An economic evaluation of agrochemicals use in two Brazilian major crops[1]

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Abstract – This research quantified the economic importance of pest and disease control for agricultural producers in Brazil. The probable economic losses that would result if agrochemicals were not applied to control the observed infestations was evaluated by means of simulations based on experimental data and economic models. Every crop management practices were assumed to be maintained except those related to the use of the agrochemical in question. Primary data from 31 representative producing regions in 14 Brazilian states were used for three harvests seasons of soybeans and corn (2014/2015, 2015/2016 and 2016/2017). The question was: how would observed producers' costs, revenues and profits change if the control of one of the observed pest or disease was suppressed, taking into account the likely rise in market prices that the reduction in supply would cause? The results indicate that the lack of pest and disease control could cause substantial economic losses to producers. For instance, failure to treat soybean rust in 2016/2017 would result in farmers' loss of more than US$ 3.7 billion, because observed aggregate profit of US$2.63 billion would turn into a loss of US$ 1.06 billion. No control of the Spodoptera caterpillar would transform observed soybean farmers' profit of US$2.63 billion into a loss of US$0.46 billion, thus totaling a profitability loss of US$3.08 billion.

Keywords: agrochemical control, economic losses, grain producing pest management.

Avaliação econômica do uso de agroquímicos em duas grandes lavouras brasileira de grãos

Resumo – Esta pesquisa quantificou a importância econômica do controle de pragas e doenças para os produtores agrícolas no Brasil. As prováveis perdas econômicas sem a aplicação de agroquími-

[1] Original recebido em 22/9/2020 e aprovado e 26/2/2021.

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cos para controlar as infestações observadas foram avaliadas por simulações baseadas em dados experimentais e modelos econômicos. Nas simulações, todas as práticas de manejo foram mantidas, exceto aquelas relacionadas ao uso do agroquímico em questão. Especificamente, os casos das safras de soja e milho em 2014/2015, 2015/2016 e 2016/2017 foram examinados com dados primários de 31 regiões representativas de produção em 14 estados brasileiros. A pergunta foi esta: como mudariam os custos, receitas e lucros dos produtores observados se o controle de uma praga ou doença observada fosse suprimido, considerando o provável aumento dos preços de mercado que a redução na oferta causaria? Os resultados indicam que a falta de controle de pragas e doenças pode causar perdas substanciais na lucratividade dos produtores. O não tratamento da ferrugem da soja em 2016/2017, por exemplo, resultaria em perda de lucratividade de mais de US$ 3,7 bilhões, já que o lucro agregado observado de US$ 2,63 bilhões se transformaria em uma perda de US$ 1,06 bilhão. A falta de controle da lagarta *Spodoptera* transformaria o lucro observado dos agricultores de soja de US$ 2,63 bilhões em uma perda de US$ 0,46 bilhão, totalizando assim uma perda de lucratividade de US$ 3,08 bilhões.

Palavras-chave: controle químico, perdas econômicas, controle de pragas na produção de grãos.

Introduction

Agribusiness has a strategic and high relevance role for the Brazilian society, such as income generation (GDP), employment, and food security. In addition, competitiveness in the agricultural sector contributes has kept food prices affordable, besides generating needed foreign exchanges through exports. Data from the Center for Advanced Studies in Applied Economics (Cepea, 2020) show that the Brazil's GDP agribusiness (agriculture, processing, and agro-services) from 1998 to 2018 was slightly above 20% of total GDP. In 2018, the agribusiness GDP amounted to U$$ 395.4 billion (21% of the national GDP). Over the past five years, soybean and corn have accounted on average for 30% of Brazil's gross agricultural production value (Brasil, 2019). Thus, any relevant agricultural production shock – regarding climate, pests and diseases, for example – may have significant negative impacts on the performance (growth and stability) of the entire Brazilian economy.

Researchers and policy makers monitor the effects of pests and diseases attacks closely, as the economic damage to production may be significant. An extreme and emblematic case was the attack of the fungus *Phytophthora infestans*, which destroyed potato production in Ireland between 1845 and 1849, when about one million people starved to death and many others moved to other countries (Charles Nelson, 1983).

Due to the importance of controlling pests and diseases, several studies have been conducted in the technical and economic fields as part of the strategy to deal with these threats, such as Kuchler et al. (1984); Stansbury et al. (2002); Kim et al. (2008); Soliman et al. (2010, 2012); Oliveira et al. (2013); De Ros et al. (2015); and Almas et al. (2016). In this study, economic losses for Brazilian growers were assessed in a hypothetical scenario in which pest attacks and diseases in soybean and corn crops in three seasons (2014/2015 to 2016/2017) were not combated.

We used technical parameters from scientific and experimental studies that quantified statistically the effects of agrochemicals on the productivity of crops attacked by pests and diseases. Field surveys provided data on production costs, including those regarding the purchase and application of agrochemicals, and gross revenues from crops. The survey database was available for typical entrepreneurial production systems in major soybeans and corn producing regions in Brazil. Economic models were used to calculate the impacts of crop output reduction on soybean and corn market prices, taking into account the importance of the international market to the formation of these prices.

