We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

BOOK CITATION INDEX
CLARIVATE ANALYTICS
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Application Technologies for Asian Soybean Rust Management

Carlos Gilberto Raetano, Denise Tourino Rezende
and Evandro Pereira Prado
São Paulo State University "Julio de Mesquita Filho", FCABO
Brazil

1. Introduction

1.1 Occurrence

Soybean rust is a foliar disease which initially surfaced and remained for many years in Asian countries such as Taiwan, Thailand, Japan and India (Ozkan et al., 2006). After that, the disease was detected in Uganda and South Africa and more recently in South America. Asian Soybean Rust (ASR) is caused by the *Phakopsora pachyrhizi* Sydon & P. Sydon fungus and has been the worst disease in soybean culture. The disease has been present on the American continent, in Paraguay and southern regions of Brazil since 2001 (Yorinori et al., 2010). The importance of ASR disease in Brazil can be evaluated by its rapid expansion and severity and the subsequent economic losses. Over three years (2001 to 2003), ASR dispersed to all soybean producing regions of Brazil, reached the whole of the American continent and was detected in the United States of America in November, 2004 (Yorinori, 2010). ASR disease, when not controlled, can cause a total loss of production (Yorinori et al., 2004). In Brazil, crops free of disease can have an average productivity of 3,300 kg ha^{-1}. However, with the production cost included for a return, net profits of 2,436 kg ha^{-1} have been seen, thus it is recommendable to control the causal agent of the disease (Yorinori, 2005). In the 2007/08 season, ASR showed the lowest severity level since the 2002/03 season, due to farmer awareness of the necessity to obey the "period of sowing interruption", instituted by many of states of the Brazilian Federation. Another cause for improvement was the predominance in the planting of earlier varieties and the improved monitoring system of the disease (Yorinori et al., 2010).

1.2 Severity of ASR disease

The permanence of the pathogen inoculum in the fields the whole year around, due to the post-harvest sowing of the summer season and due to sowing carried out under irrigation during the winter/spring crop season, it was difficult to control the disease between the 2003 and 2005 seasons. During this control period, in the western region of Brazil, the first symptoms of rust were already visible 18 to 30 days after emergence began (V3/V4) and, therefore, some crops received up to seven applications of fungicides. In 2005, with the liberation of the genetically modified soybean culture Roundup Ready (RR), between harvests, the situation became even more serious due to the permanence of the pathogen in the fields all year round (Yorinori et al., 2010). With the "period of sowing interruption",

when only the cultivation of soybeans used in research and for increasing generations provided by breeding lines is permitted under severe rust control conditions and subject to government control organs (MAPA), the severity of the disease has diminished. Nevertheless, the use of control practices of low efficiency, with inadequate fungicides, the use of reduced doses for lowering costs and inadequate number and duration of applications, unfortunately, contribute to persistence of the disease resulting in significant production losses. Continuous monitoring programs, adequate handling practices and appropriate application technology are necessary in order to guarantee the production of soybean culture. The relationship between lateness in the control of ASR and the severity of the disease is 0.25% for each day in which control is not carried out. The relationship between the return rate of the soybean and the severity of ASR is of -36 kg ha^{-1} for each severity percentage point (Calaça, 2007).

1.3 Control of the pathogenic agent

In order to define the strategies to be used for ASR control, regarding application technology, there must be an awareness of the way systemic fungicides move into plants after application and absorption has been carried out. In the present-day market, the majority of fungicides recommended for ASR control move from the base to the top of each leaf, with little chance of moving in the other direction and without the possibility of dislocation from one leaf to another (Antuniassi, 2005). Amongst the fungicides available at present for pathogen control, the triazole fungicides, when used alone, have not presented good performance, as can be seen with ciproconazole, propiconazole and meticonazole (Yorinori et al., 2010). The consistency shown in programmes for chemical control applied in a curative and preventive manner on different soybean varieties and growth stages of the crop has been evaluated by Navarini et al. (2007). The authors established that there was a tendency that higher profit rates were related to preventive applications between the R1 and R3 stages. They also established a low efficiency rate in the control of the pathogen when the fungicide propiconazole was applied in a preventive manner. A deficiency in the control of *P. pachyrhizi* was also observed 30 days after the spraying of the fungicide difeconazole on this crop, in a comparative evaluation of fungicides carried out by Soares et al. (2004). It therefore, becomes evident that triazole fungicides have some limited systemic activity (moving through the plant, especially to newly developed leaves) and are thus somewhat forgiving if the application is less than perfect. When triazole fungicides are mixed with strobilurin fungicides, they show better performance in the control of rust disease. In Brazil, it is believed that the causes of control failures may be related to technical failures in application, predominantly in a population shift which is more tolerant to triazole fungicides in some regions (*Fungicide Resistance Action Committee – FRAC*), instead of developing a tolerance or resistance to the triazole fungicides through genetic mutation of the fungus. As a precautionary measure, class representatives of the producers recommend the use of triazoles only when mixed with other groups of fungicides.

1.4 Economic impact of ASR in Brazil

An estimate of the volume of grain losses and of the economic impact of ASR in the period between 2002 and 2009 reached 34.2 million tons, a value equivalent to more than half a full soybean harvest. On the other hand, the economic impact of ASR, adding up grain losses (US$ 7.95 billions), control costs (US$ 5.76 billions) and intake losses (US$ 1.55 billions) during the same period, totalled US$ 15.25 billion (Yorinori et al., 2010). If we

consider that the world demand for soybeans is strongly linked to population increase, to world riches and to bioenergy, the necessity to minimise losses in all stages of soybean processing becomes evident. These demand indicators generate worries, particularly in Brazil, where the biofuel program has demanded a mixture of 4% biodiesel in the final fuel formulation since 2009, especially since the main source of biodiesel is soybean oil (Barros & Menegatti, 2010).

2. Fungicide spray coverage

The right moment for application is determined by climate conditions, the presence and severity of the disease, plant growth stage and fungicide efficiency (Yorinori et al., 2004). These factors, together with correct calibration of the application equipment and with correct handling practices aimed at the control of *P. pachyrhizi*, have not been sufficient to impede the advance of the disease in soybean culture. The necessity for more efficient application of phyto-sanitary products has been related to various researchers such as Adam (1977), Matuo (1990) and Van De Zande et al. (1994), amongst others. It can therefore be noted that, in order to obtain the best efficiency, the study and development of new application technologies are indispensable. Phyto-sanitary products must be applied with maximum efficiency and, for this to occur, studies of spray deposition and coverage and spray drift are necessary. This last factor is responsible for losses and is also a cause of environmental contamination (Matthews, 1992).

