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Article

Sustainable design for obtaining lime sulfur broth

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Abstract

This study aimed to produce lime sulfur broth through a systematized process to reduce energy expenditure, polluting gases into the atmosphere, and waste. The experiment was conducted in 2021. Through a design of experiments, a series of mixtures (sulfur-lime-water) were generated, which were made using control instruments within the process. Optimal mixtures were applied to Persian lime trees as a foliar fertilizer to see their behavior. The process was shown to be sustainable, clean, and cheap, and it generated little waste and has the same impact on trees as the empirical process. The sustainable process reduced polluting gases by 20%, polluting waste by 15%, and production costs by up to 30%.

Palabras clave:

environmental impact, fertilizer, systematized.

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Introduction

Crops are exposed to the attack of numerous pests, such as fungi, bacteria, insects, viruses, etc., which affect the roots, leaves, flowers, and fruits, reducing the quantity and quality of harvests and raising production costs. This has led to the massive use of synthetic pesticides instead of cheaper and less toxic products that farmers can prepare (Tejada and Escobal, 2014).

At present, some farmers are looking for cheap and efficient products to be able to have harvests that give them profits, at any cost regardless of the environment, since the current circumstances force them to do this; therefore, obtaining these products but in a sustainable way is a challenge, since controls have to be generated to ensure obtaining the expected result, helping to reduce energy expenditure, reagents and pollution, lessening the effect on their social, economic and environmental environment (Sánchez, 2019).

For the past decade, farmers and researchers have been discussing how to change the way humans live and behave to reduce their impacts on the environment, promote economic development, and improve social well-being (Curzons *et al*., 2001). The World Commission on Environment and Development, established by the United Nations in 1983, defined sustainable development as 'development that meets the needs of the present without compromising the capacities of future generations to meet their own needs' (Larrouyet, 2015).

The three pillars related to sustainable development are the economy, the environment, and society. Their relationship's purpose is to ensure economic and social development that respects the environment (Puerta, 2022). Lime sulfur broth is a mineral broth that is very useful for controlling fungal diseases in crops and provides nutrients for plant growth, flowering, and fruiting (Soto, 2013). It is used in the management of vegetables and fruit trees; pests limit production and increase costs, so it is a low-cost and easy-to-prepare alternative (Triadani, 2022).

The slaked lime $Ca(OH)_2$ reacts with elemental sulfur 'S' to produce a 'lime sulfur' used as an insecticide (Holb *et al*., 2003). The active ingredient is calcium sulfide, the chemical formula of which is CaSx. To avoid damage from pests and diseases to crops, in addition to using alternative products such as natural fungicides, it is necessary to consider other elements, such as cultural practices that influence crop health (Soto, 2010).

For example, avoiding waterlogging of the soil, performing phytosanitary pruning (removal of mature or damaged foliage from a crop), managing crop spacing for good light and air entry, removing diseased plants, collecting damaged fruits, avoiding the entry of private people into the plantation, and disinfecting footwear in a chlorine solution before entering the plots, among others (Soto *et al*., 2013).

Lime sulfur broth was first used to bathe cattle against mange. It was only in 1889, in California, that its viability as a product with insecticidal characteristics was proven. In 1902, this mixture became popular, and from then on, it began to be widely disseminated and used. Mainly to control mealybugs, mites, aphids, and thrips (Tweedy, 1967).

As a fungicide, it is in the first line and there are numerous formulas for its preparation (Herman, 1914). Grison (1852) suggested using a solution prepared by boiling slaked lime and sulfur in water and then letting the mixture decant. This solution was known for a long time as 'Grison water' and was the precursor of polysulfide with sulfur and lime, which enter into solution by boiling in water (Tejada and Escobal, 2014).

The production is low-cost but uncontrolled, expending large amounts of energy, emitting polluting gases into the atmosphere, and generating polluting waste. It is of utmost importance to generate this product due to its costs and characteristics but through a sustainable design. It is prepared using 20 kg of powdered sulfur, 10 kg of slaked lime, and 100 L of water (Molina de Cuella *et al*., 2011).

Place the water to boil in the metal bucket, taking care to maintain the volume of water constantly. Dry mix the lime and sulfur in a container. After the water boils, add the sulfur and lime mixture very carefully, mainly with the sulfur, as it is flammable in direct contact with the stove's flames (Kondo, 2022).

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Stir the mixture constantly with the wooden stirrer for about 45 min to an hour; the stronger the heat, the better prepared the broth will be. The broth is ready when, after boiling for about 45 minutes to an hour, it turns a red wine, clay tile, or brick color (Yentzen, 2018).