This paper has three sections besides this introduction. In section 2 we present data and the analytical method; section 3 presents results and some discussion; and in section 4 we make final remarks.

Data and analytical method

Methods to collect data and criteria to determine yield loss for each selected pest in the crops

For each region where survey was conducted, technical and economic crop data were collected through interviews with modal entrepreneurial farmers' groups (panels) that provide consensual information regarding prevailing cropping techniques, inputs usage and prices, plus labor and machinery employment in corn or soybean farms. The growers consulted are, as a rule, those who apply the recommended available technology and cropping practices under the guidance of specialists. This approach leads to modal aspects of high technology production systems used by profit seeking growers. Soybeans and corn regions selection relied on secondary and regional technical experts' information on modal farm main activities, size distribution and technology level as well as adoption rate and administration patterns. These interviewed groups include in addition to farmers, technicians, and consultants familiar with the production process in the regions being studied. The data surveys were conducted by Center for Advanced Studies in Applied Economics at ESALQ/USP – Cepea in the 2014/2015, 2015/2016, and 2016/2017 crop years (Cepea, 2018).

The simulation scenario assumes that, once growers use agrochemicals, they will do it in the correct form, according to technical recommendations. This assumption is essential for the use of scientific trial data as a reference to measuring expected effects.

On the other hand, within the hypothetical scenario where farmers do not apply chemicals to control pests and diseases it is assumed that other control practices and technologies being used are kept as in the original surveyed database. In other words, farmers continue applying other management tools to control pests and diseases - transgenic crops, for example.

In total, field data proceeded from 29 soybean producing regions, 13 summer-corn regions, and 19 second-corn crop regions, comprising altogether 31 distinct agricultural regions in 14 Brazilian states. The 31 regions were: Camaquã/RS, Carazinho/RS, Cruz Alta/RS, Tupanciretã/RS, Campos Novos/SC, Xanxerê/SC, Cascavel/PR, Castro/PR Londrina/PR, Guarapuava/PR, Chapadão do Sul/MS, Dourados/MS, Naviraí/MS, São Gabriel do Oeste/MS, Cristalina/GO, Mineiros/GO, Rio Verde/GO, Campo Novo do Parecis/MT, Sorriso/MT, Sinop/MT, Primavera do Leste/MT, Querência/MT, Uberaba/MG, Uruçuí/PI, Balsas/MA, Pedro Afonso/TO, Luís Eduardo Magalhães/BA, Simão Dias/SE, Paragominas/PA, and Boa Vista/RR.

Data from each surveyed producing region were then extrapolated to other IBGE (Brazilian Institute of Geography and Statistics) micro-regions according to rigorous analyses of similarity considering geographic proximity, socio-economic aspects, technology (including yields), production activities patterns (including land use structure). The sums of yearly corn and soybean total outputs calculated by adding up values from surveyed and extrapolated regions differed at most by 3.7% from IBGE official estimates for each crop.

Data collection to calculate production costs (Cepea, 2018) allowed to identify, in details, the management for pest and disease control applied in each region. The agrochemicals used in seed treatment and spraying were referenced by registry at the Ministry of Agriculture, Livestock and Supply – MAPA[7]. The five pests considered for soybean were the general soybean caterpillars (*Chrysodeixis includens* and *Anticarsa gemnatalis*), *Helicoverpa* caterpillar (*Helicoverpa armigera*), stink bugs (*Nezara viridula* and *Euschistus heros*), whitefly (*Bemisia tabaci*) and rust (*Phakopsora pachyrhizi*). For corn, the three studied pests were fall armyworm (*Spodoptera frugiperda*) caterpillar, green belly stink bug (*Dichelops melacanthus*), and corn leafhopper (*Dalbulus maisis*).

These pests and diseases were chosen because they were the economically important ones with incidence in the considered regions during the three periods. Estimates of percentage reduction in yield in case of non-treatment of specific pests and diseases were based on experimental trials conducted by research institutions. These trials estimated, on a statistical basis, the effects of using chemicals to control a specific pest or disease in accordance with technical recommendations. It is assumed, in each case, that only the pest or disease under consideration is occurring, that is, the joint effects of pests and their potential interactions were not analyzed.

Table 1 shows the loss estimates of selected pests and diseases, according to the results found by researchers in the experimental fields and published in journals, periodicals, or congressional proceedings. The value considered for yield loss corresponded to the difference between average yield in case of non-treatment (control) and yield in case of technically recommended chemical treatment.

For example, in soybean cropping, according to Corrêa-Ferreira et al. (2013) and Bueno et al. (2015), the absence of chemical control of green and brown stink bugs can cause an average yield loss of 10.6%, which ranges from 2.4%, in less severe situations, to 21% yield loss in cases of greater severity of pest attack. In this study, the impact of no chemical control on the stink bug was rounded to a 10% drop in soybean yield. The same procedure was adopted for the other pests and diseases, with the following percentages: 30% for soybean rust, 20% for whitefly, 20% for *Helicoverpa* caterpillar and 20% for soybean caterpillars. For corn, the loss considered by not treating the *Spodoptera frugiperda* caterpillar was 40%, 20% for the green belly stink bug and 30% for the corn leafhopper (Table 1).