2.1 Droplet size and spray coverage

A definition of droplet size and the volume to be applied must be a priority in the planning of an application. Further factors, such as the correct time of application, weather conditions, product recommendations and operational conditions, should be considered as a whole, looking towards maximum performance with the least losses and the least environmental impact (Antuniassi, 2010). Spray volume has the greatest impact on canopy penetration and leaf coverage. Increasing the volume improves penetration and coverage. The recommended spray volume differs for each fungicide. For aerial applications, the minimum recommended volume is 5-7 gallons per acre (47-65 L ha^{-1}). Recent research on soybean canopy coverage for ground applications at different growth stages of soybean (R1, R3 and R5) support recommendations that a spray volume of 15 gpa (140 L ha^{-1}) may provide adequate coverage of the entire canopy early in the growing season (R1 and R3) but 20 gpa (187 L ha^{-1}) is necessary later in the growing season (by R5) when the soybean canopy density and volume have increased (Brown-Rytlewski & Staton, 2010). In Brazil, the spray volume rates for conventional ground spraying of soybean have varied from 100 to 150 L ha^{-1}, but it is possible to have a reduction of 50% in spray volume using the new spray technologies and earlier varieties. In the mid-west region (Cerrado), the use of low application rates with conventional ground sprayers is limited by climatic conditions due to the high temperature (30 to 40°C) and low air humidity (12 to 30%) during the greatest part of the year. Droplet size is the second most important factor affecting canopy penetration and leaf coverage. Research has shown that fine to medium droplets, with median volume diameters (MVD) in the range of 200 to 350 μm, maximise canopy penetration and leaf coverage. Smaller droplets provide better leaf coverage but lack the momentum to penetrate the canopy. Larger droplets have the momentum to penetrate the canopy but do not provide sufficient leaf coverage. Ground speed, nozzle pressure and spray volume should be

considered when selecting nozzles for the sprayer. Choose nozzles that will produce 200-350 µm droplets at 15 to 20 gallons per acre (140 to 187 L ha^{-1}) while travelling at the desired speed. In most cases, nozzles for herbicide applications should not be used for fungicide applications as they are designed to generate larger droplets at lower application rates. All nozzle manufacturers use a spray classification system (ASAE standard S-572) of six categories with corresponding colours to classify the droplet size range produced by nozzles under various operating pressures. The colour of the nozzle itself should not be confused with the colours listed in Table 1. The nozzle colour describes the flow rate for the nozzle and the colours on the table describe the nozzle's droplet size range. When using droplet size classification charts, select nozzles that produce droplets near the fine end of the medium (yellow) category.

Droplet category	Colour	Symbol	MVD (µm)
Very fine	Red	VF	<150
Fine	Orange	F	150-250
Medium	Yellow	M	250-350
Coarse	Blue	C	350-450
Very coarse	Green	VC	450-550
Extremely coarse	White	XC	>550

Michigan State University – Department of Plant Pathology, USA

Table 1. ASAE Standard S-572 Spray Quality Categories

Ground speed affects spray volume and vertical droplet velocity. Taking into consideration that in order to apply fungicides, a fine to medium category of drops are indicated, and that the maximum wind speed during spraying should not surpass 9.6 km h^{-1} (Andef, 2004), a critical new situation presents itself in the field. Auto-propelled sprayers present innovations that give greater stability to the spray booms and with this, the operational speed increases to values rearing and even above 16 km h^{-1}. The immediate consequence of this operational situation is that the relative wind between the boom in displacement and the air canopy which is present between the spray boom and the intended crop have a braking effect, contrary to the downward speed of the fine droplets generated at the tips of the sprayers. This process help with evaporation and also with the drift of the fine spray droplets and hinders its arrival on the crop canopies to be treated. A second consequence depends on middle-sized droplets that manage to maintain their falling speed in spite of the opposite effect generated by the dislocation speed of the boom. Research carried out recently on winter cereals, by the Institute DLG in Germany, shows that these droplets deposit themselves, on the whole, only on one side of the plants, with the other side ("shady side") consistently lacking in droplets (Boller & Raetano, 2011). The research also revealed that an increase in the displacement speed of the equipment implies in a greater deposit of droplets on the upper third of the plants and fewer droplets deposited on the lower leaves.

The increase in spraying pressure may partially compensate for this effect; however; one cannot emphasise too strongly that excessive working pressure is one of the most important factors that facilitate spray droplet drift. This picture deserves particular attention, due to the fact that the actual and future tendency is the increase in the displacement speed of the spray equipment by land. In the same situation, spray nozzles with flat double spray outlets show a slight increase in the quantity of droplets deposited on the side known as "the shady

side". The most balanced situation was obtained when ends with flat double jets, with differentiated angles in relation to the vertical position, were utilised. The results indicate that this type of outlet may be efficient for a more even deposition of the droplets, on both sides of the plants, when the displacement speed of the boom is around 12 km h^{-1} (Boller & Raetano, 2011). There are basically two ways to increase coverage: 1) reduce droplet size and 2) increase carrier volume (application rate). Large droplets do not provide good coverage and result in chemical wastage. Increasing the application rate may be equally undesirable. It requires frequent refilling of the sprayer tank. This wastes time that may be extremely valuable when there is a short period of opportunity to spray. Ideally, we want to have as many small droplets on the target as possible. However, extremely small droplets have a tendency to drift. Research has shown that there is a rapid decrease in the drift potential of droplets whose diameters are greater than approximately 200 μm. When extremely small droplets are released from the nozzle, they quickly lose the momentum that is needed to push the droplets into the canopy. Also, these extremely small droplets do not last long after they are released from the nozzle. Most of them evaporate within a few seconds (Ozkan, 2010). The single most important factor affecting the control of ASR disease is to get a thorough coverage of soybeans with the fungicide, which is much different and more challenging than spraying for weeds and insects. The most effective coverage on soybean plants can be obtained with both the horizontal as well as vertical distribution of the fungicide on soybean leaves. Asian soybean rust usually shows its symptoms in the lower parts of the plant first and works itself up towards the top of the plant. The most effective spray equipment and methods for applying fungicides on soybean plants to control Asian soybean rust was studied by Ozkan et al. (2006). A second component of the study was to determine the effect of spray quality (fine, medium, coarse) on spray deposition and coverage using three different sizes (8002, 8004 and 8005) of the XR type of a flat fan nozzle operated at different spray pressures. The application rate was kept constant at 145 L ha^{-1} for all the treatments. The average spray coverage on the middle part of the soybean canopy (0.6 m above the ground) varied from 1.3 to 7.3% among the treatments. The Jacto sprayer provided the highest spray coverage on the middle part of the canopy, followed by Top Air sprayer and the boom sprayer with a TX-18 hollow cone nozzle that produced the lowest spray coverage on the middle part of the canopy, followed by Turbo duo, and then XR 8002 nozzles. The average spray coverage at the bottom part of the soybean canopy (0.3 m above the ground) varied from 0.5 to 3.9% among the treatments. Similarly to the coverage on the middle part of the canopy, the Jacto sprayer provided the highest spray coverage on the bottom part of the canopy, followed by the boom sprayer with the canopy opener and then the Top Air sprayer. The boom sprayer with XR 8002 nozzles produced the lowest spray coverage on the boom part of the canopy, followed by hollow cone TX-18 nozzles. XR 8002 flat fan nozzles and hollow cone nozzles had smaller MVD than other treatments with the boom sprayer. The authors observed that among the three spray qualities (fine, medium and coarse), the medium quality spray provided the highest coverage and the fine quality spray provided the lowest coverage at both middle and bottom parts of the canopy. When compared to the XR 8004 flat fan pattern nozzles with medium spray quality, Twinjet, Turbo dual pattern nozzles and hollow cone nozzles provided very low coverage on the middle and bottom parts of the canopy. Droplets from Twinjet, turbo dual pattern and hollow cone nozzles had poor penetration capabilities because these droplets had horizontal velocities. The horizontal movement of droplets consumed kinetic energy and caused droplets to

