https://doi.org/10.1590/1678-992X-2023-0194
ISSN 1678-992X
Scientia Agricola
Research article

Economic benefit of an optimized copper spray program for citrus canker and black spot control in Brazil

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Edited by: José Belasque Junior

Received August 16, 2023
Accepted November 05, 2023

ABSTRACT: Copper-based formulations are used extensively to manage two of the leading citrus diseases that affect the São Paulo (SP) citrus belt, Brazil, namely, citrus canker and citrus black spot. Since the early 2010s, studies have identified the critical period and ideal frequency of copper applications to control each disease. Consequently, results have led to an optimized joint spray program replacing the traditional one and an essential reduction in copper use without affecting control quality. These research studies have presented the benefits of copper use reduction, although the potential economic impact has not been calculated. The present study aimed to estimate the value of copper potentially saved by adopting the optimized spray program for citrus canker and citrus black spot control per hectare and in the entire SP citrus belt since 2017, when both diseases began to be managed concomitantly. The optimized program allowed for a ~56 % reduction in metallic copper usage (~10 kg ha^{-1} per season). This amount of copper saved corresponds to ~120 dollars per hectare per season. Moreover, if the optimized program were to be used throughout the SP citrus belt, the average saving is estimated at ~56 million dollars per season. These results showed that economic analysis reinforces the value of scientific research herein by adjusting disease management for the production chains' maintenance, development, and sustainability.

Keywords: *Phyllosticta citricarpa, Xanthomonas citri* subsp. *citri*, research benefit, production cost, citrus diseases

Introduction

Copper is one of the main inputs to prevent crop losses caused by diseases in citrus-growing areas. Insoluble copper formulations are essential for managing citrus canker, caused by the bacterium *Xanthomonas citri* subsp. *citri* (Hasse 1915) Constantin 2016 and citrus black spot, caused by the fungus *Phyllosticta citricarpa* (McAlpine) Aa, 1973 during the spring and summer months when frequent rainfall and warm temperatures coincide with the presence of flushing and young fruit (Silva Junior et al., 2016a, b; Behlau et al., 2017). In addition to causing premature fruit drop, both diseases also affect the fruit quality in the fresh market by blemishing the fruit rind and restricting trade to areas where these diseases are not present (Gottwald et al., 2002; Yonow et al., 2013).

Despite the efficiency in controlling citrus canker and black spot, the excessive use of copper may negatively affects citrus orchards. It may affect the development of citrus trees due to phytotoxicity and damage to roots caused by accumulation in the soil (Lamichhane et al., 2018). The indiscriminate use of copper may lead to the selection of resistant strains of *X. citri* and reduce its effectiveness in controlling citrus canker (Behlau et al., 2011, 2020). Furthermore, over the last few years, there has been an increase in the cost of metallic copper used in formulations applied in agriculture. Thus, while no highly effective measures are available for the control of diseases affecting citrus and other crops (Lamichhane et al., 2018), studies are focused on the reduction of copper to minimize environmental impacts and reduce costs (Ninot et al., 2002; Zortea et al., 2013).

Since 2017, there has been an increase in copper use in the São Paulo citrus belt after the adoption of the risk mitigation system for citrus canker. Thus, studies have been developed to rationalize copper consumption by identifying the optimal spray timing, rate, volume, and frequency for citrus canker and black spot control. Results have led to an important reduction in copper without affecting the quality of the control (Behlau et al., 2017, 2021a; Lanza et al., 2018; Silva Junior et al., 2016a, 2022; Ferreira et al., 2022).

These research studies have shown the benefits of reductions in copper use on an experimental scale, but the potential economic impact has yet to be extrapolated. Therefore, the objective of this study was to estimate the economic benefit of an optimized copper spray program for joint management of citrus canker and black spot, not only per hectare but also in the entire SP citrus belt.