Measurement of economic impact due to non-treatment with chemicals of pests and diseases

Impact of non-treatment on production costs

In this section, we calculated the cost reduction due to non-treatment for pest or disease control under analysis. This reduction has two components – purchasing cost of the agrochemical plus its application costs, that is, machinery and labor. This cost impact, that is, cost reduction per hectare due to the non-treatment of pest i for a region j in the crop year k, is represented by the equation (1):

$$IC_{ijk} = TC_{ijk} - TC_{jk} \quad (1)$$

The impact on aggregate cost for region j (ICR_{ijk}) in crop k is defined by the equation (2):

$$ICR_{ijk} = IC_{ijk} \times Area_{jk} \quad (2)$$

where:

IC_{ijk} = Impact on Total Cost (TC[8]) per hectare due to non-treatment of pest i in region j in crop year k; $IACR_{ijk}$ = Impact on aggregated cost for region j due to non-treatment of pest i

[7] AGROFIT: Sistema de Agrotóxicos Fitossanitários. Available at: <http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons>. Accessed on: June 14 2021.

[8] Total Cost (TC) is defined as the sum of actual operating costs (inputs – such as fertilizers, seeds, pesticides, fuels –, preventive maintenance of machinery and implements, labor, farm overhead, internal production transportation, outsourced services, and working capital expense), depreciation, capital costs (interest on machinery inventory and farm improvements) and cost of land.

Table 1. Selected pests or diseases for soybean and corn crops, yield loss reported in the literature, and average value adopted in the economic impact simulation.

Crop	Pest/disease	Authors	Great severe (%)	Average (%)	Less severe (%)	Average assumed (%)
Soybean	Stink bug[1]	Bueno et al. (2015) Corrêa-Ferreira et al. (2013)	-21	-10.6	-2.4	- 10
	Helicoverpa armigera	Bonamichi et al. (2015)	-30	- 14.4	-4.0	- 20
	Whitefly (*Bemisa tabaci*)	Vieira et al. (2013)	-30	-22	-12	- 20
	Soybean caterpillar [2]	Bueno et al. (2010)	-26	- 18.8	-14	- 20
	Soybean rust (*Phakopsora pachyrhizi*)	Godoy et al. (2015, 2016, 2017)	-33.9	- 27.4	-5.7	- 30
Corn	Fall armyworm (*Spodoptera frugiperda*)	Cruz et al. (2002); Valicente (2015)	- 52	- 43	- 34	- 40
	Green belly stink bug (*Dichelops melocanthus*)	Cruz et al. (2002); Valicente (2015)	-25	-22	-21	- 20
	Corn leafhopper (*Dalbulus maidis*)	Toffanelli & Bedendo (2002)	- 45.7	-29.8	-17.5	-30

[1] Green stink bug (*Nezara viridula*) and brown stink bug (*Euschistus heros*); soybean caterpillar: Soybean looper (*Chrysodeixis includens*) and Velvetbean caterpillar (*Anticarsa gemmatalis*). [2] Soybean looper (*Chrysodeixis includens*) and Velvetbean caterpillar (*Anticarsa gemmatalis*).

in crop year k; TC_{jk} = Total Cost per hectare observed in region j in crop year k; TC_{ijk} = Total Cost per hectare without treatment of pest i in region j in crop year k; $Area_{jk}$ = Total cultivated area of the crop of interest in region j in crop year k.

To determine the impact on TC at Brazil level (ICB_{ik}) of non-treatment for pest i in crop year k, the regional values of non-treatment impact of pest i on crop-year k (ICR_{ijk}) are summed for all N = 558 producing micro regions of the crop considered for Brazil, defined by equation (3):

$$ICB_{ik} = \sum_{j=1}^{N} ISCR_{ijk} \quad (3)$$

Price adjustment (soybean and corn) to production drop

Due to pest attacks and diseases, with the consequent drop in yield in a scenario without chemical treatment of crops, which would decrease product supply, prices may react (increase), affecting the domestic and international markets. Therefore, in the short-term context, that is, in a current harvest, the Impact on Profitability with Adjusted Prices (IPAP) resulting from the production drop is calculated considering expected increase in market prices.

In a region j producing one of the products under analysis (soybean or corn) affected by a pest or disease i in the crop year k, the observed Profit of growers (PF_{jk}) from one of those products is given by equation (4):

$$PF_{jk} = [P_{jk} \times y_{jk} \times Area_{jk}] - TC_{jk} \times Area_{jk} \quad (4)$$

where: P_{jk} is the observed crop price in region j in crop year k, y_{jk} is the crop yield in that same region and harvest (tons per ha). In addition,

$$GR_{jk} = P_{jk} \times y_{jk} \times Area_{jk} \quad (5)$$

is Gross Revenue observed in region j and harvest k.