easily settle on the top leaves. The influence of the size of droplets from different nozzles on soybean spray coverage was studied by Antuniassi et al. (2004). The authors verified that very fine quality spray obtained with hollow cone TX VK6 nozzle and Twinjet flat fan TJ 60 11002 nozzle, and fine quality spray with a flat fan pattern XR 11002 nozzle, provided greater coverage in middle and bottom parts of the soybean plants when compared to the extremely coarse spray quality produced by air induction flat fan nozzles. The effects of spray nozzles (flat fan pattern, pre-orifice flat fan, air induction flat fan and air induction twin flat fan) and volume rates (115 and 160 L ha^{-1}) on chemical control of rust and the deposition of tebuconazole fungicide sprayed on soybeans of the Emgopa 313 variety, were studied by Cunha et al. (2006). The results showed that, despite the fact of the volume rate of 160 L ha^{-1} and of the use of pattern flat fan nozzles, they provided larger fungicide distribution uniformity in the plant canopy. There was no influence of the nozzle type neither of the application volume in the control of the rust, as well as in the soybean yield. In part, the results described by Raetano & Merlin (2006) ratified those observations that have been made by Cunha et al. (2006). The experiments were conducted in 2004/05 and 2005/06 seasons, using soybean, IAC-19 variety, with the same sprayer equipment and near application volumes (99 and 143 L ha^{-1}; 100 and 150 L ha^{-1}). The values of spray deposition were less influenced by nozzle type (hollow cone, flat fan and twin flat fan), both with fine spray quality. It is recommended for Asian soybean rust control that droplets have a size of 200 to 300 μm (OZKAN, 2005), but droplets smaller than 100 μm can be used with drift control in spraying with air assistance delivery systems near to the sleeve boom.

3. Fungicide application techniques

Nowadays, Asian soybean rust (ASR) deserved special attention due to its severity and difficulty of control, since it develops in the aerial part of plants, damaging the physiology and contributing to a drastic reduction of grain yield. For efficient control and cost-cutting, spray techniques and spray equipment must be improved. Studies show that the use of air assistance in the sleeve boom, connected to the hydraulic system of the tractor, can reduce the drift, increase droplet penetration into the plant canopy and improve the spraying distribution (Bauer & Raetano, 2000; Cooke et al., 1990; Taylor et al., 1989; Taylor & Andersen, 1991).

3.1 Air assistance delivery system in boom sprayers

The use of air assistance in phyto-sanitary product application is very old. However, the enthusiasm in using this spray technology started in 1980, as reported by Robinson (1993). Four years later, the Degania Sprayers Company in Israel developed a sprayer, revolutionary at the time, equipped with air assistance on the spraying sleeve boom. However, only since the end of the 1980s and the beginning of the 1990s has air assistance been effectively adopted in sleeve boom sprayers. In Europe, this technology was introduced by Hardi, and in Germany, in 1996, seven manufacturers exhibited equipment with air assistance in the *Agritechnica* agricultural trade show (Koch, 1997). At that time, the Brazilian industry also incorporated this technology to tractor-driven trailing sleeve boom sprayers. The incorporation of this technology to sleeve boom sprayers was an attempt to improve spraying penetration in the target culture, reduce drift and the number of applications required, increase the time available for carrying out the spraying and enable changes to the spraying height over the culture (DEGANIA SPRAYERS Co., s.d.). For

applying phyto-sanitary products on low-stem cultivation, the spraying sleeve booms equipped with air assistance appeared as the ideal tools to improve application quality (smaller droplets, in higher numbers), increase productivity (lower volume and replenishment, higher displacement speed and extended spraying times), reduce drift (the machine's wind speed is greater than the environmental wind) and exposure to these products (Sartori, 1997). After twenty years of using air assistance in sleeve boom sprayers, a great deal of information must still be clarified about the interactions between air volume and speed which are more appropriate for different cultures, the angle of the nozzles on the boom in relation to the air, spraying height and displacement speed, amongst other factors which enable wider spraying coverage and lower losses.

