Doi: 10.33158/ASB.2015v1i1p25

# The use of soybean integrated pest management in Brazil: a review

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## ABSTRACT

The adoption of integrated pest management (IPM) in soybean is a great example of how this technology is essential to guarantee crop sustainability and productivity. In Brazil, up to 1970, soybean was cultivated with the use of pesticides applied without the adoption of any economic threshold to base this decision. As a consequence, a six-insecticide spraying per crop season used to be the average insecticide dosage. With the introduction of Soybean-IPM, the use of pesticides was reduced to approximately two applications per season. Comparing these two contrasting situations, the advantages of using IPM methods cannot be ignored, since they are economically and mostly environmentally feasible. Despite the benefits provided by Soybean-IPM, this program was abandoned in Brazil, and its principles were almost forgotten, and, as a consequence, insecticide use increased. The success and failures of Soybean-IPM in Brazil will be further analyzed in this review in an attempt to point out how safe this technology is and whether there is any risk in fully adopting this approach.

**Key words:** IPM, soybean, pest management, insecticide.

## INTRODUCTION

The soybean [*Glycine max* (L.) Merrill] crop is extensively cultivated in large areas all over the world. It supplies half of the global demand for vegetable oil and protein (Oerke and Dehne 2004). Among the largest world producers, Brazil yielded approximately 69 million metric tons of soybean during the 2009/2010 season, followed by the US in that same period (USDA 2012). This production, however, could still be maximized if problems with insects could be mitigated (Oerke 2006). Therefore, in order to reduce the negative consequences of pest outbreaks and improve soybean profits in a sustainable way, growers must control the phytophagous arthropods with the adoption of Soybean Integrated Pest Management (Soybean-IPM) techniques (Zalucki et al. 2009).

Overall, the IPM is an approach (grouping different technologies) used for the management of different crops aiming at maintaining the agro-ecosystem sustainability, by keeping it as close as possible to a biological equilibrium (pests versus natural mortality). This concept was established worldwide in the late 50's and searches primarily for the consonance of a control method based on ecological, economic and social principles. Furthermore, the IPM is based on the premise that crop plants can tolerate certain levels of injury with no economically significant yield reduction (Higley and Peterson 1996) (Figure 1). In this context, Stern et al. (1959) defined the Economic Injury Level (EIL) as the lowest pest population that is able to cause economic damage to plants. However, to avoid reaching the EIL and the consequent yield reduction, several factors should be taken into consideration, such as weather events that can delay the implementation of a control measure and the time needed for the control measures to become efficient against the pests, among others. Therefore, the decision of whether or not to control a pest population should always be made before the EIL is reached. So, the appropriate time to start the control measure in order to prevent pest population from reaching the EIL was defined as the Economic Threshold (ET) (Pedigo et al. 1986). Thus, insecticides should not be preventively applied on the soybean crop and their use is only justifiable when pest population reaches the recommended ET for that specific pest specie being evaluated.

In Brazil, however, up to 1970, soybean was still cultivated with the use of various noxious pesticides (DDT, endrin, toxafen among others), applied without the adoption of any ET-based criterion. As a consequence, a six-insecticide spraying per crop season used to be the average insecticide dosage (Bueno et al. 2011a). Due to this overuse of pesticides, Embrapa Soybean, a Federal institution founded in 1975, together with other insti-

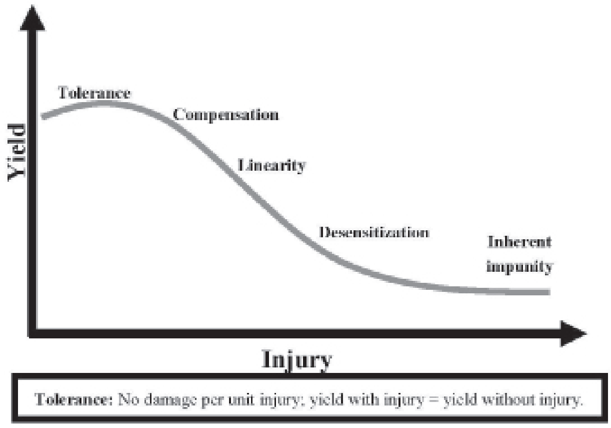

**Figure 1**. Injury x yield relationship (Adapted from Higley and Peterson 1996)

tutions (Emater from the State of Paraná, IAPAR and different universities), started to introduce Soybean-IPM in Brazil, firstly among growers from Parana State, where the Embrapa Soybean headquarters were established. With the introduction of Soybean-IPM among Brazilian soybean growers, especially after having trained them on the use of more-selective pesticides to protect natural enemies and beneficial insects, insecticides began to be used more appropriately, with growers taking into account ET for pest control, which helped them to define the real need for control (Kogan 1998; Panizzi et al. 1977a). Only after 3 to 4 years of Soybean-IPM adoption in Brazil, the use of pesticides was reduced in this country to approximately two applications per season (Panizzi 2013). By comparing these two pesticide contrasting situations, the advantages of using IPM methods cannot be ignored, since they are economically and mostly environmentally feasible (Panizzi 2013; Kogan 1998).

