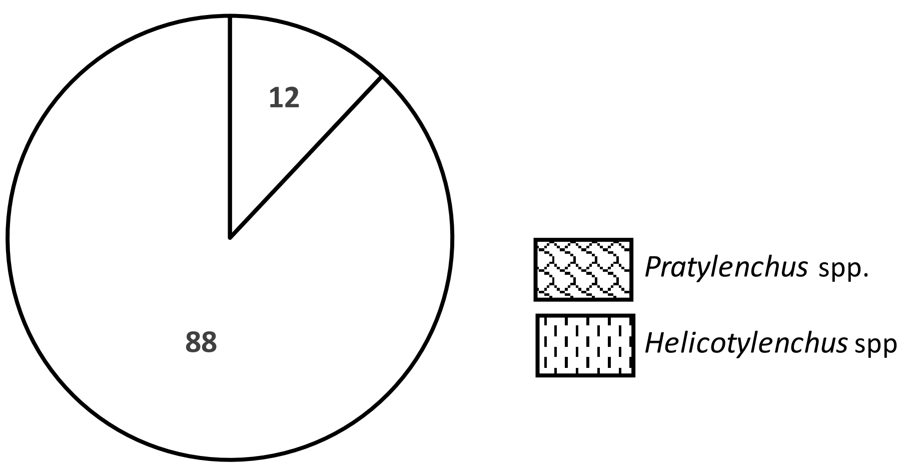



**Figure.4** Composition of the phytoparasitic nematode population 60 days after planting pineapple (*Ananas comosus* MD-2) stem shoots in beds applied or without applying with a solution of oxyfluorfen (Zeus® 24EC-Rainbow) 3 L ha$^{-1}$+ Mocap 72EC 10 Lha$^{-1}$in 2400 L of water. Each data represents the average of 20 repetitions and each repetition included the roots of 5 plants.




In the establishment of coffee nurseries, it is common to apply a mixture of the pre-emergent oxyfluorfen and Mocap® 72EC, after the beds have been prepared and before planting. When planting is delayed and weed germination is observed, paraquat or glyphosate is added to the previous mixture. So, with a single application they obtain control of weeds and soil pests when establishing coffee nurseries. In the solutions evaluated, the final pH varied between 7.1 and 7.4. According to Deer and Beard (2001); Fishel (2002); Tharp and Sigler

(2013) a water pH greater than 7 creates alkaline conditions that can cause some agrochemicals to undergo degradation or decomposition, a process known as alkaline hydrolysis. In general, insecticides are said to be much more susceptible to hydrolysis than fungicides, herbicides, defoliants, or growth regulators (Schilder, 2008; Deer and Beard, 2001). Different authors (Deer and Beard, 2001; Fishel, 2002; Schilder, 2008) indicate that hydrolysis can be rapid in the pH range of 8 to 9, but they also refer to the fact that it is not generalized and depends on each product. For example, Gómez *et al.,* (2006) found no differences in weed control with the herbicides Glyphosate, Fluazifop-p-butyl and Bentazon when the recommended rate of the product was used in water with pH of 8.5; 6.5 or 4.5. However, Esqueda and Tosquy (2015) reported loss of control of *Ixophorusunisetus* with the use of Glyphosate in solutions with water of pH 8.

As indicated by Gómez *et al.,* (2006), it is common for technicians to recommend the use of solution pH modifiers, often without justification. In the case of the labels of the evaluated products; Zeus® 24EC (oxyfluorfen), Velpar® 75WG (hexazinone), Trombo® 80 WG (diuron-urea), Sellapax® 80 WG (ametrine) and Mocap® 72EC (ethoprophos), none indicate that the solution must have a specific pH and the manufacturer is the best source to optimize the biological effectiveness of their products. Therefore, if there was compatibility and physical stability in the solutions, it would be expected that the biological efficacy of the products would not be affected.

The herbicides oxyfluorfen 24EC, hexazinone® 75WG, ametrine 80WG and diuron-urea 80WG are applied as pre-emergent to control grasses and broadleaf weeds and Mocap® 72EC is recommended for the control of symphylids (Bull, 1997; Araya, 2019a), nematodes (Sipes and Schmitt, 1995; Bull, 1997; Rebolledo *et al.,* 2011; Araya *et al.,* 2021) and other soil pests in different crops. The evaluated Mocap® 72EC rate of 10L (1x) in 2400 L of water per hectare generated concentrations of 3000 ppm of ethoprophos in the solution and it is known that concentrations of 100 ppm in applications of 100 ml of solution in drench in plants grown in pots significantly reduce nematodes (Chávez *et al.,* 2018).

Mocap® is an organophosphate insecticide-nematicide whose mode of action consists of inhibiting acetylcholinesterase (Roberts and Hutson, 1999; Devine *et al.,* 2008) of the nervous system of pests (symphylids-nematodes). Therefore, the application of any of the solutions evaluated is appropriate, given that during the establishment of pineapple plantations, the simultaneous presence of soil pests such as symphylids and nematodes is common, in addition to the emergence of weeds.

So, with a single application, weeds and the attack of symphylids (Araya, 2019), nematodes (Milla and García, 1983; Bull, 1997; Araya *et al.,* 2021) and other soil pests reported in the crop such as white grub (*Phyllophaga*) are prevented (Milla and García, 1983; Salazar *et al.,* 2015; Calvo *et al.,* 2016).

This was confirmed with the field application of the Zeus® 24EC (oxyfluorfen) solution at 3 L $ha^{-1}$ + Mocap® at 10 L $ha^{-1}$ where no symptoms of phytotoxicity were found and the absence of weeds, symphylids and a reduced number of plant-parasitic nematodes were observed.

So, if there is compatibility and physical stability of the solution, the biological effectiveness of the products is not compromised. However, if you want to ensure that there is no hydrolysis, you can lower the pH of the water to 6 - 6.5 with an acidifier such as citric acid, before adding the pre-emergent and the insecticide-nematicide.

The separate treatment of soil pests (symphylids and nematodes) and weed control has been the recommended practice (Rebolledo *et al.,* 2011) and that many pineapples growers practice in their cultivation. However, the shortage of labor, the availability of water and machinery and the cost of the work promotes the use of mixtures such as those evaluated in this research.

## Author Contributions

Daniel Herrera: resources, investigation, methodology. Fernán Paniagua: investigation, methodology, formal analysis. Jorge Abarca: validation, methodology, writing. Dyan Morales: validation, methodology. Oscar Cortes: investigation, methodology, reviewing, Juan Delgado: resources, methodology, reviewing. M. Araya: investigation, formal analysis, writing original draft, 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

**Conflict of Interest** The authors declare no competing interests.

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