3.1.1 Characterisation of the technology

Tractor-driven sprayers with air assistance can be coupled to the tractor's hydraulic power take-off (third point) (those with lower capacity tanks or of the trailing type). These sprayers are equipped with one or two fans, usually axial, positioned near the centre section of the spraying sleeve boom, which distribute a very high air volume in an inflated duct assembled over the boom and nozzles (Matthews, 2000). The speed of the air generated may vary with the fan rotation (rpm), and generally it does not follow a linear relationship. Also, air speed variations could occur along the boom, at the ends, when compared to the speed achieved in its centre section (Raetano, 2002). The established standards for evaluating with accuracy the speed of the air generated by sleeve boom sprayers equipped with air assistance was necessary to standardise the measuring distance in relation to the air exit opening, as well as to specify anemometers that are able to record high air speeds (30-40 m s^{-1}). Thus, Kunz (2010) developed two methods for air speed and volume measuring in spray booms equipped with air assistance. In the first method, a wooden mould was placed at the outlet of the air curtain, in a vertical position, in the direction of the air flow, and measurements were taken with the anemometer at pre-established distances. This form of measuring became know as the "ruler method". This method makes it very difficult to determine the main vector of the air flow that comes out in a continuous manner through the rectangular opening on the lower part of the inflated sleeve, which makes it difficult to measure the air speed with precision. New air-speed readings are now taken beforehand, using a nylon thread fixed to the air outlet, to indicate the point of air flow displacement vector, which substitutes the ruler method. In this way, it makes it very much easier to identify the main air flow and increases the precision and uniformity of speed values obtained with the anemometer. In a similar manner to the ruler method, pre-defined distances are marked off on the nylon thread, so that measurements can be taken with greater ease and accuracy. This procedure is called the "thread method" (Figure 1). Due to the dynamic behaviour of the air flow, it becomes difficult to identify the vector of the air flow that comes out under high speed from the system, principally at distances of 0.25 and 0.50 m, which causes a great variation in the speed data obtained with the ruler method, as can be seen in Table 2. The air speed values obtained with the thread method present greater uniformity in relation to the ones obtained with the ruler method, especially at distances of 0.25 and 0.50 m from the air outlet. This can be observed through the variance values (%) of the data, which were smaller with the thread method (Table 2). The average values of the air speed obtained with the thread method were greater, probably due to the correct identification of the main air flow vector when measured by this method. Measuring the air speed, therefore,

becomes more precise and easier, especially at longer distances in relation to the air flow at the spray boom.

Fig. 1. "Nylon thread method" for measuring air speed in a sleeve boom sprayer.

Distance (m)	Average*	S.D.	Variance	CV %	Min*	Max*	Amplitude*
Ruler method of measurement							
0.0	70.14	10.00	100.05	14.26	53.40	97.20	43.80
0.25	41.71	5.70	32.55	13.68	31.20	54.00	22.80
0.50	29.49	8.20	67.27	27.81	20.50	51.80	31.30
Nylon thread method of measurement							
0.0	71.57	10.09	101.83	14.10	59.50	93.60	34.10
0.25	43.64	4.04	16.33	9.26	36.60	51.00	14.40
0.50	35.26	3.53	12.47	10.01	28.80	41.90	13.10

*Values expressed in km h^{-1}.

Table 2. Descriptive statistics of the air speed data obtained along the spray boom with different evaluation methods.

3.1.2 Air speed on spray deposition

Raetano & Bauer (2003) evaluated the effects from air speed variation (50%, 75% and 100% of the maximum fan rotation capacity) on the spraying sleeve boom, when depositing phyto-sanitary products on bean culture. Forty-eight days after sprouting begins, 200 g of copper oxide per 100 L of water were applied with AXI-110015 tips at 206.7 kPa and JA-1 at 1,033.5 kPa, either with air assistance or not, using a Model Falcon vortex sprayer. The broth volume was 100 L ha^{-1} in both operational conditions. The air speed variation did not influence the deposit levels in the culture, but the use of air assistance, operated at full fan capacity, resulted in better deposit levels on the abaxial surface of the leaflets positioned in the lower portion of the plants. Cereal-cultivated soil contamination can be reduced to

approximately 40% when using 50% of the maximum speed of the air generated by the fan in a sprayer equipped with air assistance on the sleeve boom, when compared with conventional application (without air), as reported by Taylor & Andersen (1997). The deposit and losses of spraying broth in the cultivation of bean (*Phaseolus vulgaris*), 26 days after sprouting, and using sprayers equipped with air assistance on the sleeve boom and conventional sprayers (without air) and volumes of 60 and 100 L ha-1, have been evaluated by Raetano & Bauer (2004). The higher volume resulted in greater deposits, but high losses to the soil (above 60%) have been noted, even when using air assistance with air speed corresponding to 50% of the maximum fan rotation. In part, such results have been assigned to 40% of the soil bare of vegetation at this growth stage of the culture. The air volume generated may vary from 0 to 2000 m^3 per hour per boom, depending on the number and power of the fans distributed on variable-size booms that could reach 30 m in length. The air distributed in the inflated duct is forced to pass through a continuous or intercalated opening, in a perpendicular direction to the one in which it has been generated, in a descending direction. The effects of chemical control of the rust and deposition fungicide sprayed under four speeds (zero, 9, 11 and 29 km h-1) by a spray boom on soybean crop were evaluated by Christovam (2008) and Prado et al. (2010). Significant differences were obtained in the lower part of the plants for spray deposition using higher speed of air assistance. On the top part of the plants, greater levels of deposition were seen when spraying without air assistance was carried out. The rust severity was more intense in treatments without air assistance. Raetano & Bauer (2003) evaluated different velocities of air assistance near the spray boom and concluded that air assistance, with maximum air speed generated by the fan (29 km h-1) and a flat fan nozzle (AXI 110015 type), provided greater spray deposition on the abaxial leaf surface, on the bottom part of the bean plants. The data of the soybean crop yield at different air speeds using an air-assisted sprayer for Asian soybean rust management was compared in the 2006/07 (Christovam et al., 2010a) and 2007/08 (Prado et al., 2010) seasons (Figure 2). Air speeds used in both studies were zero, 9, 11 and 29 km h-1.
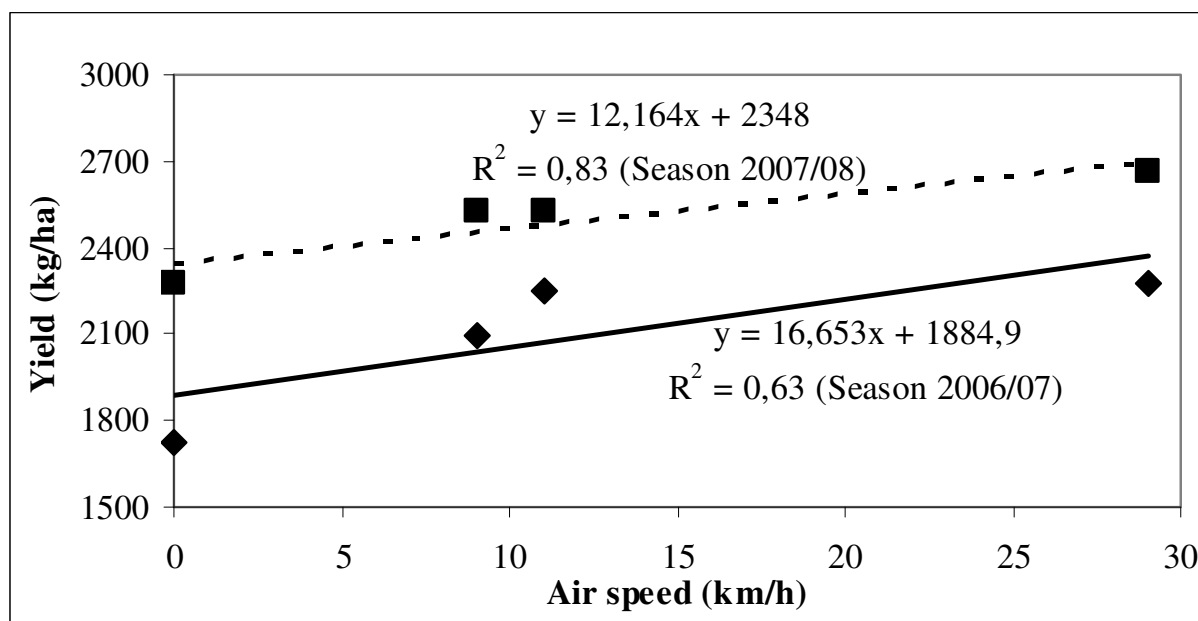