Despite the benefits provided by Soybean-IPM, during the last decade or so, this program was mostly abandoned in Brazil and its principles were almost forgotten. The Soybean-IPM disuse has happened mainly due to low insecticide costs as well as the relative simplicity of insecticide use (Bueno et al. 2011a), especially when insecticide hazardous side-effects are not taken into consideration. As a consequence, insecticide applications reached again a level of four to six sprayings per crop cycle (Panizzi 2013), impairing the efficiency of all existing biological control agents living in soybean crops (Carmo et al. 2010). The increasing use of insecticides been a reality not only in soybean cultivated in Brazil but also in different crops cultivated in several other parts of the world (Song and Swinton 2009; Meissle et al. 2010).

An important breakthrough in the history of soybean in Brazil, which also had an impact on this Soybean-IPM disuse process, was the arrival and spread of soybean rust caused by the fungi *Phakopsora pachyrhizi*. The first Brazilian report on soybean rust was during the 2001/2002 crop season. Fungicide application, which was rare before the occurrence of soybean rust, became common on an average of 2 or even 3 sprayings per soybean season. Not only did this fungicide bring disease control but also some of its undesirable side-effects. Some of the efficient fungicides against *P. pachyrhizi* are also harmful to entomophatogenic fungi such as *Nomuraea rileyi* and others less studied species such as *Pandora* sp. or *Zoophthora* sp. (Sosa-Gómez 2012). In addition to the beneficial fungi that can be affected by fungicides, predators and parasitoids might also be harmed by those sprayings (Bueno et al. 2008). Moreover, in an attempt to make control practice quicker and simpler, soybean growers started to use insecticides mixed with these fungicides or even earlier in the crop season with herbicides applied in a single operation. This practice has been generally adopted by soybean growers in Brazil in an attempt to optimize the agricultural operation, even without performing pest sampling and therefore without taking ET into consideration. Moreover, the mixture of insecticides with fungicides and/or herbicides for spraying is also done for large-scale economy reasons. This mix, however, should not be used in fixed times (without the crop being pest sampled), mainly when insect outbreaks, plant diseases and/or weeds do not occur simultaneously (Zalucki et al. 2009), as it is sometimes erroneously performed by some Brazilian growers. These issues might be emphasized as some of the reasons why Brazil is nowadays ranked as the largest world pesticide consumer (Higley and Peterson 1996). Excessive use of agrochemicals might also be performed in other countries, endangering, without any doubt, soybean crops sustainability on a global perspective, what will be thoroughly discussed in this review using the Brazilian example as a case-study.

## Soybean integrated pest management

There is a great number of complex pest species that might attack soybean in Brazil as well as other places around the world. However, despite this pest variety, the most important phytophagous arthropods may be grouped into insects from the Lepidoptera order, mainly from the family Noctuidae, as the caterpillars and the stink bugs (Hemiptera: Pentatomidae). There are also some less important defoliator beetles (Coleoptera: Chrysomelidae), mites, and the whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae) that might be included in this soybean pest list; however, their occurrence is more restricted than that of Pentatomidae and Noctuidae pests (Heineck-Leonel and Corseuil 1997; Lima et al. 2002, Roggia 2010; Siqueira 2011; Vieira et al. 2011). Extending this list, there are also the white grubs, *Phyllophaga cuyabana* and *Lyogenis suturalis* (Coleoptera: Melolonthidae), and the *Sternechus subsignatus* (Coleptera: Curculionidae), that might be considered important soybean pests for some Brazilian regions. Soybean-IPM will then be discussed for the most important pests from this list and the successes and failures of the Brazilian Soybean-IPM experiences analyzed briefly.