Materials and Methods

Extension of the São Paulo state citrus belt

The SP citrus belt comprises orchards in the states of São Paulo and west-southwestern Minas Gerais (Figure 1). The total average area cultivated with citrus in the SP citrus belt from 2017 to 2022 was 458,082 ha, according to the tree inventory and orange crop forecast published annually by Fundecitrus (https://www.fundecitrus.com.

br/pes/estimativa) (Table 1). This belt includes the largest sweet orange-growing area in the world, with 394,952 ha, representing 86 % of the entire belt. The remaining area of approximately 63,130 ha was occupied by orchards of acid limes, lemons, tangerines, and other orange cultivars that are not processed by the juice industry. During the period assessed, ~79 % of the citrus orchards were older than five years (360,064 ha). The cultivated area per citrus species and orchard age, in hectare and proportion, for each season are shown in Table 1.

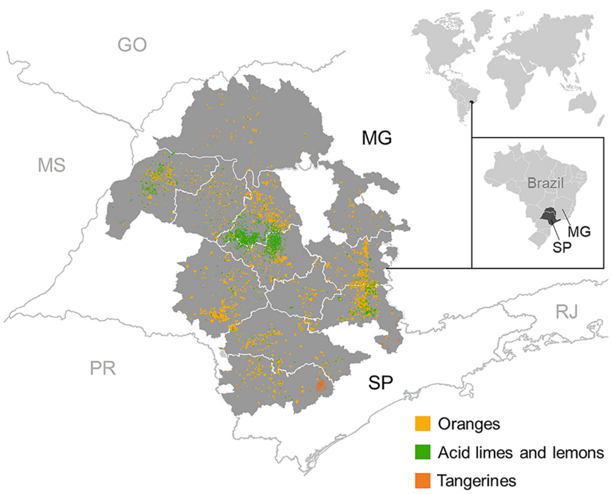

Figure 1 – Distribution of citrus production and location of the São Paulo citrus belt in Brazil, composed of citrus-growing areas in the states of São Paulo (SP) and west-southwestern Minas Gerais (MG). GO = state of Goias; MS = state of Mato Grosso do Sul; PR = state of Paraná; RJ = state of Rio de Janeiro.

The information on the size of the citrus belt and the proportion of each age range was used to calculate the weighted average amount of copper use per hectare per season based on the tree size and spray volume and, ultimately, to estimate the total amount of copper potentially used per season in the entire citrus belt according to both the traditional and the optimized copper spray programs.

Premises of the traditional and the optimized copper spray programs

The traditional program is based on a copper spray program developed in the 1980s and 1990s for citrus canker and citrus black spot control (Leite Junior and Mohan, 1990; Canteros et al., 2017; Silva Junior et al., 2016b). In turn, the optimized copper spray program is based on the results of a series of experiments developed by Fundecitrus since the early 2010s, which has led to more rational use of copper in the SP citrus belt (Scapin et al., 2015; Behlau et al., 2010, 2017, 2021a, b; Lanza et al., 2018; Silva Junior et al., 2016a, 2022; Ferreira et al., 2022). The main differences between the traditional and the optimized copper spray programs are related to a lower load of copper in the latter due to a shorter period

Table 1 – Citrus production area and proportion of orchards by age for oranges, other citrus types, and all citrus in the São Paulo citrus belt for the 2017/2018 to 2022/2023 seasons.