The Profit of total Brazilian growers observed in crop year k (PF_k) is:

$$PF_k = \sum_{j=1}^{N} PF_{jk} \quad (6)$$

and Gross Revenue observed in crop year k is:

$$GR_k = \sum_j GR_{jk} \quad (7)$$

and Total Cost for Brazil is:

$$TC_k = \sum_j TC_{jk} \quad (8)$$

Now we assume that the control of pest or disease i in region j is not carried out in crop year k. Every observed costs item is kept constant except those directly (agrochemical costs) or indirectly (application costs) related to the control of pest or disease i. Then PF_{jk} would change to PF_{ijk}, where P_{ijk}, y_{ijk} and TC_{ijk} are substituted for P_{jk}, y_{jk} and TC_{jk}.

$$PF_{ijk} = [P_{ijk} \times y_{ijk} - TC_{ijk}] \times Area_{jk} \quad (9)$$

and Gross Revenue of Brazilian growers in all regions j without control of pests or diseases i in crop year k is given by:

$$GR_{ik} = \sum_j GR_{ijk} = \sum_j P_{ijk} \times y_{ijk} \times Area_{jk} \quad (10)$$

Total Cost for Brazil without treatment is:

$$TC_{ik} = \sum_j TC_{ijk} \quad (11)$$

The corresponding profit is:

$$PF_{ik} = \sum_j PF_{ijk} \quad (12)$$

It is noteworthy that P_{ijk} is the expected market price in crop year k, using the models in the literature, given the phytosanitary shock of the untreated pest attack, as explained below.

Therefore, the impact on profit resulting from the attack of uncontrolled pests or diseases i in region j in crop year k – IPF_{ijk} - is given by equation (13):

$$IPF_{ijk} = PF_{ijk} - PF_{jk} \quad (13)$$

For the entire country, adding regional values, the impact on profitability in crop year k would be given by equation (14):

$$IPF_{ik} = \sum_j IPF_{ijk} \quad (14)$$

Now we explain how to obtain P_{ijk} - the price value that results from market adjustment due to expected production variation (drop) in a scenario without treatment against pest i in crop year k. We considered that soybean and corn have their prices determined in the foreign market, and then are internalized at a constant percentage transaction cost (α), without changes in the exchange rate. Thus, if p is the international price, the domestic price to producer p_d is as in equation (15):

$$p_d = (1 - \alpha)p \quad (15)$$

Therefore, given a percentage change in external price ($\Delta p/p$), the percentage change in p_d has the same magnitude: $\Delta p_d/p_d = \Delta p/p$.

The world market is considered to operate according to its supply (S_W) and demand (D_W), both depending on the international price (p). In equilibrium, we have:

$$S_W(p) = D_W(p) \quad (16)$$

The world supply can be divided into two parts: the supply from Brazil (S_B) and the supply from the rest of the world, that is, from the other producing countries (S_{RW}) as in equation 17:

$$S_W(p) = S_{RW}(p) + S_B \quad (17)$$

The equilibrium is showed in equation 18:

$$D_W(p) = S_W(p) \quad (18)$$

Assuming that, due to the non-control of pests at the national level, there is an exogenous percentage variation $\Delta S_B/S_B$ in the Brazilian production, the percentage impact on world price and thus in Brazil is obtained by equation (19):

$$\Delta p\% = \Delta p/p = \\ = \{(S_B/D_W)/n_W - [e_{RW}(S_{RW}/D_W)]\}\ \Delta S_B/S_B \quad (19)$$

which is obtained by total differentiation of (15) considering (14) and the definitions of elasticities of demand and supply.

The ratio S_{RW}/S_W represents the share of the rest of the world supply in world demand; S_B/D_W is the share of Brazil's supply in world demand; e_{RW} is the price elasticity of supply from the rest of the world; and n_w is the price elasticity of world demand for the product.

To determine price variation ($\%\Delta p$) – the percent variation of domestic price compared to observed price - for each product, we needed to obtain national and international market parameters for the products studied. The share of Brazilian production and production supplied by other countries (rest of the world) in relation to world demand was taken from United States Department of Agriculture (USDA, 2018), for the 2010/2011 to 2016/2017 harvests.

Supply and demand elasticities of the main soybean producing countries were obtained from FAPRI (2011) and in Kim et al. (2008). The elasticities of world demand and the rest of the world supply for soybean were computed by the weighted average elasticities for each country, with weights corresponding to each country's participation in soybean crushing. For corn, the parameters were obtained by similar procedure by authors.

Table 2 summarizes the parameters of the rest of the world supply elasticities and the world demand elasticities for soybean and corn used in equation 12.

Equation 12 adopts the Brazilian supply (ΔS_B) as a variation, which expects the crop yields decreases as result of pests or diseases attack, in the absence of chemical control, as shown in Table 1.

Table 2. Parameters adopted for the rest of the world supply and world demand elasticities for soybean and corn.

Elasticities	Product	
	Soybean	Corn
Elasticities-price of supply from the rest of the world (e_{RW})	0.3300	0.2001*
Elasticities-price of world demand (n_w)	- 0.2128	-0.056*

Source: Kim et al. (2008), FAPRI (2011) and *authors' calculations.