Fig. 2. Effect of the air speed on soybean crop yield, 2006/07 and 2007/08 agricultural season using a sleeve boom sprayer. Botucatu, SP, Brazil.

There is a positive correlation between air speed and soybean crop yield. When compared, the soybean yield using the maximum air speed generated by the fan (29 km h^{-1}) in conventional spraying (without air), increases of 31.9% and 17.1% can be seen in the 2006/07 and 2007/08 seasons, respectively. As can be verified, in the last agricultural season, the increase in soybean yield was lower, due the higher severity of ASR on the Conquista variety (Figure 2). The effect of different air speeds (0, 9, 11 and 29 km h^{-1}) in chemical control of pests on soybean crop, Conquista variety, was evaluated by Prado (2009), after insecticide spraying using an air-assisted sprayer. The use of air speed generated by the fan in the maximum rotation (29 km h^{-1}) provided greater control of the lower velvetbean caterpillar (*Anticarsia gemmatalis*). This effect was not observed with longer caterpillars (> 1.5 cm) because the lowest caterpillars are more easily located in the lower part of the soybean plants. Thus, the lower caterpillars received an additional amount of insecticides due the effect of air assistance with maximum air speed into the canopy. In general, there was not a statistically significant difference between air speeds on stink bug control after insecticide spraying on soybean culture.

3.1.3 Nozzle angle on spray deposition

The positioning angle of the spraying nozzle in relation to the air curtain (Figure 2), generated by the equipment (vertical, descending), as well as the nozzles and air curtain, simultaneously, in relation to the vertical position, may significantly influence the deposit levels and the spraying distribution. Nowadays, in sleeve boom sprayers equipped with air assistance, the angle variations of the nozzles and air curtain, in relation to the vertical position, pro or against the tractor-sprayer assembly displacement, are made simultaneously clockwise or counterclockwise, with the single-cylinder command. The results research carried out under controlled conditions and in the field have shown that the positioning of the nozzle at 30° forward of the displacement in conventional sprayers (without air) provides a significant increase in deposits on the leaf surface of different vegetal species: *Cyperus rotundus* (Silva, 2001), *Brachiaria plantaginea* (Tomazela, 2006) and *Glycine max* (Bauer, 2002). In England, research carried out in wind tunnels with plants cultivated on trays have confirmed that the spraying angle forward of the displacement, in the presence of air assistance, increased deposit on cereals and reduced soil contamination (Hislop et al., 1995). Nowadays, one may position the spraying nozzles and air curtain at angles of 15° and 30° in relation to the vertical position in sleeve boom sprayers equipped with air assistance, made in Brazil. The use of air angled forward of the displacement with fine droplets could substantially increase spraying deposit levels on vertical targets. These results were obtained from practical experiences published by the Hardi Int. Tech. Reports in potato culture which indicated that spraying penetration and retention are greater with air assistance positioned at an angle forward of the displacement on the leaves in the lower portion of the plants. In the upper portion, the retained broth volume was virtually not influenced by the air exit angle, pro or against the equipment displacement (Taylor & Andersen, 1997). The effect of the nozzle angle and air-jet parameters in an air-assistance sprayer on the biological effects of ASR chemical protection was studied by Christovam et al. (2010b). Four air levels (0, 9, 11 and 29 km h^{-1}) were combined at two nozzle angles 0° and 30° for the sprayings using flat fan AXI 110015 nozzles. The spraying with triazole fungicide was realised in R2 and R5.2 growth stages of soybean at 142 L ha^{-1} of volume rate. For the evaluation of spray deposition, a cupric tracer was used. At the bottom part of the plant, spraying with maximum air speed

generated by the fan and nozzles angled at 30°, it was essential to promote doubled deposits on the abaxial leaf surface (Table 3). Maximum air speed (29 km h^{-1}) and nozzles angled at 30° resulted in an increase in spray deposits on adaxial surface of leaves in the bottom part of the plants (Table 3).

Air Speed (km h^{-1})	Adaxial surface				Abaxial surface			
	Angle 0°		Angle +30°		Angle 0°		Angle +30°	
	μl cm^{-2}		μl cm^{-2}		μl cm^{-2}		μl cm^{-2}	
0	1.2425	a A	0.6962	b AB	0.6585	a A	0.2444	b B
9	0.6997	a A	0.9865	a AB	0.3621	a A	0.4527	a B
11	1.147	a A	0.6395	b B	0.4651	a A	0.3292	a B
29	0.6287	b A	1.2663	a A	0.4904	b A	0.8552	a A
DMS Angle	0.46				0.24			
DMS Air speed	0.62				0.33			
CV (%)	34.17				34.16			

The same larger letters in the column, did not differ by the Tukey test (p<0.05).

Table 3. Average values of deposits of the copper tracer in an artificial target (filter paper) on leaf surfaces, in the bottom part of the soybean plants, Conquista variety, in relation to different spraying angles. Botucatu, SP, 2006/2007.