Orchard age	2017/2018		2018/2019		2019/2020		2020/2021		2021/2022		2022/2023		Average	
years[a]	ha per season	%	ha per season	%	ha per season	%	ha per season	%	ha per season	%	ha per season	%	ha per season	%
Oranges[b]														
1 to 2	17,041	4.2	23,047	5.7	25,716	6.5	31,227	7.9	41,046	10.6	42,684	11.0	30,127	7.7
3 to 5	48,447	12.0	37,472	9.3	31,262	7.9	34,183	8.6	36,225	9.4	51,509	13.3	39,850	10.1
6 to 10	141,481	35.1	123,238	30.7	101,625	25.7	87,790	22.2	75,567	19.5	67,294	17.4	99,499	25.1
> 10	195,597	48.6	217,713	54.2	237,161	59.9	242,471	61.3	234,331	60.5	225,586	58.3	225,477	57.1
Sub-total	402,566	100.0	401,470	100.0	395,764	100.0	395,671	100.0	387,169	100.0	387,073	100.0	394,952	100.0
Acid limes, lemons, tangerines, and other oranges[c]														
1 to 2	6,439	13.5	13,079	20.4	13,298	20.7	13,630	21.5	12,879	20.0	12,951	17.3	12,046	18.9
3 to 5	10,938	23.0	14,866	23.2	15,486	24.1	15,410	24.3	16,014	24.9	23,261	31.1	15,996	25.1
6 to 10	14,443	30.3	20,223	31.5	20,216	31.4	19,581	30.9	19,919	30.9	23,516	31.4	19,650	31.1
> 10	15,788	33.2	15,998	24.9	15,342	23.8	14,766	23.3	15,618	24.2	15,119	20.2	15,438	24.9
Sub-total	47,609	100.0	64,165	100.0	64,343	100.0	63,387	100.0	64,429	100.0	74,848	100.0	63,130	100.0
São Paulo citrus belt														
1 to 2	23,480	5.2	36,126	7.8	39,014	8.5	44,857	9.8	53,925	11.9	55,635	12.0	42,173	9.2
3 to 5	59,385	13.2	52,338	11.2	46,748	10.2	49,593	10.8	52,239	11.6	74,770	16.2	55,846	12.2
6 to 10	155,924	34.6	143,461	30.8	121,841	26.5	107,371	23.4	95,486	21.1	90,810	19.7	119,149	26.0
> 10	211,385	47.0	233,711	50.2	252,503	54.9	257,237	56.0	249,949	55.3	240,705	52.1	240,915	52.6
Total	450,175	100.0	465,635	100.0	460,107	100.0	459,058	100.0	451,598	100.0	461,921	100.0	458,082	100.0

[a]Data from the tree inventory and orange crop forecast for the São Paulo and west-southwestern Minas Gerais citrus belt (https://www.fundecitrus.com.br/pes/estimativa). [b]Group composed of early-maturing (Hamlin, Westin, Rubi, Valencia Americana, Seleta, and Pineapple), mid-season (Pera), and late-maturing (Valencia, Natal, and Folha Murcha) cultivars intended for juice processing in the citrus belt. [c]Group composed of acid limes (Tahiti, Persian, Galego and Mexican), Sicilian lemon, tangerines and their hybrids (Ponkan and Murcott), and other minor sweet oranges (Washington, Baianinha, Charmute and Lima) that are not used for juice processing.

of sprays associated with lower rates of metallic copper and spray volumes.

In the traditional spray program, the spraying period runs from Aug to May with an interval of 30 days. Differently, in the optimized program, the spraying period is shorter, spanning from Sept to Mar, but more frequent, with an interval of 21 days between sprays. Thus, the average number of sprays per season is similar in both programs (Table 2).

Prior to studies that adjusted the spray volume to the tree row volume (TRV) (Scapin et al., 2015; Behlau et al., 2021a; Silva Junior et al., 2016a), visual runoff was the primary reference used to determine the volume of water used for copper applications in citrus orchards. Even though this method also considers the tree size to adjust the spray volume as the orchard develops, it leads to an excessive use of water and copper. Noteworthy in both spray programs is that the rate of metallic copper used per hectare per spray increases with orchard age but to a lesser extent in the optimized program (Table 2). In the traditional spray program, the metallic copper rate ranges from 0.75 to 2.25 kg ha^{-1}, which results in the cumulative use of 6.8 to 20.5 kg metallic copper ha^{-1} per season. By contrast, in the optimized program, the metallic copper rate per spray and the total amount applied per season varies from 0.5 to 1.0 kg ha^{-1} and from 4.3 to 8.6 kg ha^{-1}, respectively. This represents, during the season, a reduction of between ~37 and 58 % compared to the traditional spray program.

Copper costs

The avoided copper amount associated with the corresponding cost reduction was used to estimate the economic benefits of the optimized over the traditional spray program. This study focused only on the copper costs because the labor and machinery expenses for copper sprays are disbursed together with other sprays to control other diseases and pests affecting citrus. The first step was to obtain the copper prices paid by growers. Because the prices paid per kg in large amounts of copper usually bought by larger growers is substantially lower than that paid by small growers, the average price paid for metallic copper from 2017/2018 to 2022/2023 was obtained separately from these two groups of growers of the citrus belt by direct interviewing of growers and sales representatives. Small growers were considered those with a total citrus area of up to 1,000 ha, and large growers those with a total citrus area above 1,000 ha. The price of metallic copper was converted from Brazilian reais (R$) to US dollars ($) using the average monthly purchase exchange rate from each year (Bacen, 2023). The second step was to estimate the weighted average cost of metallic copper based on the proportion of large and small properties within the citrus belt according to the tree inventory and orange crop forecast for the SP citrus belt (https://www.fundecitrus.com.br/pes/estimativa).