The advantages it provides due to its multiple modes of action (repellent, nutritional, acaricide, fungicide, and insecticide); it is essential to use it in different concentrations for each specific case; it is also an easy broth to make and has a broad spectrum of action (Guerra, 1985). It is a low-cost product compared to the traditional and permissible one in organic agriculture (Díaz, 2017).

It has the disadvantage of not being applied to cucurbit crops (melon, watermelon, pumpkin, squash, cucumber, and others of this family), as it causes premature aging (Díaz, 2017). Unlike other mineral broths, lime sulfur broth has a broad spectrum of action, including nutrition, repellent, miticide, fungicide, and insecticide (Penteado, 2000).

Insects, mites, or nematodes can hardly develop resistance, as it can evolve like pest insects (Domínguez, 2023). It is also very beneficial to use above ground, as it decompacts and oxygenates the soil at the same time, so plants grow healthier and stronger (Domínguez, 2023). This broth is very useful for almost any fungal disease; once the ingredients are available, it is made quickly and is immediately applicable (Domínguez, 2023).

The research aimed to produce lime sulfur broth in a controlled way to reduce pollution to the atmosphere and soil and reduce the energy expenditure made when doing it conventionally. The hypothesis is that lime sulfur broth produced in a controlled manner has the same effectiveness as that produced traditionally; the difference is that contamination is reduced by having the process controlled (Jiménez *et al*., 2011).

Materials and methods

Materials

The lime sulfur broth is composed of a mixture of three components, which are easy to acquire in any farm supply store: 93% sulfur, lime (Calidra), and water (Domínguez, 2023).

Designs of experiments

According to the reviewed bibliography and the current applications of the product, in addition to considering the elements to be reacted, which are three, a 3 x 3 design of experiments was developed to find the formulas to produce (Table 1), visualizing the excess or lack of any of these elements at the time of the reaction; this was determined by eliminating some of the proposed mixtures from the design, the base mixture is 10 L H_2O, 2 kg S, 1 kg lime (Chapin, 1916).

Table 1. Design of experiments.

Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)	Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)	Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)
1	10	2	1	10	5	2	1	19	0	2	1
2	10	2	0.5	11	5	2	0.5	20	0	2	0.5
3	10	2	0	12	5	2	0	21	0	2	0
4	10	1	1	13	5	1	1	22	0	1	1
5	10	1	0.5	14	5	1	0.5	23	0	1	0.5
6	10	1	0	15	5	1	0	24	0	1	0
7	10	0	1	16	5	0	1	25	0	0	1
8	10	0	0.5	17	5	0	0.5	26	0	0	0.5

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Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)	Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)	Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)
9	10	0	0	18	5	0	0	27	0	0	0

Formulas for production

The reaction that occurs is important, and for this, the three elements that make up the product must be present; if any of them is not present, that mixture is automatically eliminated since, as mentioned, the interaction of the three elements is important for the desired reaction to occur; therefore, the final result is shown in Table 2.

Table 2. Formula to reproduce as a result of the experiment design.

Formula	Water (H_2O) (kg)	Sulfur (S) (kg)	Lime (CaO) (kg)
1	10	2	1
2	10	2	0.5
3	10	1	1
4	10	1	0.5
5	5	2	1
6	5	2	0.5
7	5	1	1
8	5	1	0.5

Mixing

Unlike the conventional method, which uses firewood without any control, here we use gas to make the mixture, which is controlled by a regulator. A metal container with water is placed on top of the gas stove to heat it. Once the water reached boiling temperature, sulfur and lime were added at the same time with great care, mainly with sulfur, as it is flammable in direct contact with the flames of the stove (Abbot, 1945).

Another alternative is to dry mix both lime and sulfur in a container and then slowly add it to the boiling water; this is a safer way to carry out the procedure (Figure 1). Stir the mixture constantly with the wooden stirrer for about 45 min to an hour. The broth is ready when, after boiling for about 45 minutes to an hour, it turns a red wine, clay tile, or brick color. Let it rest (cool), filter and store in dark, tightly covered containers.

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Figure 1. Production of lime sulfur broth.

After removing all the broth from the metal container where it was prepared, a yellowish-green sandy sediment remains at the bottom of the container as a result of the remains of sulfur and lime that did not mix during the preparation of the broth. This byproduct should not be discarded; on the contrary, it constituted what was called lime sulfur paste, which is used to cover the places where branches are cut when pruning trees, helping to prevent fungi from entering, etc.