Table 3 shows price changes compared to observed prices for soybean and corn calculated by applying equation (12). That is, the last three columns of the table show the impact on prices in response to the yield loss resulting from non-treatment with chemicals for each pest or disease selected in the study. For example, in soybean crop, the lack of chemical control for caterpillar would lead to a 20% reduction in yield (and output), which would result in a 14.4% price change ($\%\Delta p$) in the 2014/2015 crop year, 14.9% in 2015/2016, and 15.3% in 2016/2017.

In calculating the variation in Brazilian supply, we considered that, in some years, there might be no incidence of these pests in all regions, but only in part of them. This was the case for the following pests: whitefly and stink bug in soybean, and corn leafhopper. The regions where occurrence of losses due these pests incidence were considered are listed in Table 4.

In the case of the whitefly, according to primary data survey, the attack is still limited. Thus, the regions affected by this pest and for which losses were calculated are those shown in Table 4. In those regions, non-treatment was considered to lead to a 20% production loss. In other regions, yield was not changed; thus, the shock impact on production in Brazil caused by whitefly was calculated to be 4.5% for the 2014/2015 crop year. To calculate price variation, according to (12), variation of Brazil's production (drop) was rounded to 5%, which led to a 3.6%

Table 3. Variation of national production and price due to non-treatment with chemicals of each pest or disease selected for soybean and corn crops.

Pest/disease	Δ Production (%)			Δ Price (%)		
	2014/2015	2015/2016	2016/2017	2014/2015	2015/2016	2016/2017
			Soybean			
Soybean caterpillar	-20.0	-20.0	-20.0	14.4	14.9	15.3
Helicoverpa armigera	-20.0	-20.0	-20.0	14.4	14.9	15.3
Stink bug	-10.0	-10.0	-10.0	7.2	7.5	7.6
Whitefly	-5.0	-4.0	-7.0	3.6	3.0	5.4
Soybean rust	-30.0	-30.0	-30.0	21.6	22.4	22.9
			Corn			
Fall armworm	-40.0	-40.0	-40.0	14.3	13.6	13.6
Green belly stink bug	-15.0	-9.6	-17.4	5.4	3.3	5.9
Corn leafhopper	-	-1.4	-6.6	-	0.5	2.2

increase in the 2014/2015 harvest price. For the 2015/2016 and 2016/2017 crop year, the production variations were calculated to be 4% and 7%, respectively, resulting in price variations of 3.0% and 5.4%, in the same sequence.

Likewise, in the analysis of green belly stink bugs, the negative shock of 20% on the production was considered only for the regions shown in Table 4, in each harvest year. Thus, the production of corn variation (drop) in Brazil was calculated to be 15% and the price variation (increase), 5.4% for the 2014/2015 harvest (Table 3). For the 2015/2016 season, the negative shock of 20% on production was calculated over production for the regions listed in Table 4, resulting in a 9.6% reduction in total production and 3.3% increase in prices. Finally, for the 2016/2017 harvest, the negative shock of 20% in reducing production in the regions pointed in the Table caused a negative variation in total production of 17.4% and a positive price variation of 5.9% (Table 3).

For corn leafhopper, we considered the production decrease in the regions shown in Table 4, only for 2015/2016 and 2016/2017 crop years. For the other regions yield was not changed. As a result, the corn domestic production variation due to the pest was 1.4% and 6.6%, which resulted in price variations of 0.5% and 2.2%, respectively, for the 2015/2016 and 2016/2017 crop year (Table 3).

From the data in Table 3, new values of total production cost (*TC*) and gross revenue (*GR*) were estimated for each region j and each crop i considering, the production drop from the shock caused by pests and diseases. Price reactions to declining availability of these agricultural products were also considered.

Results and discussion

Total cost (TC) reductions due to not controlling selected pests

Table 5 shows the reduction in *TC*, given by the Impact on Cost for Brazil (ICB_i in equation (3)), due to the non-application of pesticides for the control of soybean and corn pests and diseases, considering data from the 2014/2015, 2015/2016, and 2016/2017 harvests, and in real values adjusted with IGP-DI index (General Price Index – internal availability) for June 2017.

Take the case of the *Helicoverpa armigera* caterpillar of soybean. The simulation of the absence of its chemical control indicates that the cost for the Brazilian producer would fall by US$ 1.03 billion (3.0% of the total cost) in

Table 4. Regions considered to measure impacts of selected pests according to their incidence in each crop year.