The cost of metallic copper in each spray program was calculated in dollars per hectare ($ ha^{-1}) and in million dollars (mi $) per season based on the total area of the citrus belt (Table 1). The cost per hectare was multiplied by the total area (ha) of citrus to obtain the cost of metallic copper in the entire citrus belt per season (Table 1). Average costs of metallic copper per hectare and in the citrus belt were also calculated based on data from the six seasons. Finally, the copper cost reduction was calculated, per hectare and in millions of dollars, by the difference in the metallic copper cost in the traditional compared to the optimized program. The estimation is based on a scenario in which the entire citrus belt follows one or the other spray programs.

Table 2 – Spray period, number of sprays and average amount of metallic copper used in the traditional and the optimized spray programs in the São Paulo citrus belt by orchard age and six-seasons average (from 2017/2018 to 2022/2023) per hectare and in the São Paulo citrus belt.

Orchard age	Spray period	N° of sprays	Amount of metallic copper			
					Thousand tons per season	
					Sweet oranges for juice	Citrus for fresh market
years			kg ha^{-1} per spray	kg ha^{-1} per season		
Traditional spray program						
> 0 to 2	15 Aug to 15 May	9.1[a]	0.75	6.8	0.2	0.1
3 to 5			1.50	13.7	0.5	0.2
6 to 10			2.00	18.2	1.8	0.4
> 10			2.25	20.5	4.7	0.2
Average[c]			2.00	18.0	Total: 8.1	
Optimized spray program						
> 0 to 2	15 Sept to 15 Mar	8.6[b]	0.50	4.3	0.1	0.1
3 to 5			0.75	6.5	0.3	0.1
6 to 10			1.00	8.6	0.9	0.2
> 10			1.00	8.6	1.9	0.1
Average[c]			0.90	8.0	Total: 3.7	

[a]Number of copper sprays per season is based on a 30-day spray interval from Aug to May. [b]Number of copper sprays per season is based on a 21-day spray interval from Sept to Mar. [c]Based on the weighted average by the proportion of areas (ha) of different ages in each season from 2017/2018 to 2022/2023 considering all the citrus belt according to Table 1.

Results

The efforts to rationalize the copper input in the citrus orchards of the SP citrus belt have led to a potential reduction of 56 % in the volume and costs of this protectant fungicide/bactericide. Based on the proportion of the orchard area under different ages in the entire citrus belt (Table 1), the weighted average amount of copper potentially applied, whether the traditional or the optimized spray program was widely used, was 18.0 and 8.0 kg ha^{-1} per season, respectively. These amounts could have led to total copper consumption in citrus plantings of 8.1 or 3.7 thousand tons in the SP citrus belt, representing an average of 2.0 and 0.9 kg copper ha^{-1} per spray (Table 2).

The price paid for metallic copper ($ ha^{-1}) from 2017 to 2022 ranged from $ 11.40 to $ 15.90 for small growers and from $ 9.14 to $ 15.10 for large growers. Taking into account that during this period, the proportion of farms with a citrus-growing area smaller than 1,000 ha (small growers) ranged from 66 % to 69 %, and of farms with an area greater than 1,000 ha (large growers) from 31 % to 34 %, the weighted average of the price paid for metallic copper ranged from $ 10.70 to $ 15.65. The price paid by smaller growers was, on average, 10 % higher than that of large growers. The price of copper changed abruptly in 2021 when an increase of > 50 % was observed compared to the previous year (Table 3). This coincided with an increase in the international price of copper as a commodity, while the exchange rate increased by only 4 % in the same period (NASDAQ, 2023).