## Defoliators

### *Anticarsia gemmatalis* (Hübner, 1818) (Lepidoptera: Eribidae)

The velvetbean caterpillar, *A. gemmatalis*, is one of the most important defoliator that occurs in soybeans from Argentina to the Southeast of the United States (Panizzi et al. 1997a; Panizzi et al. 1977b; Gazzoni et al. 1994). However, the occurrence of this species is restricted to the American continent, where it damages different crops, especially soybean, *G. max* (Kogan1998; Ford et al., 1975; Herzog and Todd 1980). To complete its larval development, this caterpillar consumes from 85 to 150 $cm^2$ of leaf area (Moscardi and Carvalho 1993; Bueno et al. 2011b) but the majority of this leaf consumption is performed by larvae from 4th to 6th instar, which are the caterpillars ≥ 1.5 cm that must be scouted during the pest sampling for management decisions (Batistela et al. 2012).

### Soybean looper species (Lepidoptera: Noctuidae)

The sub family Plusiinae has different caterpillar species associated with soybeans among which, Chrysodeixis includens Walker, 1858, is the most important specie followed by *Rachiplusia* nu (Lepidoptera: Noctuidae). Until the 1990s, Plusiinae was of secondary importance to soybean since it was kept under control mainly by the action of entomophatogenic fungi and parasitoids. By that time, Plusiinae numbers in soybean was never superior to 10% of *A. gemmatalis* (Corrêa et al. 1977; Moscardi 1993). Due to this low occurrence, specific insecticides against Plusiinae were rarely used. However, during the last years (after 2000), Plusiinae outbreak occurrence has increased in soybean, mainly from *C. includens*, due to the abusive use of non-selective chemicals (mainly fungicides and insecticides) that has reduced natural biological control that used to prevent *C. includens* outbreaks (Sosa-Gómez et al. 2003).

### *Spodoptera spp.* (Lepidoptera: Noctuidae)

Similarly to the soybean looper, *Spodoptera* spp. used to be considered of secondary importance in soybeans. In the last 10 years, however, caterpillars from this genus have occurred more frequently in soybeans, what has brought some economic losses to growers. The increasing occurrence of this genus has made these caterpillars be now considered key pests by some soybean growers, mainly in some Brazilian states such as Goias and Mato Grosso, for example (Bueno et al. 2008). Among this specie complex, the most important species for soybeans are the Southern armyworm, *S. eridania*, as well as the *S. cosmioides*, which besides leaves also damage pods, significantly reducing yields (Abdullah et al. 2000; Santos et al. 2000). Bueno et al. (2011b) analyzed the soybean consumption data of different caterpillar species and reported on how dangerous Spodoptera spp. might be to soybean crops, specially *S. cosmioides* which had a feeding capacity of nearly the double of the other studied species, what might request a special attention in the Soybean-IPM, as further discussed in the defoliator pest management topic of this review.

## Beetles (Coleoptera: Chrysomelidae)

The most important beetles that attack soybeans are the *Diabrotica speciosa*, *Cerotoma arcuata* and *Maecolaspis* sp. from the Chrysomelidae family (Pinto et al. 2008). Adults from these species are generally found in small numbers in soybean and, due to their low individual defoliation capacity, control measures are usually unnecessary. However, ET for triggering any insecticide application against these pests is evaluated based on defoliation levels, what groups all defoliator species in the same ET (Bueno et al. 2013), and this will be further discussed in the following section of this review.

Differently from the adults that are leaf feeders, Chrysomelidae larvae live in the soil and feed on plant roots. Some published work reports that high larvae infestation might reduce up to 45% soybean root node formation and, therefore, highly impair plant nitrogen fixation (Layton 1983). This, however, hardly ever occurs and, so far, there is not a single Brazilian report on soybean yield reduction due to the attack of these species feeding on soybean roots. It is important to point out that there are still no studies on this subject, what might lead to the wrong evaluation of the problem. In addition, some yield reduction might still be happening without any register of it (Nava et al. 2003).

## Defoliator pest management

First of all, in order to adopt Soybean-IPM, a sampling procedure must to be well performed. This will indicate the real amount of defoliators present within a given area of the crop field and, therefore, provide adequate parameters to take control decisions based on the accurateness of the ET levels. Pest sampling and ET adoption are some of the keystones for Soybean-IPM (Figure 2), and, therefore, are crucial to the success of this technology. In this soybean scenario, insecticide spraying must be only initiated when 20 large (≥1.5 cm) caterpillars are counted per sample-cloth (1-meter-soybean line) (Figure 3).