Final product

Once the mixture is finished, the final product must be left to cool and rest for 24 hours, obtaining the result for each proportion as shown in Figure 2; it could be observed that in formulas 5, 6, 7, and 8, very little fertilizer is produced; in terms of cost-benefit, it is perceived that is not convenient to produce these mixtures (Figure 3).

DOI: https://doi.org/10.29312/remexca.v15i6.3302

Figure 2. Flow diagram, process to obtain lime sulfur broth.

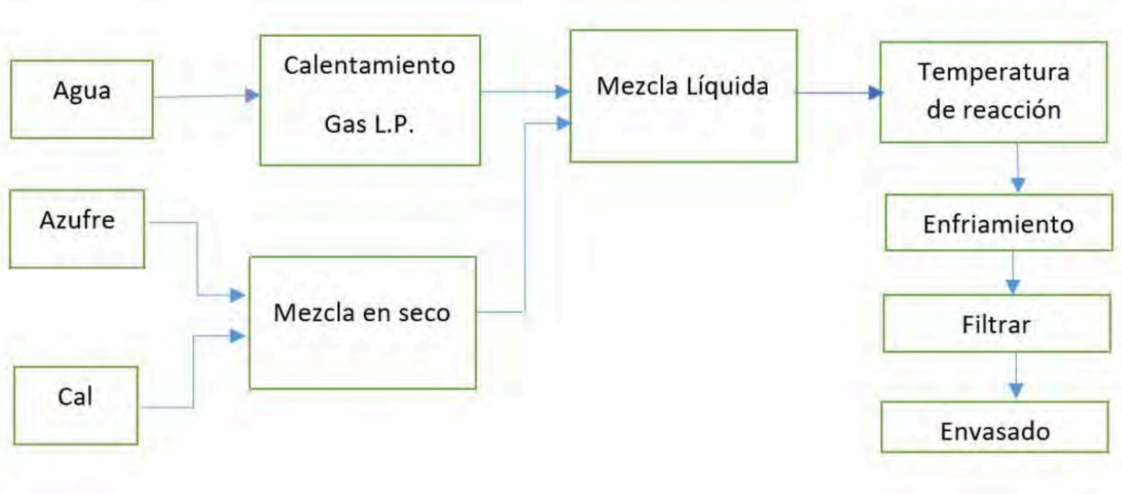

Figure 3. Product obtained from each proportion.

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Fertilizer testing

Once the formulas to be experimented with have been obtained, their results are demonstrated; for this, two Persian lime trees were planted for each product obtained, plus the controls, which are trees that are allowed to follow their growth process as they usually do; this refers to the fact that they develop traditionally. The following variables will be measured to find the optimal formula: length of the tree from the graft union, the diameter of the tree 5 cm above the graft union, the color of the leaves, and whether there are flowers or fruits. The product is applied every 15 days, and the aforementioned variables are measured every week for six months.

Results and discussion

Temperature control

The normal or traditional process in which the product is obtained does not consider control; this process was carried out empirically, and there is no parameter to measure to have control over the process. It was proposed to control various variables such as temperature; a digital thermometer (thermocouple) is used to obtain the numerical value at which the reaction takes place, which is when the characteristic reddish color was observed; this piece of data is of great help since when reaching the necessary temperature the heating stops, reducing the production of gases into the atmosphere, and expending less energy, as shown in Table 3.

Table 3. Reaction times and temperature.

Formula	Reaction time (min)	Temperature (°C)
1	47’ 35”	95
2	47’ 43”	95
3	47’ 15”	95
4	46’ 56”	95
5	45’ 22”	95
6	44’ 25”	95
7	45’ 48”	95
8	44’ 47”	95

Another variable is time; it can be observed that the reaction occurs between 45 and 50 min. Controlling these two variables ensures that the appropriate reaction occurs, thus obtaining the desired product with the specific characteristics for its application in the trees and guaranteeing a good production of the necessary quality.

Waste and product obtaining

A variable of utmost importance for this article and that cannot be left out is profitability (cost-benefit) since it is known that farmers look for economical products to make their profits yield. It is important to note that the product obtained through the process will be used in various crops, trees, etc.

The idea of controlling the variables of the production process is to ensure that in each series that is produced, we have the security of obtaining enough (optimizing the reaction) to use it continuously depending on the needs and the cycle of the crop, tree, etc.; in addition, according to the sustainability variables, the least amount of waste is generated; this means that almost all the reagents are transformed into products, which will contribute to the environment; the mixture that generates the largest amount of product and the least waste to the environment was observed in Table 4.

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Table 4. Product obtained and waste.