The metallic copper costs following the traditional and the optimized spray programs from 2017 to 2022 as well as the potential savings by using the latter were estimated per hectare (Figure 2A) and for the entire SP citrus belt (Figure 2B) considering the citrus-growing area in each year. Following copper price fluctuations (Table 3), estimated copper costs for the traditional and optimized programs remained stable from 2017 to 2020, substantially increased in 2021, and a downward trend in

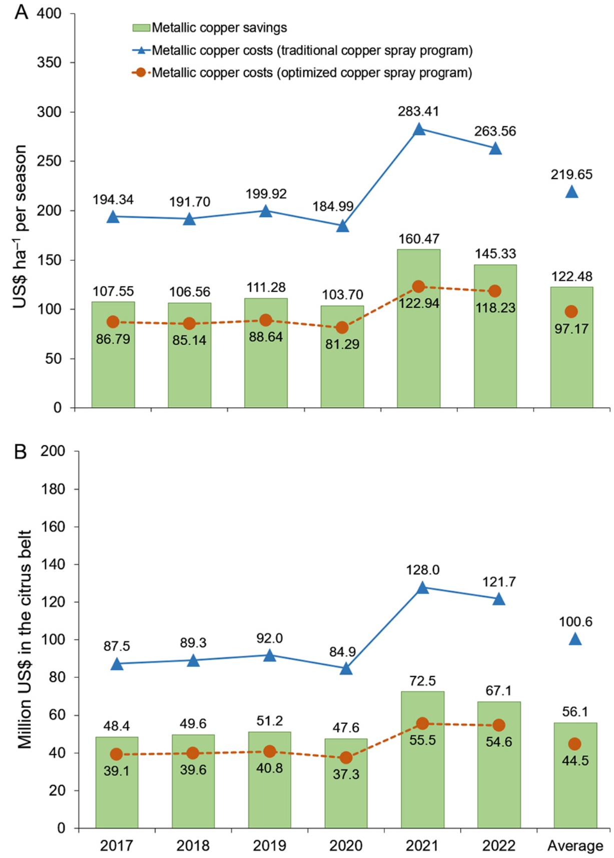

Figure 2 – Average costs of metallic copper used in the São Paulo (SP) citrus belt based on the traditional (continuous line) and optimized (dashed line) spray programs for joint management of citrus canker and citrus black spot, and the potential cost saving (bar) with the use of the optimized copper spray program from 2017 to 2021, and the six-year average in $ ha^{-1} per season (A), and in millions $ for the whole SP citrus belt (B). The metallic copper costs are based on the amount of metallic copper presented in Table 3 and the metallic copper prices presented in Table 2. The estimate is based on the entire citrus belt following one or the other of the spray programs.

Table 3 – Percentage of citrus growing area and price of metallic copper paid by growers in the São Paulo citrus belt by the size of the citrus farm for the 2017/2028 to 2022/2023 seasons.

Size of citrus farm	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022	2022/2023
	Citrus growing area[a]					
ha	---------- % ----------					
0.1 to 1,000	69	67	66	68	68	68
Above 1,000	31	33	34	32	32	32
	Price of metallic copper[b]					
	---------- US$ kg^{-1} ----------					
0.1 to 1,000	11.40	11.04	11.33	10.25	15.90	15.82
Above 1,000	9.14	9.68	10.44	10.11	15.10	14.08
Weighted average[c]	10.70	10.59	11.03	10.21	15.65	15.25

[a]Data from the tree inventory and orange crop forecast for the São Paulo and west-southwestern Minas Gerais citrus belt (https://www.fundecitrus.com.br/pes/estimativa). [b]Price of metallic copper was converted into U.S. dollars ($) using the average exchange rate per season (BACEN, 2023). [c]Average price of metallic copper based on the weighted average price of metallic copper paid by the citrus grower based on the size of the citrus farm (US$ kg^{-1}) per season in Brazil.

2022 (Table 3, Figure 2A-B). Until 2020, copper costs for the traditional program ranged from $ 184.99 to $ 199.92 ha^{-1} per season, as opposed to $ 81.29 and $ 88.64 for the optimized program. In 2021, with the rise in copper price, the estimated cost of copper for the traditional and the optimized programs were $ 283.41 ha^{-1} and $ 122.94 ha^{-1} per season, respectively. This represented an increase of approximately 55 %, in comparison to the previous year. In 2022, there was a slight drop in the estimated copper costs for each spray program to $ 263.56 ha^{-1} and $ 118.23 ha^{-1}, respectively (Figure 2A).