Localidade	Whitefly - Soybean			Sting Bug - corn			Leafhopper - Corn	
	2014 /2015	2015 /2016	2016 /2017	2014 /2015	2015 /2016	2016 /2017	2015 /2016	2016 /2017
Carazinho, RS				●		●		
Cruz Alta, RS						●		
Xanxerê, SC				●		●		
Campos Novos, SC				●	●	●		
Cascavel, PR				●	●	●		
Guarapuava, PR				●				
Londrina, PR					●	●		
Uberaba, MG						●		●
Unaí, MG					●			
Paragominas, PA		●	●		●	●		
Sorriso, MT	●	●	●	●		●		
Sinop, MT	●	●	●	●		●		
Primavera do Leste, MT				●		●		
Campo N. do Parecis, MT			●	●	●	●		
Querência, MT			●	●	●	●		
Pedro Afonso, TO			●					
Dourados, MS				●	●	●		
Naviraí, MS				●	●	●		
Chapadão do Sul, MS						●		
São Gabriel do Oeste, MS					●			
Cristalina, GO	●	●			●	●	●	
Mineiros, GO				●	●	●		●
RioVerde, GO					●	●		●
Balsas, MA		●	●	●		●		
Uruçuí, PI	●		●		●	●	●	●
Luis E. Magalhães, BA	●		●	●		●		●
Simão Dias, SE						●		

2014/2015; US$ 0.66 billion (2.2%) in 2015/2016, and US$ 0.84 billion (2.3%) in 2016/2017 crop year. The other caterpillars would have reduced private cost of US$ 0.68 billion (2.0%), US$ 0.51 billion (1.7%), and US$ 0.51 billion (1.4%), respectively, for the three subsequent crop years. The decreasing trend of the amount saved due to the non-treatment of chemical control can be explained by the increased use of glyphosate-tolerant and caterpillar-resistant soybean in the main producing regions of Brazil, during the analyzed period. In addition, the weather conditions in the 2015/2016 and 2016/2017 crop year were less favorable for the development of caterpillars in the crops.

Regarding soybean stink bugs, non-treatment would decrease the crop *TC* by R$ 0.78 billion (2.3%) for the 2014/2015 harvest, considered throughout Brazil; US$ 0.72 billion

Table 5. Impact on *TC* for pest or diseases *i* (ICBi), in value and percentage, of soybean and corn crops in Brazil, due to non-treatment to control of selected pests and diseases, in the affected regions – 2014/2015, 2015/2016, and 2016/2017 crop year.

Crop	Pest/disease	ICB_i (US $ Bi)			ICB_i (%)		
		2014/2015	2015/2016	2016/2017	2014/2015	2015/2016	2016/2017
Soybean	*S. caterpillar*	-0.68	-0.51	-0.51	2.0	1.7	1.4
	Helicoverpa	-1.03	-0.66	-0.84	3.0	2.2	2.3
	Stink bug	-0.78	-0.72	-1.11	2.3	2.4	3.0
	Whitefly	-0.20	-0.22	-0.37	0.6	0.7	1.0
	Soybean rust	-1.87	-1.95	-2.53	5.5	6.6	6.9
Corn	Fall armworm	-0.20	-0.33	-0.29	1.5	3.2	1.9
	Green belly stink bug	-0.12	-0.10	-0.23	0.9	1.0	1.5
	Corn leafhopper	-	-0.01	-0.05	0.0	0.1	0.3

Exchange rate: 2014/2015: R$ 3.08/US$; 2015/2016: R$ 3.85 and 2016/2017: R$ 3.17.

(2.4%) for 2015/2016, and US$ 1.11 billion (3.0%) for 2016/2017 crop year. For whitefly, TC reduction would be US$ 200 million (0.6%), US$ 220 million (0.7%), and US$ 370 million (1.0%), respectively, for the three crop years.

The cost of stink bug and whitefly treatments has been increasing in Brazil. According to farmers and regional technicians, this is related to migration of pests from a year to another. As a response farmers are intensifying land use with successive different crops and watching for roadside hosts thus improving crop residue management.

Assuming now the absence of soybean rust control, the production cost would be reduced by US$ 1.87 billion (5.5%) in the 2014/2015 harvest; US$ 1.95 billion (6.6%) in 2015/2016, and R$ 2.53 billion (6.9%) in 2016/2017.

Table 5 also shows impacts on TC for Brazil (ICB_i) due to non-treatment with pesticides for insect control in corn. The data indicate that the cost reduction in the agricultural sector to control the Fall armworm (*Spodoptera*) would be US$ 195 million, which represents a 1.5% reduction of the *TC* for the 2014/2015 crop year, US$ 330 million (3.2% decrease of *TC*) for 2015/2016, and US$ 289 million (1.9%) for the 2016/2017 crop year. For green belly stink bugs, the *TC* reduction was around US$ 120 million (0.9% of *TC*) for the 2014/2015 crop year, US$ 100 million (1%) for 2015/2016, and R$ 229 million (1.5%) for the 2016/2017 crop year. In the case of the corn leafhopper, the *TC* would reduce by US$ 7.7 million (0.1%) and by US$ 45.4 million (0.3%), respectively, for the 2015/2016 and 2016/2017 crop year.

Impact on profitability by non-treatment of crops for selected pests

Table 6 shows (a) observed plus extrapolated total values of gross revenue (GR_k), total cost (TC_k) and total profit ($PF_k = GR_k – TC_k$) values for all Brazilian growers, for the scenario observed in the surveys (i.e., considering that control treatments pests and diseases were effectively employed) and (b) in the absence of control treatment in the case of pest or disease *i* (GR_{ik}, TC_{ik} and PF_{ik}). The table also presents the impact on price-adjusted profitability for Brazil ($IPFB_i = TPF_i – TPF$) of not treating selected pests and diseases in total extrapolated soybean and corn crops for the periods examined.