It is important to point out that this ET based on number of caterpillars was originally proposed for the velvetbean caterpillar, *A. gemmatalis*, which was the most important defoliator insect occurring in soybean crops from Argentina to the Southeastern United States at that time (Panizzi and Corrêa-Ferreira, 1997; Hoffmann-Campo et al. 2003); however, nowadays, the situation has changed. Today, other insects, such as caterpillars from the genus *Spodoptera*, the southern armyworm, *S. eridania*, as well as the *S. cosmioides*, are considered key pests by some soybean growers, mainly in the Brazilian states of Goias and Mato Grosso. *Spodoptera cosmioides* as defoliators, differ in damaging capacity from *A. gemmatalis*, consuming almost the double, and thus, requiring a close reevaluation of the 20-caterpillar ET (Bueno et al. 2011b). Taking this into consideration and that these different caterpillar species usually occur together in soybean fields, an insect-injury equivalent based on feeding capacity of each pest species might be developed. In order to do this, the differences in injury among the species must be taken into accounted. When *A. gemmatalis* was the single species chosen as the standard equivalency specie, all others were related to this standard on the basis of their consumption potential. Insect-injury equivalence was statistically different for *S. cosmioides* (Table 1), being close to the double of *A. gemmatalis*, the species from each the actual economic threshold (ET) of 20 caterpillars per meter was developed. Therefore, injury equivalence must be 2 for *S. cosmioides* and 1 for all other tested specie and the recommended ET to trigger the beginning of insect control would then be 20 insect equivalents (Bueno et al. 2011b).

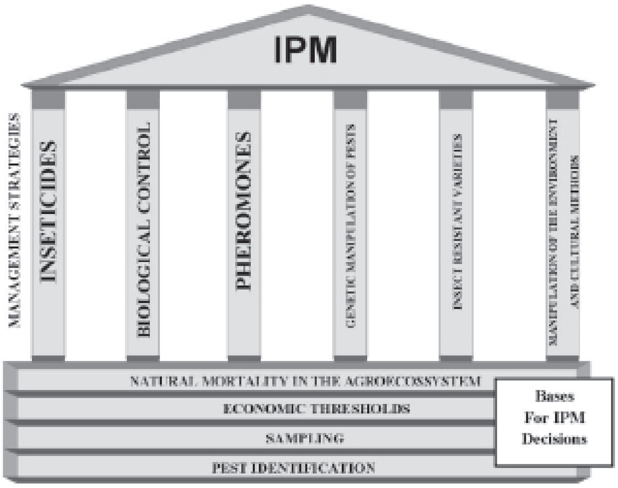

**Figure 2.** Illustration of an Integrated Pest Management program in analogy to the construction of a house

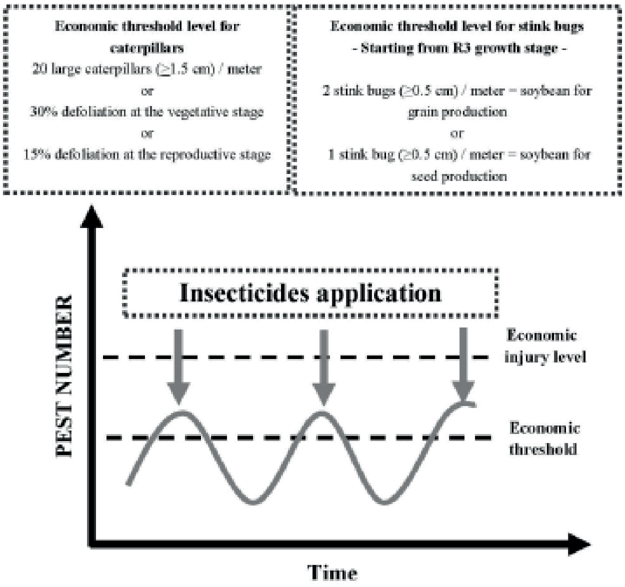

**Figure 3.** Graphic representation of the moment in which pest control measures have to be adopted on the soybean field according to Integrated Pest Management (IPM) recommendations

Alternatively to the number of caterpillars, ET for the defoliator species can be based on defoliation levels (Figure 3). The major benefit of this ET is that it will group all defoliator species, including the Chrysomelidae species that do not have an ET regarding to their adult numbers, for example. Currently, the recommended ETs for defoliation levels differ slightly around the world. In Brazil, pest control measures are initiated either when 30% defoliation (in the vegetative stage) or 15% defoliation (in the reproductive state) is observed. However, in the United States, soybean plants can withstand as much as 35 percent foliage loss up to their blooming period. During blooming and when pods begin to form and fill out, any higher than 20 percent foliage loss will decrease yield (Andrews et al. 2009).