The potential savings with copper varied accordingly and reached, on average, $ 107.27 ha^{-1} from 2017 to 2020, and $ 152.90 ha^{-1} from 2021-2022. During the entire period, the cost of the traditional and the optimized spray programs costs assessed averaged at $ 219.65.61 and $ 97.17 ha^{-1}, respectively, generating an average potential savings of $ 122.48 ha^{-1} per season, which also corresponds to a 56 % reduction in copper expenditures (Figure 2A).

When the cost reduction in copper use between the traditional and optimized programs is extrapolated to the citrus belt, the differences and impact of the adjustments become even more evident. If the entire SP citrus belt used the traditional spray program, the copper costs would be $ 84.9 million in 2020, based on when copper prices were lower, and $ 128 million in 2021, when copper prices had an abrupt increase. However, with the adoption of the optimized program, the expenditures on copper were $ 37.3 and $ 55.5 million, resulting in a potential saving of $ 47.6 million and $ 72.5 million, respectively. Despite the downward trend in copper prices in 2022, the potential cost saving ($ 67.1 million) was similar to the previous year for the entire SP citrus belt (Figure 2B). Considering the six-year average, the estimated cost of copper was $ 100.6 million based on traditional practice and $ 44.5 million if using the optimized program. This corresponds to $ 56.1 million saved per season with copper following the optimized program over the entire SP citrus belt (Figure 2B).

Discussion

The results of the present study revealed that the use of an optimized joint copper spray program may reduce the amount of copper required for the control of citrus canker and black spot by up to ~56 % and, at the same percentage, the cost of copper per hectare and across the entire SP citrus belt. The application of copper during spring and summer every 14 to 21 days using 40 and 70 mL of spray mixture m^{-3} tree canopy at 30 to 40 mg metallic copper m^{-3}, until achieving 0.7 to 1 kg of metallic copper ha^{-1} per application (Ferreira et al., 2022; Behlau et al., 2017, 2021a; Silva Junior et al., 2016a) leads to a 10 kg ha^{-1} (from 18 to 8 kg ha^{-1}) reduction in the use of metallic copper per hectare in comparison to the traditional program. Considering that all growers were using the optimized spray program, it is estimated that 3.7 thousand tons could have been used per season in the SP citrus belt, representing a reduction of 4.3 thousand tons compared to the traditional spray program. The amount of copper used in the traditional spray program may be used to treat almost twice the area following the copper rates of the optimized program without reducing the quality of disease control.

Optimizing the management of plant disease is relevant in the current scenario of scarce environmental and financial resources and the need to increase production and economic efficiency. Global markets are demanding a reduction in the use of copper in agriculture through the establishment of maximum residue limits and amounts used per unit area cultivated or even the banishment of its use in organic systems (Lamichhane et al., 2018). Although there are attempts to use alternative strategies, e.g., biological control and induction of systemic resistance (Llorens et al., 2015; O'Brien, 2017; La Torre et al., 2018; Chen et al., 2020; Poveda et al., 2021), there is no viable and effective copper substitute for control of plant disease, particularly those caused by bacteria (Graham and Leite Junior, 2004; La Torre et al., 2018). Therefore, producers need to continue using copper but should apply it based on optimal quantities for disease control, thereby avoiding excessive use and minimizing the impact on food quality and soil biota, and reducing the risk of phytotoxicity and selection of copper-resistant populations of plant pathogens (Khan and Scullion, 2000; Lamichhane et al., 2018; La Torre et al., 2018; Marin et al., 2019; Behlau et al., 2012, 2020).

A reduction in the amount of copper applied in citrus orchards in the SP citrus belt may not only increase the efficiency of disease control as has been comprehensively reported (Scapin et al., 2015; Silva Junior et al., 2016a; Behlau et al., 2017, 2021a, b; Lanza et al., 2019) or minimize the adverse effects that cumulative use may impose on the citrus trees (Lamichhane et al., 2018; La Torre et al., 2018; Behlau et al., 2012, 2020), but also generate substantial reduction in production costs. For example, the research efforts to reduce copper use by the citrus industry have lowered the average cost of copper from $ 219.65 to $ 97.17 ha^{-1} per season, a reduction of $ 122.48 ha^{-1} per season, which represents an annual saving of $ 56.1 million over the SP citrus production belt. The savings equate to 6.1 million boxes of oranges at current prices or could be used to purchase approximately 720 tractor and sprayer sets per year, which would contribute to improving the control of all citrus diseases and pests more efficiently. The opportunity to reduce costs becomes even more urgent as the cost of copper-based formulations used in agriculture has increased dramatically in recent years.