Nozzles angled at 30°, in the same direction of the sprayer displacement, combined with air assistance (29 km h^{-1} of air speed) positively influenced the control of disease as well as the yield of the Conquista variety crop. This fact confirms the importance of spraying performed with nozzle angles in the same direction of the sprayer movement, which can contribute significantly to Asian soybean rust control, considering the disease epidemiology. The choice of the best combination of air speed and nozzle angle in air-assisted sprayers is influenced by architecture and growth stage of the plants to obtain a desirable biological effect in soybean Asian rust chemical protection with this technology. Conventional spraying (without air) and air-assistance at 0° (vertical) and 30° (forward to displacement of the equipment) are shown in Figures 3A, 3B and 3C, respectively. The spray boom angle interference, with or without air assistance near the boom, on spray deposit levels were studied by Scudeler & Raetano (2004) in potato culture. The higher deposits were evidenced with nozzles positioned at 0° and 30°, with the presence of air assistance, both at the top and bottom part of the potato plants. The lower spray deposits were obtained with nozzles positioned at 30° in the opposite direction to the displacement of the sprayer. In addition to the volume rate, generated air speed and nozzle angle in air-assisted sprayers, other factors, such as displacement speed of the tractor-sprayer assembly, presence of vegetal coverage in the area or not, vegetal coverage type (monocotyledonous or dicotyledonous, plant density, architecture and plant cuticle characteristics), positions of insect pests and plant pathogens, agrochemical product characteristics, droplet size and environmental conditions, especially wind speed, may influence the efficacy of phyto-sanitary control. It is necessary to develop studies with variations in air speed combined at different angles of spray nozzle on spray deposition and coverage. Dynamic systems for air speed evaluation combined at different nozzle angles and the performance of these in spraying could be better studied.

Fig. 3. Air-assisted sleeve boom sprayer in the following operation modes: A – conventional spraying (without air); B – spraying with air assistance at 0º (vertical) and C – spraying with air assistance angled at 30º forward to the displacement of the tractor-sprayer assembly on soybean crop.

3.1.4 Effect of the air-assistance delivery system on soybean productivity

The influence of an air-assisted delivery system on soybean productivity, var. Conquista, 2006/07 and 2007/08 seasons are shown in Figure 4. The spraying treatments used to control *P. pachyrhizi* fungus were applied on soybean plants (R2 and R5.2 growth stages) using a triazole + strobilurin spray mixture and volume rates between 120 at 150 L ha^{-1}. The data of soybean crop productivity after two sprayings with different technologies was submitted to a variance analysis and the averages were compared by Tukey's test (p<0.05).
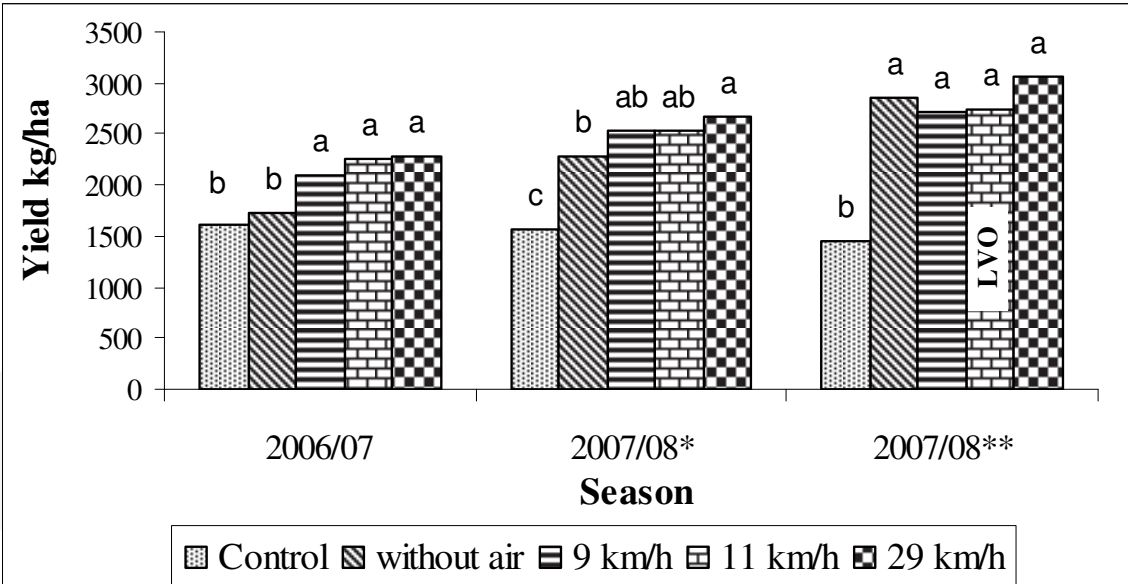

Fig. 4. Effect of treatments: control (not treated); air-assistance delivery system at zero (without air), 9, 11 and 29 km h^{-1} air speed; rotating nozzle-LVO with a third part of spray volume (40L ha^{-1}) on soybean productivity. The Conquista variety was used in the 2006/07 and 2007/08 agricultural seasons. Botucatu, SP, Brazil (2006/07 - Christovam et al. 2010b; 2007/08* - Prado et al. 2010; 2007/08** - Christovam et al. 2010a).

In general, this technology provided higher productivity, in relation to that with conventional spraying (without air) and control (not treated). A higher increase in soybean productivity was obtained with maximum air speed generated by the fan (29 km h^{-1}). The

air assistance constituted an optional implement on the boom sprayers that can increase up 30% the equipment cost in relation to conventional sprayers which do not have this technology. Although the use of this technology should not be recommended on soils without vegetation or even on early stages due to the smaller foliar area. This method provides several advantages that have been mentioned before.