Despite these small differences, it is important to emphasize that soybean tolerates great defoliation levels without significant yield reduction (Haile et al. 1998). Earlier results report defoliation levels of up to 50% without yield loss (Pickle and Caviness 1984). Many of these studies used to determine the economic

**Table 1.** Consumption ($cm^2$) by lepidopteran larvae and insect-injury equivalent calculated for five species of lepidopteran larvae feeding on four soybean cultivars (Adapted from Batistela et al., 2012).

| Pest species | Soybean genotypes | | | |
|---|---|---|---|---|
| | **Coodetec 219RR** | **MSoy 6101** | **MSoy 8787RR** | **Conquista** |
| | **Insect total consumption ($cm^2$)** | | | |
| *Anticarsia gemmatalis* | 92.6 ± 4.5 bA[1] | 74.2 ± 4.2 bcA | 94.9 ± 6.3 bA | 90.0 ± 3.4 bA |
| *Chrysodeixis includens* | 92.7 ± 4.5 bA | 63.9 ± 7.4 cB | 63.9 ± 7.5 cB | 64.0 ± 4.5 cB |
| *Spodoptera cosmioides* | 183.6 ± 14.9 aA | 184.8 ± 8.9 aA | 185.4 ± 5.4 aA | 175.1 ± 5.7 aA |
| *Spodoptera eridania* | 107.2 ± 6.9 bA | 98.3 ± 11.0 bA | 101.9 ± 5.0 bA | 86.9 ± 7.2 bA |
| *Spodoptera frugiperda* | 118.0 ± 6.4 bA | 90.0 ± 9.3 bB | 115.1 ± 5.7 bA | 95.4 ± 8.2 bAB |
| | **Insect-injury equivalent** | | | |
| *Anticarsia gemmatalis* | 1.00 ± 0.05 bA | 1.00 ± 0.06 bA | 1.00 ± 0.07 bA | 1.00 ± 0.04 bA |
| *Crhysodeixis includens* | 1.00 ± 0.05 bA | 0.86 ± 0.10 bA | 0.86 ± 0.11 bA | 0.71 ± 0.05 bA |
| *Spodoptera cosmioides* | 1.98 ± 0.16 aB | 2.49 ± 0.12 aA | 1.95 ± 0.06 aB | 1.94 ± 0.06 aB |
| *Spodoptera eridania* | 1.16 ± 0.07 bA | 1.32 ± 0.15 bA | 1.07 ± 0.05 bA | 0.97 ± 0.08 bA |
| *Spodoptera frugiperda* | 1.27 ± 0.07 bA | 1.21 ± 0.13 bA | 1.21 ± 0.06 bA | 1.06 ± 0.09 bA |

[1] Means of consumption or insect equivalent followed by similar upper-case letters in the row, and lower-case letters in the column are not statistically different using Tukey's studentized range test at 5% probability. Original data followed by statistics performed on data transformed in $\sqrt{X}$.

threshold currently recommended for controlling the major defoliator pests; however, they were carried out in the 1970's or 1980's, although some recently published research papers have shown that these levels are still reliable (Bueno et al. 2013). Among recent research works, Batistela et al. (2012) showed that even the newer cultivars, regardless of the type of growth habit (determinate or indeterminate), tolerate the defoliation levels proposed by the economic threshold (Figure 3) without a significant reduction in productivity/yield (Figure 4). Therefore, so far, there is no scientific evidence showing that more recent cultivars (early maturity group and indeterminate growth habit, for example) are more sensitive to leaf area losses as feared by lots of Brazilian soybean growers.