The establishment of an efficient spray program for control of citrus canker and citrus black spot using a lower amount of copper was only possible to achieve because of applied scientific research. In the last eleven years, the Fundo de Defesa da Citricultura (Fundecitrus) with additional financial support from the Fundação de

Amparo à Pesquisa do Estado de São Paulo (FAPESP) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) in Brazil spent a combined $ 1.14 million on research projects focused on the rational use of copper in citrus orchards in the SP citrus belt. Taking into account the accumulated savings in the SP citrus belt from 2017 to 2022 (336.4 million dollars), these research studies have resulted in a return of approximately $ 295 for each dollar invested, which increases year-on-year with the continued accumulation of the economic benefits from the adoption of the results over the coming seasons. Noteworthily, the investment in research corresponds to only 2 % of the value potentially saved every year during the six years that the two diseases have been jointly managed in the SP citrus belt or to the amount spent on copper per season using the optimized spray program in only one large farm of 9.5 thousand hectares, which occupies ~2 % of the SP citrus belt.

In addition to citrus, copper rates are being downsized in several crops to control different diseases, e.g., from 1 kg of copper ha^{-1} to 200 g of copper ha^{-1} for the control of downy mildew in grapevine (Cabús et al., 2017), and from 3 kg of copper ha^{-1} to 1.25 kg of copper ha^{-1} for the control of late blight in potato (Bangemann et al., 2014) depending on the pathogen pressure. As reviewed, crops such as apple, coffee, tomato, pome fruit, walnut, mango, and olive also make significant use of copper-based formulations to control different diseases (Lamichhane et al., 2018). Thus, there is even more significant potential for a reduction in copper use and a concomitant cost reduction if the spray programs in these crops were also subjected to an optimized approach. Other studies have not shown the economic impact of optimizing copper use. In contrast, our study fills this deficiency by comprehensively demonstrating the extent of the economic benefits of reduced copper use in citrus orchards as a means of not only encouraging growers to adopt a more economical, environmentally sound, optimized copper spray program but also more broadly, to help convince the agricultural sectors of the importance of investing in scientific research to develop solutions to improve sustainability and profitability of crop production.

Reducing the amount of copper used in crops not only brings economic benefits. In addition to cost reduction, it contributes to reducing environmental pollution and maintaining the balance of the ecosystem without failing to control diseases efficiently. While another more sustainable strategy is developed, it is essential to use the technologies and alternatives (that are few) to manage these diseases with responsibility using innovative practical solutions. The value of research, well-illustrated in this study, will continue to contribute to developing solutions to lower dependence on copper to manage plant diseases. Indeed, copper products may eventually be replaced by more environmentally sound materials, including biological control agents or genetically improved cultivars. This will be a major advance towards truly more sustainable agricultural production.

Acknowledgments

The authors thank Fundo de Amparo à Pesquisa do Estado de São Paulo (FAPESP, grants #2013/05550-9, #2020/05701-0) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, #458052/2014-0) for financing part of this study. The authors thank CNPq for the research productivity fellowships to the first author (grant #307163/2020-2) and second author (grant #316910/2021-0).

Authors' Contributions

Conceptualization: Behlau F, Silva-Junior GJ. **Data curation:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC. **Formal analysis:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC. **Funding acquisition:** Behlau F, Silva-Junior GJ. **Investigation:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC. **Methodology:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC, Adami ACO, Miranda SHG. **Project administration:** Behlau F, Silva-Junior GJ. **Resources:** Behlau F, Silva-Junior GJ. **Supervision:** Behlau F, Silva-Junior GJ. **Writing-original draft:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC. **Writing-review & editing:** Behlau F, Silva-Junior GJ, Moreira RR, Monteferrante EC, Adami ACO, Miranda SHG.

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