3.1.5 Air assistance and spray drift

Air assistance in the spraying sleeve boom significantly improves the penetration of spraying, especially in high cultures and high leaf density, such as potato, in addition to reducing drift (Koch, 1997). However, these effects were not observed when air-assisted spraying is done on bare soil or plants in the first stages of growth. Also, according to Matthews (2000), air-assisted spraying penetration is better when compared to conventional spraying on wide-leaf cultures, such as cotton. In Holland, tests with the air-assisted sprayer Twin (Hardi) have been carried out on potato cultivation. Generally, air assistance reduced drift by sedimentation by 50% and the air-carried drift by 75%. In Holland, the accepted drift percentage by sedimentation is 8-10% for a distance of 1.5 to 2.0 metres from the boom, and around 0.2% for 5.0 to 6.0 metres intervals. The recommendation for making spraying in Holland is with a wind speed less than 5.0 m sec^{-1}. In Germany, the accepted drift values by sedimentation when applying phyto-sanitary products range from 0.6 to 0.1%, respectively, for distances of 5.0 to 30.0 metres from the spraying sleeve boom (Jorgensen & Witt, 2000). Considering the drift limits accepted for spraying in Germany, the safe distance for applying near water channels (irrigation/draining) in that country is 10.0 metres for 80% of the herbicides approved for use, and 20.0 metres for other herbicides. France and Belgium comply with the drift limits accepted in Germany. Artificial targets have been also used by the Morley Research Centre for simulating venomous plants in the sugar beet. The variations in the deposit values for air-assisted spraying were lower when compared to those achieved with the conventional sprayer (Taylor & Andersen, 1997). These authors have also demonstrated the influence of air assistance on drift percentage reduction compared with conventional application (without air), by obtaining 90, 84, 83, 76, 68 and 61%, respectively, when spraying barley, bean, pea, Brussels sprouts, lettuce and leek, with fine droplets. Nowadays, studies involving computer models aim at clarifying the relationship among the air released drift risk and deposit on target. Preliminary studies have shown that the increase of the displacement speed with air-assisted sprayers may reduce drift, but provide lower evenness in the target culture treatment (Miller, 1997). However, aiming at reducing the application volume, Nordbo (1992) has demonstrated lower variation and improved deposit by using air assistance. The density, architecture, cuticle type (pilose, glabrous and waxy) and growth stage of the vegetal species in the area are factors influencing phyto-sanitary control efficiency when using air-assisted sleeve boom sprayers. Fine droplets provide larger deposits on plants, especially monocotyledons, but are very susceptible to drift. Their penetration capacity in cultures is small, and then the loss to the soil must be limited. Therefore, air assistance enables using fine droplets more efficiently, by reducing the drift and increasing the deposits on the target, in addition to providing higher penetration of these droplets in cultures with higher leaf density, and reducing losses to the soil (Jorgensen & Witt, 1997). On the other hand, coarse droplets generally provide good drift control. In dicotyledons, the deposits do not depend only on droplet size (Nordbo, 1992). Unlike the results with smaller diameter droplets, coarse droplets provide significantly lower deposits on vertical surfaces (monocotyledons), and

especially in the first growth stages, by increasing the loss to soil proportionally to their size (Jorgensen & Witt, 1997). In vegetables, where droplet retention is limited by the presence of waxy layers on the cuticle, further studies are required, especially with air-assisted spraying, in order to evaluate the application quality (Koch, 1997). In the absence of vegetation (bare soil), air assistance may increase drift and deflect the air from the sprayer by the soil, unlike the effect which occurs in the presence of vegetation, with the impact of droplets on the leaf surface (Matthews, 2000).

3.2 Alternative spray technologies on soybean

Nowadays, other technologies are available to the boom sprayers enabling higher spraying droplet canopy penetration in soybean culture. The difficulty in controlling Asian soybean rust and late season diseases has favoured the development of new spraying techniques, particularly due to the difficulty in reaching the exact target to be controlled. Thus, the use of the opener, rotating system nozzles, hose drops and electrification of droplets associated with air assistance can be mentioned.

3.2.1 Opener

Conventional sprayers linked to an artefact providing the canopy opener at the same spraying way can turn out to be an economic and effective alternative to soybean growers with lower purchasing power (Zhu et al., 2008b). These authors found that spraying performed with conventional sprayers linked to a canopy opener did not results significant differences in the coverage of the spray in the middle part of soybean plants when compared to spraying carried out using air assistance. However, the canopy opener coverage and air assistance along the bar was higher compared to treatments where the spraying was conducted by the conventional system without the canopy opener. Thus, the opener and spray boom coupling can provide deposition results similar to those obtained with the use of air assistance, besides being a more economical alternative to Asian soybean rust control (Figure 5). Considering the difficulties in controlling ASR by fungicide spraying, Prado (2011) evaluated the effectiveness of the canopy opener compared to conventional sprayers and air assistance in the spray boom on spraying deposition, rust control efficiency and soybean productivity. The experiment was conducted in a randomised block

Fig. 5. Canopy opener artefact fixed to the spray boom in a soybean crop.

experimental design with six treatments: conventional spraying (T1), spraying with air assistance at maximum capacity of the fan rotation in the boom (T2), spray with a canopy opener to a depth of 0.10 m (T3), spraying with a canopy opener to a depth of 0.10 m with air assistance (T4), spraying with a canopy opener to a depth of 0.20 m (T5) spraying with a canopy opener to a depth of 0.20 m with air assistance (T6) and control treatment (without spraying) (T7) in four replicates, totalling 28 plots. The area of each plot was equivalent to 70 m². The depths of 0.10 and 0.20 m refer to the distance from the canopy opener in relation to the top of the soybean plant. In addition to the distance between the canopy depth opener and the top of the plants, there is also a predetermined horizontal distance of 0.15 m between the boom and the canopy opener. The function of the canopy opener is to promote the soybean plants to slope forward, opening a space in the plant canopy and thus facilitating the flow, and consequently droplet deposition, on the bottom of the soybean plants. The sprayer used in the experiment was the Advance Vortex model 2000 with an 18.5 m long boom, 37 flat fan XR 8002 nozzles spaced 0.50 m apart operating at a pressure of 295 kPa and a spray volume of 150 L ha^{-1}. The comparative effect of these different technologies on soybean productivity after three fungicide pyraclostrobin + epoxiconazole mixture sprayings at a dose of 25 + 66.5 g a.i ha^{-1} in the development stages R2, R3 and R5, as shown in Figure 6. The treatment T5 (spraying with a canopy opener at a depth of 0.20 m) had a higher productivity increase (54%) compared to control treatment. All treatments which received fungicide had significantly higher yields than the control treatment. There was no difference between the canopy opener and air assistance on soybean yield, making it an interesting and economical alternative for the control of Asian soybean rust. These results corroborate those obtained by Zhu et al. (2008).
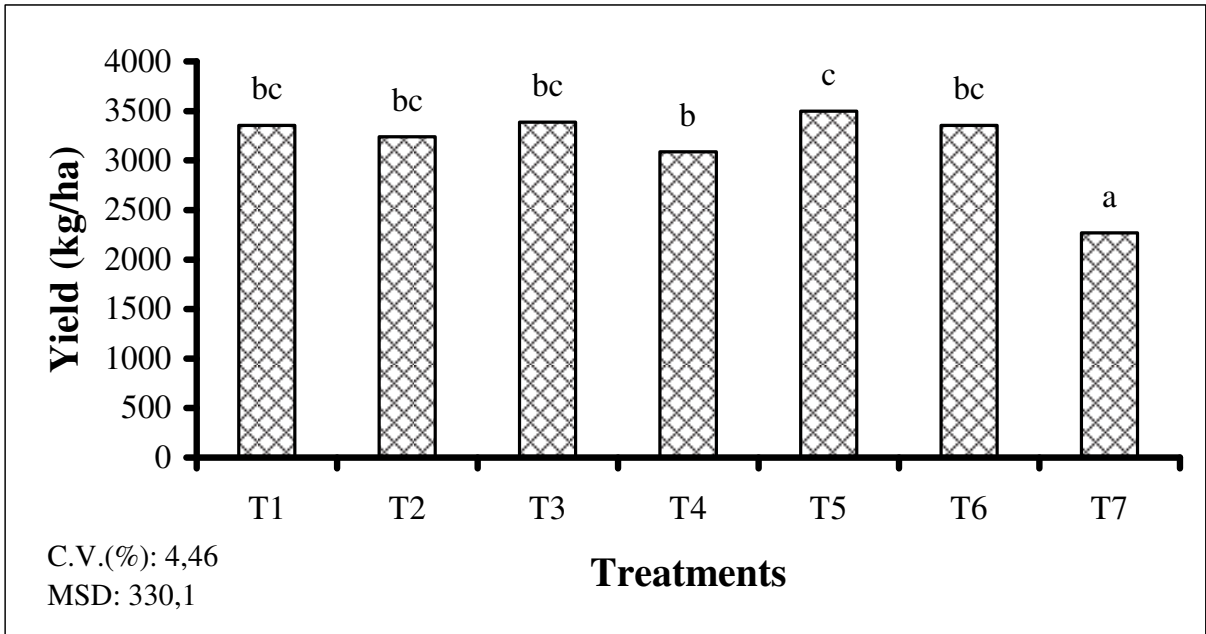