Considering the case of soybeans, it is noted that in the 2016/2017 crop year, the observed profit was US$ 2.63 billion, a negative profit of US$ 0.68 billion occurred in 2015/2016 and there

Table 6. Real Total Gross Revenue (*TGR*), Total Total Cost (*TTC*) and Total Profit (*OP*) and their values for the case of non-control of selected pests and diseases. Soybean and corn. Crop year: 2014/2015, 2015/2016, and 2017/2018.

Crop year	Crop	(a) Observed (US$ Bi)				(b) Effect of non-treatment of pest (US$ Bi)			
		Pest	GR_k	TC_k	PF_k	TGR_i	TTC_i	TPF_i	IPF_i
2016/2017	Soybean	S. caterpillar	39.50	36.87	2.63	36.43	36.89	-0.46	-3.08
		Helicoverpa	39.50	36.87	2.63	36.43	36.64	-0.21	-2.84
		Stink bug	39.50	36.87	2.63	38.27	36.05	2.21	-0.41
		Whitefly	39.50	36.87	2.63	38.52	36.66	1.85	-0.78
		Soybean rust	39.50	36.87	2.63	33.99	35.05	-1.06	-3.69
	Corn	Fall armworm	10.87	14.96	-4.09	7.41	13.88	-6.47	-2.38
		Green belly Stink bug	10.87	14.96	-4.09	9.58	14.40	-4.82	-0.73
		Corn leafhopper	10.87	14.96	-4.09	10.37	14.77	-4.40	-0.30
2015/2016	Soybean	S. caterpillar	28.74	29.41	-0.68	26.42	29.49	-3.07	-2.39
		Helicoverpa	28.74	29.41	-0.68	26.42	28.90	-2.49	-1.81
		Stink bug	28.74	29.41	-0.68	27.79	29.00	-1.21	-0.53
		Whitefly	28.74	29.41	-0.68	28.36	29.29	-0.94	-0.26
		Soybean rust	28.74	29.41	-0.68	24.61	28.25	-3.63	-2.95
	Corn	Fall armworm	8.26	10.29	-2.03	5.63	9.59	-3.95	-1.92
		Green belly Stink bug	8.26	10.29	-2.03	7.75	10.06	-2.31	-0.29
		Corn leafhopper	8.26	10.29	-2.03	8.15	10.27	-2.11	-0.09
2014/2015	Soybean	S. caterpillar	36.08	33.94	2.14	33.03	33.71	-0.68	-2.82
		Helicoverpa	36.08	33.94	2.14	33.03	32.78	0.25	-1.89
		Stink bug	36.08	33.94	2.14	34.81	33.42	1.40	-0.74
		Whitefly	36.08	33.94	2.14	35.83	33.92	1.91	-0.23
		Soybean rust	36.08	33.94	2.14	30.72	32.66	-1.94	-4.08
	Corn	Fall armworm	10.24	12.68	-2.44	7.02	11.76	-4.73	-2.29
		Green belly Stink bug	10.24	12.68	-2.44	9.10	12.30	-3.20	-0.76
		Corn leafhopper	-	-	-	-	-	-	-

Exchange rate: 2014/2015: R$ 3.08/US$; 2015/2016: R$ 3.85 and 2016/2017: R$ 3.17.

was a profit of R$ 2.14 billion in 2014/2015. The negative value found in 2015/2016 is explained by the reduction in gross revenue due to the smaller output in the northern and eastern Mato Grosso, southern Maranhão, southern Piaui, western Bahia and Tocantins regions. The heavy drought in these regions caused by the El Ñino occurred during the most critical crop period (December), when it rained very little (in some regions, virtually nothing).

Still in Table 6, we analyze data on non-treatment of soybean caterpillars. *TEGR* would fall to US$ 36.43 billion, down US$ 3.07 billion from the original observed value of US$ 39.50 billion recorded in the 2016/2017 crop year. The *TETC* would be US$ 36.89 billion, that is, non-treatment would be US$ 17.2 million higher than the observed value. Thus, the profit of US$ 2.63 billion would turn to a loss of US$ 460 million, totaling a drop in profit (negative $IPAPB_i$) of

US$ 3.08 billion for Brazilian growers. Similar results would occur in the other two crops considered. The biggest losses for soybean would be due to the non-treatment (*PPi*) of soybean rust: US$ 1.06 (3.12) billion in 2016/2017 and US$ 3.63 billion in 2015/2016, with loss of profitability ($IPAPB_i$) of US$ 3.69 billion and US$ 2.95 billion, respectively.

Table 6 also presents results for corn. For this product, losses were observed in the three crop years considered. Although the economic results for corn have negative values, the decision of producer to include corn for crop rotation and/or successive cultivation in the production system is due to some agronomic aspects. These include improvements in soil physical quality (soil structure and porosity), which facilitates root development with less compacted soil. Another aspect is the chemical and biological improvement of the soil in which the addition of biomass (shoot and root), along with sowing on straw, increases the organic matter content and microbial life, recycling, decomposing organic materials, and improving the use of nutrients.