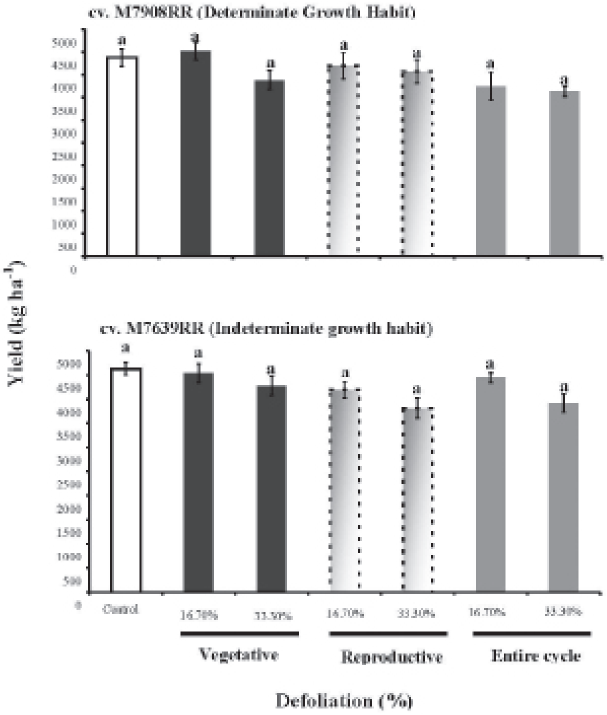

**Figure 4.** Mean soybean production (±SE) after different defoliation intensities (%) at different developmental stages of two soybean cultivars (M7908RR and M7637RR) Means followed by the same letter are not statistically different between each other (Reid 1975)

This tolerance to defoliation occurs because soybean plants have the characteristic of producing leaf area in excess. This characteristic, which is also present in other plant species, allows that even under some defoliation, these plants still achieve maximum interception of solar radiation for photosynthesis (Murata 1961, Stern and Donald 1962). This happens because a small loss of leaf area can be compensated by the greater light penetration in the lower leaves, which were once shaded, leading to an increase in total production of photosynthesized products by the plant, with grain yield similar to the plants without defoliation or even inducing a slightly higher yield than that of the non-defoliated (Turnipseed 1972). Therefore, the growers' fears to wait for these ETs to be reached to start insecticide spraying are meaningless. Any preventive insecticide application will be characterized as pesticide overuse and increase in costs, reducing profits and endangering crop sustainability over the years.

## Stink bugs (Hemiptera: Pentatomidae)

Several stink bug species are considered main soybean pests in Brazil due to the damage they cause to crops. Stink bug feeding directly damages the seeds, making the product less suitable for human consumption or as seed for growers. The most important stink bug species in Brazil are the *Euschistus heros* (Fabricius) and *Piezodorus guildinii* (Westwood).

On one hand, *E. heros* is a neotropical pentatomid occurring in South America, mainly in the continent's warmest regions. This specie used to be the third major component of the pentatomid-pest complex on soybean and, lately, it is known to be fast expanding in Brazil towards the Southern Region. Once rare in soybean, this stink bug is nowadays the most common species in this crop, even in areas where its occurrence was uncommon, such as in Rio Grande do Sul state (Roggia 2010). On the other hand, *P. guildinii* is one of the most damaging stink bug specie to soybeans in Brazil and the whole South America. Moreover, this specie is probably the most widely distributed species since it occurs further north in the neotropical region. Even though less common than *E. heros*, in certain Brazilian soybean production areas, *P. guildinii* is the major pentatomid pest, taking its damage potential into consideration.

The economic importance of stink bug damage to soybeans, combined with the need to develop more integrated management of stink bug populations, is motivating researchers worldwide to look for methods to reduce pesticide use for stink bug control (Panizzi and Corrêa-Ferreira 1997; Venzon et al. 1999; Knight and Gurr 2007). However in Brazil, mainly due to the lack of efficient insecticides to control this pest and due to the various reported cases of stink bug resistance to pesticide, soybean growers started preventively insecticide sprayings against this pest without any respect to the established ET (Bueno et al. 2011a). This strategy, however, is not helping to manage stink bug outbreaks, which has been more common each season in Brazil and can be nowadays considered one of the major threats to crop productivity.

## Stink bug pest management

Similarly to defoliators, the first and one of the most important steps to Soybean-IPM success in managing stink bug outbreaks is a well performed sampling procedure and the adoption of a recommended economic threshold to triggers a control measure against the pest (Figures 2 and 3). Unfortunately, in Brazil, growers are trying to control stink bugs without sampling. Most of the stink bug insecticides are used in Brazil mixed with fungicide at the appropriated timing to spray against the soybean rust *P. pachyrhizi*, as previously mentioned in this review. This will not necessarily be the best timing, since stink bugs and soybean rust might not occur simultaneously. This almost preventive spraying has just worsened the stink bug threat to soybean crops in Brazil and must be avoided due to different negative effects: 1) selection of resistant populations of stink bugs to the main insecticides used; 2) Low number of insecticides with different mechanisms of action; 3) deficiencies in the application technology of these products; and 4) ecological imbalance caused by the abusive and disordered use of broad spectrum insecticides early in the development of the culture (Bueno et al. 2011a; Carmo et al. 2010; Bueno et al. 2008).