Formula	Product obtained (ml)	Waste (g)
1	3 200	2 720
2	4 600	2 870
3	3 600	3 430
4	4 400	3 001
5	400	2 200
6	1 000	1 870
7	1 550	1 350
8	1 900	1 780

The reactions that are approved are where there is the highest amount of product obtained since what the farmer requires is to reduce costs by a larger quantity of products that they will apply to the field and that these guarantee abundant and high-quality harvests, generating greater profits, which is a current problem of the Mexican countryside; in addition, having mixtures where the elements react almost entirely generates less waste that can impact the environment and for the little that is generated, we can look for applications such as using the remaining paste to heal the plants every time a cut is made, etc.

Experimental variables

Having the quantities of the final product for each mixture (Table 4) and according to the cost-benefit for the farmers, it was decided to use the first four formulas since product applications have to be made every 15 days and the quantities obtained in formulas 5 to 8 are not enough for a production cycle; therefore, formulas 1 to 4 are used, which must be applied every 15 days to the trees where we will test their efficiency and for this the variables are measured every week, obtaining results for each measurement as shown in (Table 5).

Table 5. Results obtained after six months.

Tests	Fd-Id	Fl-Il	Color	Flow	Flower or fruit
1	1.4	11	V	1	1
	0.9	13	VA	1	1
2	1.2	8	V	1	1
	0.7	10	VA	1	0
3	0.8	7	V	1	0
	1.2	8	VA	1	1
4	1.4	13	V	1	1
	1.8	16	V	1	1
5	0.8	6	VA	1	0
	0.6	5	VA	1	0

The variables are Fd-Id (final diameter-initial diameter), Fl-Il (final length-initial length), color, vegetative flow, and flower or fruit (material to be used for measurement: vernier and tape measure). These measurements allow us to see the development of the tree in its life cycle, reaching the exact maturity to obtain the final fruit and that the fruit is in good condition for consumption.

All the tests generate positive results since, in a greater or lesser proportion, nutrients are given to the trees; these results are compared with test 5, which is control trees, to which the amount of product that has been used over the years is applied (they developed conventionally), generating

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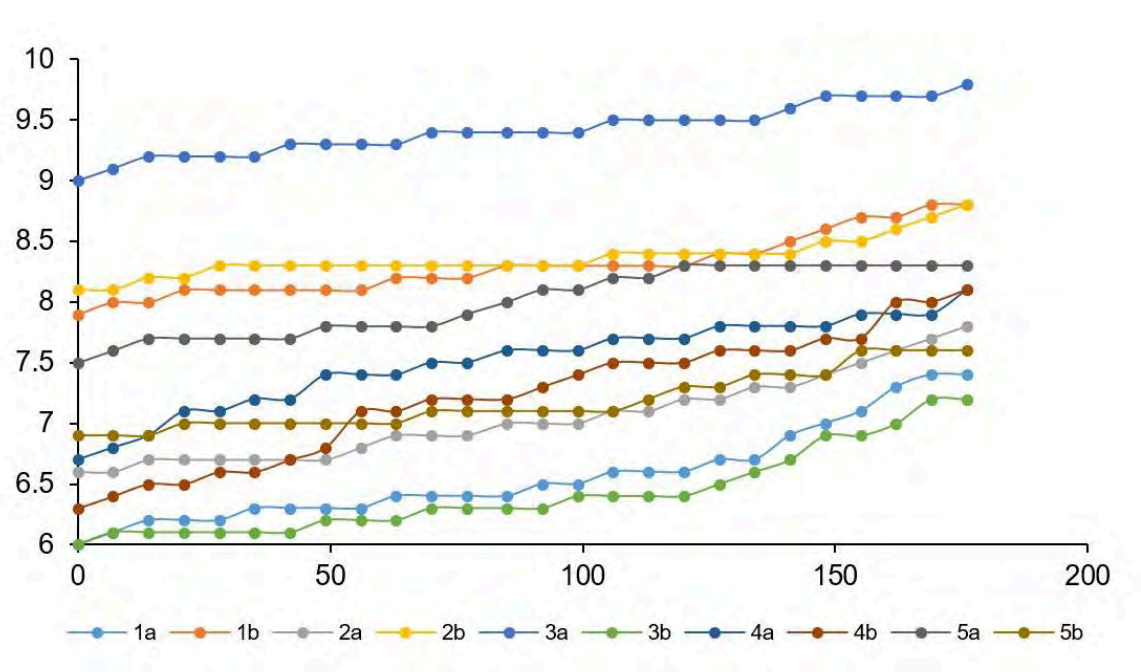
great costs and pollution; in addition, they tend to become sick more easily due to the attack of fungi, bacteria, etc.