Therefore, the inclusion of corn in the crop rotation system increases soybean yield, as corn improves the efficiency of nutrient extraction. A study on 21 harvests (1988/1989 to 2008/2009) showed a 17% soybean yield gain when cultivated in the summer following summer corn cultivation (Franchini et al., 2011). On the other hand, the non-treatment of fall armworm (*Spodoptera*) in the 2016/2017 harvest would increase the loss in corn production from US$ 4.09 billion to US$ 6.47 billion, with a loss of profitability ($IPAPB_i$) of US$ 2.38 billion

In summary, we found that in all cases studied for soybean and corn over the years considered, non-treatment of pests reduces profits, as indicated by negative IPF_i values. In other words, the total cost (*TC*) reduction due to non-chemical treatment is smaller than the decrease in gross revenue (*GR*) (due to decreased output even if accompanied by an increase in market price). Therefore, the results indicate that, from the producer's viewpoint, it is preferable to carry out chemical control rather than saving on chemical treatment expenses.

It is concluded that the absence of chemical control of pests and diseases implies significant economic losses for soybean and corn growers. But incidence may milder in some regions; some pests and diseases are amenable to nonchemical control. So it is important to clarify that the effect of pest and disease occurrence can differ among regions, what demands careful consideration of each case under analysis. Thus, while all the soybean-producing regions considered were affected by *Helicoverpa*, for example, in the years studied, the occurrence of whitefly did not take place in part of the regions, as previously described; therefore, in these regions, not only productivity loss did not occur, but there was also a benefit due to price increase caused by output losses in other regions.

Another interesting case occurred for the corn leafhopper, for which few studies have been conducted to quantify yield loss due to its attack. In addition, few chemicals are registered for its control; thus, the most common measures for pest control are seed treatment or selection of pest-resistant cultivars. Still another interesting case is the one of soybean rust, which is controlled by chemical pesticides and agronomic practices, such as sanitary void, control of crop residues (voluntary soybean – "guaxa" or "tiguera"), shortening of the production cycle, and plant breeding. These practices help to contain the severity of pest incidence and reduce fungicide use and costs.

The negative IPF_i values for all pests studied in corn and soybean crops, in the three seasons analyzed, mean that chemical control of pests is worthwhile, since the damage generated by their incidence is large. Nevertheless, this does not mean that the producer prefers chemical treatment to other technology for disease and pest control.

Farmers, like other economic agents, use their rationality to seek the economic sustainability of their business. Therefore, if there is an alternative control mechanism, either biological, chemical, mechanical, or combination, such as in integrated pest management (*IPM*), which proves to be economically viable, farmers will tend to include it in the set of usable technical possibilities and choose the most profitable one at any given time. On the other hand, if the impact on profitability ($IPAPB_i$ values) is positive, surely many growers would choose not to control the disease or pest, because the cost of control would outweighs the loss of gross revenue.

Final remarks

This study contributed to advancing the quantitative assessment of the broad economic effects of pests and disease agrochemical control in the Brazilian agriculture. It was clear that control is economically compensatory for the set of Brazilian soybean and corn growers, regarding the pests considered in this study. If the technical control recommended is not carried out, profits decrease or even become losses.

For example, the non-treatment of soybean rust in 2016/2017 would result in income losses of over US$ 3.79 billion (nearly 9% of revenues) to soybean growers. The non-control of fall armworm (*Spodoptera*) would cause a loss of roughly US$ 2.37 billion (22% of revenues) to corn growers. Moreover, in all cases, domestic and international prices would be increased, with impacts – to be assessed – on the cost of living in Brazil and in the entire world. These price increases could also stimulate cultivated area expansion, with implications – to be assessed – on land use in Brazil.

An alternative to chemical treatment to prevent yield loss is the use of management techniques. However, these techniques are not available for all relevant pests and diseases and alternative management procedures may face additional difficulties: unawareness of existing possibilities; requirement of broader level of technical knowledge to plan and implement them; risks that these control methods may not be as effective as chemical methods; among others. It is worth mentioning that evaluating these alternatives was not a goal of this paper. However, eventually in the production systems represented in the regions surveyed, some of these alternatives were already being used by some growers and regions and may spread overtime if economically effective.

This paper makes a point about the current economic importance to growers of the use agrochemicals to control pests and diseases. If growers do not use them, they might face large losses in yields and income. The consequences to society may also be severe, be it in terms of cost of living or of availability of external currency.

Consequently, in order to guide growers to less intensive use of agrochemicals, it is essential to provide them with alternative pests and disease management tools, which are economically and technically feasible and accessible. In the same token, actions and policies should focus on sanitary and environmental education to improve the selection among available technologies, and also assure the use chemicals in the proper way.

Future research should incorporate the representation of farmers with financial and human capital endowments lower than those of the farmers considered in this study. Such farmers have smaller shares in the markets, but they are numerically important part of the socioeconomic mosaic of the Brazilian agriculture.

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