Brazilian soybean growers, however, fear to wait for ET to start controlling stink bugs. Despite all this fear, there is no result that proves that ET is not efficient. A study on this subject has been carried out in Brazil, since 2010 (Bueno et al. 2013). This study aimed at comparing the efficiency of the management used for different intensities of stink bugs infestations [ET (2 stinkbugs ≥ 0.5 cm / meter); ¼ ET (0.5 stinkbugs ≥ 0.5 cm / meter)] and the application of insecticides mixed with herbicides and fungicides (the increasingly common practice adopted by some Brazilian soybean growers) in the management of the soybean crop pests. The treatments evaluated were applications of insecticides (or mixtures of them) at different crop developmental stages (Table 2). The preliminary results of this study indicated that, in general, even with a smaller population of stink bugs treated with ¼ of the ET (0.50 stink bugs ≥ 0.5 cm/meter - treatment 2) as compared to the other tested treatments (Figure 5) this treatment did not have any significant gain in productivity/yield (Table 2). In contrast, this treatment had a higher number of insecticide applications and, consequently, higher environmental costs, since six applications of insecticides were performed, while in the treatment 1, which followed the ET recommended by research for soybean destined to the grain production (2 stink bugs ≥ 0.5 cm/meter), only two insecticides applications were needed during the crop cycle.

Moreover, an analysis of the quality of the grains showed damage from stink bugs [scale of 6 to 8, which means the seeds (%) with embryos killed by the stink bugs] during a tetrazolium test. The result was statistically different only for the control treatment that had 13.7% of the grains with dead embryos. Treatment 1 (economic threshold recommend for stink bugs); 2 (1/4 of the economic threshold for stink bugs); and 3 (use of insecticides in combination with herbicide and fungicide) were statistically similar and showed percentages of seeds with dead embryos lower than 6% (Table 2).

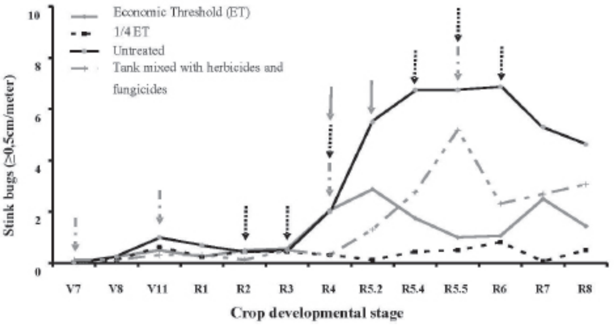

**Figure 5.** Mean population (±SE) of stink bugs along the soybean crop developmental stages after different treatments (indicated by the arrows) for pest control. County of Arapongas, State of Paraná, Southern Brazil, 2010/2011 crop season (Bueno et al., 2013)

Such amount of damage (6%) is still allowed, even in the category of soybean for seed production, which is more rigorous than that accepted by the experiment performed, which was carried out in a soybean field aimed to grain production. Therefore, the chemical application at the right moment was considered the most sustainable treatment among all the different management practices evaluated and must always be adopted by growers. Thus, similarly to the previously mentioned for defoliators, the absence of sampling and economic thresholds for the stink bugs complex observed in Brazil and the overuse of insecticides have brought more harm than benefits, especially when there is no indication that the recommended economic thresholds are not safe to ensure yield associated with sustainability on the field.

## The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae)

*Bemisia tabaci* is a polyphagous pest of agricultural importance throughout the world (Prabhaker et al. 2005), mainly in tropical and subtropical regions (Nauen and Denholm 2005). Further extension of its geographical range from subtropical and tropical agriculture systems has occurred to include temperate climate areas; consequently, *B. tabaci* is now globally distributed and found in all continents except Antarctica (Martin et al. 2000).

This pest used to be of secondary importance to soybean crops, but, in recent years, in some states of Brazil, this species has become a key-pest, reducing yields and increasing soybean costs due to the insecticides used for its control (Vieira el at. 2011). *B. tabaci* nymphs and adults feed in soybean plant phloem and obtain sap containing various sugars. Their excretions, called honeydew, may contain different metabolized sugars, which accumulate on the upper surfaces of plant parts where it serves as a substrate for sooty molds, *Capnodium* sp. (Oliveira et al. 2001). It may accelerate early soybean leave senescence and consequently cause yield loss. In addition to direct injuries caused by feeding, *B. tabaci* can also transmit viruses (carlavirus, closterovirus, geminivirus, luteovirus and potyvirus, among others) in several different crops including soybeans (Morales and Anderson 2001). On soybean plants, the whitefly is the vector of a virus of the carlavirus group responsible for the disease called soybean stem necrosis. Soybean plants infected with this virus display necrosed stems, which as the symptoms progress may kill the entire plant.