All the formulas applied generate changes compared to the controls; it is observed how the diameter of the trees becomes thicker, which indicates the strength that is obtained, but formula number 4 gives the best results, as indicated in Figure 4.

Figure 4. Graph of diameter behavior.



Also, according to the controls regarding the length, all the applied formulas generate changes, showing the progressive growth of the trees, but again, formula 4 gives us the best results, as shown in Figure 5.

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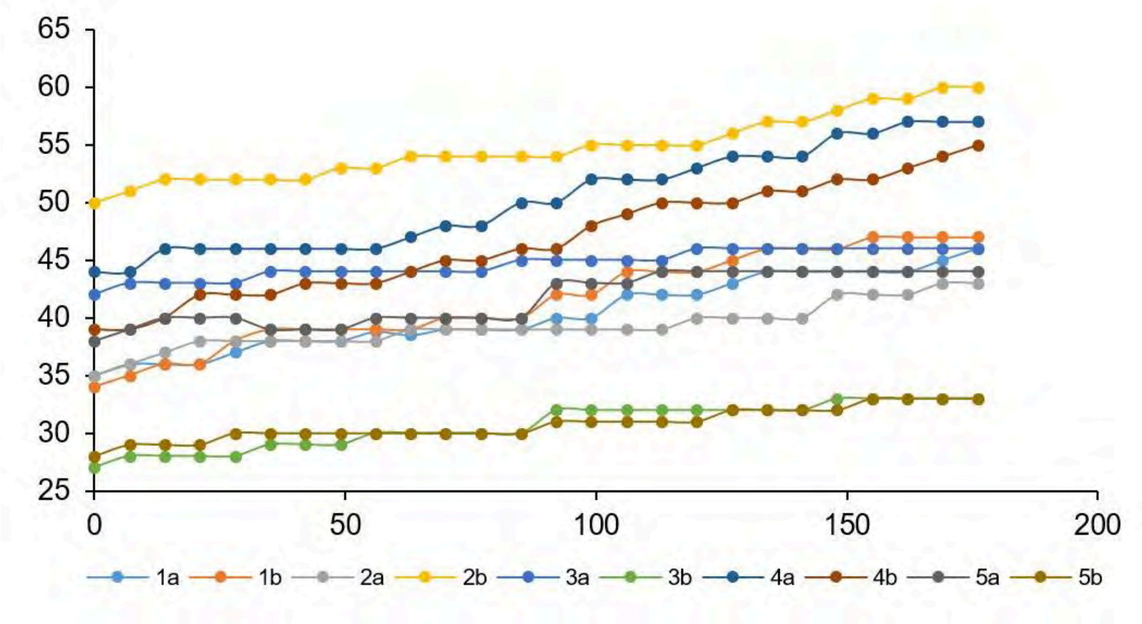
Figure 5. Behavior of tree lengths.



Regarding the other variables such as color, flower or fruit, and flow, all the formulas provide the necessary properties and characteristics to the trees; although, the one that gave the conclusive results was 4. The control supported us in comparing that carrying out the process of tree development in a normal way does not give the best yields or adequate quality compared to the formulas implemented, which give very good results in growth, development, and production, in addition to taking care of the environment.

Conclusions

It is necessary to control the process to have better product results; the above by controlling the reaction temperature, which occurs at 95 °C, where the reddish color of the product is observed, which indicates that the elements have reacted and the heater should be turned off, thus reducing gas emissions into the atmosphere and energy expenditure; in addition, time control, which indicates that the reaction is within the necessary parameters for it to occur properly and obtain our product, which ranges from 45 to 50 min.

Number 4 should be produced, as it shows the best parameters in trees, greater thickness, and length, indicating good development towards maturity. The leaves obtain the characteristic green color of a well-nourished tree, and vegetative flow and flowering are generated in less time, which indicates the strength that each tree reached to obtain the fruit, with the necessary quality for consumption. The cost-benefit analysis is also of great impact since, for its production, we use less number of reagents and it gives us an excellent yield (greater amount of product), generating less solid waste that impacts the environment.

The amounts of gases into the atmosphere, as well as solid waste through the controlled process, are lower than in the empirical way in which the process is carried out, thus generating less impact on the environment, and considering that the few solids generated can have other uses, a sustainable process is complied with since we reduce the impacts on the environment by 20%, economically costs are reduced by up to 30% by using fewer inputs, while, socially, the new generations are taught to take care of the environment and be responsible for caring for the planet.

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