### *Bemisia tabaci* management

The increase in soybean production costs due to *B. tabaci* infestations in Brazil is mainly a consequence of lack of awareness about the number of pests that justifies its control (ET). This has led soybean growers to apply insecticides indiscriminately. Many soybean growers are applying insecticide to control whiteflies at low infestation levels. In Brazil, for example, insecticide spraying usually occurs when 10 nymphs per leaflet are present. Often, this control is decided empirically by field technicians, according to personal perceptions acquired through their field experience. This excessive use of insecticides has only worsened the problem with pests, since it favors the selection of resistant insects to the chemicals used, making the soybean production system unsustainable (Palumbo et al. 2011).

First results reported that soybean plants are highly tolerant to whitefly injury, and only whitefly infestations severe enough to trigger sooty mold growth have been reported to be able to reduce soybean yield and, therefore, justifying the use of insecticides (Vieira 2009). Therefore, the application based on levels of infestations of 10 nymphs per leaflet would certainly be much too early, incurring unnecessary costs and environmental danger. Nevertheless, the exactly number of insects that trigger sooty mold formation and/or start to reduce yield is still unknown.

It is important to take into consideration, though, that soybean high tolerance to whitefly injury might differ among cultivars (Vieira et al. 2011). For example, Lambert et al. (1995) observed significant differences in soybean varietal response to whitefly population densities. Similarly, antixenosis soybean resistance response to whitefly infestation was recorded by Lambert et al. (1997) for the 'Perrin', 'Cook', and 'N88-91' soybean genotypes, compared to the susceptible varieties 'Braxton' and 'Cobb', under field conditions. Moreover, soybean tolerance to soybean stem necrosis, transmitted by the whitefly, can also vary among cultivars (Vieira 2009). Therefore, it is important, to take cultivar susceptibility to whitefly and virus into consideration in the Soybean-IPM control measurements against this pest. In this context, since there are soybean cultivars with resistance to 'soybean stem necrosis' available; growers can manage this problem by sowing resistant cultivars; however, they still need to worry about whitefly as a sucking pest and control *B. tabaci* outbreaks before it is severe enough to trigger the growth of sooty mold. Then, the non-use of insecticides to control *B. tabaci* , when the number of nymphs is still below the level of 40 nymphs per leaflet, should be avoided. However, unfortunately, this has been a mistake made by many Brazilian soybean growers.

## CONCLUSIONS

In order to maintain the sustainability of soybean production at medium and long terms, a better alternative to the overuse of pesticides is the integrated pest management (IPM), which proposes the rational use of insecticides as well as the harmonious integration of different control strategies (Zalucki et al. 2009). In the Soybean-IPM approach, the natural biological control of pests is always prioritized according to which other auxiliary tactics, including the use of selective pesticides, are only used as complementary resources, and harmoniously applied in order not to impact the biological control agents in a correct practice of IPM, whose concept contains economic, ecological, and toxicological principles. In this context, the benefits of Soybean-IPM adoption are outstanding but, unfortunately, its use has been abandoned due to the low cost of insecticides and simplicity of its use associated with a constant battle for higher crop yields, what has brought about several undesirable consequences.

Prior to the adoption of Soybean-IPM in Brazil, at the beginning of the 1970s, an average of six insecticide applications were made per crop season, using broad-spectrum insecticides. After Brazil adopted Soybean-IPM, in addition to the use of more selective products to protect natural enemies and beneficial insects, insecticides began to be used more appropriately, with growers considering the economic thresholds for pest control. As a result, the use of pesticides was reduced to approximately two applications per crop season. But lately, after this technology had been progressively abandoned, the number of insecticide application has increased again to four or six spraying per season, what represents a serious threat to this crop. As a result, alternatives to increase Soybean-IPM adoption are urgently required in order to assure yield associated to sustainability, a goal that will be just accomplished with the fully adoption of Soybean-IPM.

## ACKNOWLEDGMENTS

The authors are grateful to CNPq, Embrapa Soybean and CAPES for their financial support.

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**Received: January 02, 2015.**
**Accepted: February 26, 2015.**
**Published: April 02, 2015.**