Fig. 6. Effect of different treatments: conventional spraying (T1); air-assistance (T2); *canopy opener* at a depth of 0.10 m (T3); *canopy opener* at a depth of 0.10 m with air assistance (T4); *canopy opener* at a depth of 0.20 m (T5); *canopy opener* at a depth of 0.20 m with air assistance (T6) and treatment control (without spraying) on soybean yield.

3.2.2 Rotating system nozzles

Recently, the use of centrifugal energy to produce spray droplets (rotating system nozzle) is an interesting alternative application technology to control Asian soybean rust, using oily formulations, low spraying volumes and, consequently, a greater operational performance of sprayers. In Brazil, new techniques for pesticide application using low volumes and rotating nozzles have been developed in the mid-west region (Cerrado) for soybean rust control in soybean culture. The rotating nozzle low volume oily (LVO) and different levels of air speed with an air-assisted sprayer on spray deposits were compared by Christovam et al. (2010c) on Asian soybean rust control and soybean productivity. Two experiments were carried out in the experimental area of FCA/UNESP, Botucatu, SP, Brazil, on a soybean crop of the Conquista variety, in the 2007/2008 season. In the first experiment, three air levels (0, 9 and 29 km h^{-1} air speed generated by a fan) with flat fan XR 8002 nozzles and a spray volume of 130 L ha^{-1} were compared with a rotating nozzle – using LVO at 40 L ha^{-1} of spray volume (Figure 7). The second experiment was carried out under the same conditions as the previous experiment, including a control treatment (untreated plants). The grades varied between 0.6 and 78.5% disease severity. In general, air assistance promoted the increase on deposit levels on the adaxial surface of the leaf located in the top part of the plants. Therefore, in the bottom part, there was not a significant difference in spray deposits between the spraying techniques. Also, the abaxial surface did not show differences in deposit levels, in the top or bottom part, between the spraying techniques. The use of air assistance, when compared with the rotating nozzle system, did not show significant differences in spray deposits on adaxial or abaxial surfaces of the leaves in the bottom part of the plant. Monteiro (2006) observed results very similar to those obtained in the current study. This author performed a study that aimed to evaluate the spraying efficiency of a rotating atomiser system - LVO using 25 L ha^{-1} of fungicide outflow on a soybean crop, when compared to a sprayer equipped with hydraulic nozzles at a spray volume of 150 L ha^{-1}. The treatments sprayed with the fungicidal mixture provided a weight of 1000 seeds and productivity significantly higher in comparison with untreated plants (control). The highest increase of productivity was obtained with the maximum air speed generated by the fan (29 km h^{-1}) near to the spray boom using 130 L ha^{-1} when compared with the control treatment. The spray volume

Fig. 7. Spraying with an air-assisted sprayer and rotating system nozzles fixed at the spray boom on soybean culture.

applied with the rotating system nozzle – LVO was 40 L ha^{-1}. Therefore, it did not provide the same increase in productivity compared with the treatment using air assistance at the maximum speed. The rotating system nozzle was 30% more economical than the treatment with a spray volume of 130 L ha^{-1}, with or without air assistance near the boom, using the Advance Vortex 2000 sprayer.

3.2.3 Hose drops

Another possibility to improve spraying coverage with boom sprayers is addressed by spraying with three flat fan nozzles involving the entire planting row, of which two of them are positioned near the bottom of the plants or positioned on opposite sides between the crop rows and near the bottom of the plant. The structures that support the spray nozzle from the spray boom at its lower end are called hose drops. In the USA, there are several reports on the use of flat fan nozzles placed in the hose drops ends, which move in the line between the culture, with volumes around 140 L ha^{-1} in Asian soybean rust treatment (Ozkan, 2005), although their culture is planted at greater spacing than those in Brazil with early cultivars. In Brazil, growers with difficulty will adopt hose drops in this application in order to obtain better spray coverage of the leaves on the bottom part of soybean plants. However, the differences in the growth habits, foliage degree and plant architecture of the varieties and the smaller spacing between planting rows makes the use of this technology difficult.

3.2.4 Electric charge (electrostatic) in spray droplets

Nowadays, air assistance can be combined with electrification (by induction) of the spraying droplets, aiming at reducing drift and exposure of appliers and the environment to phyto-sanitary products. An experiment was carried out in commercial areas of the soybean crop, Cidade Verde Farming, Primavera do Leste, MT, Brazil, on soybean plants of the Monsoy 8757 variety in the 2009/2010 agricultural season. Sowing was performed in 12/11/2009, leaving 0.45 m spacing between planting rows and 14 seeds per linear metre. The experimental design was in random blocks, with six treatments constituting three application techniques: conventional spraying, air-assisted spraying and air-assisted spraying combined with electrically charged droplets in two spray volumes, 50 and 100 L ha^{-1}, in four replications, totalling 24 experimental plots. The experimental plots were 24.0 x 100.0 m (width x length). The width of the plots corresponded to the boom size of the sprayer used in this research. During spraying, a self-propelling sprayer (Uniport 3000 model) was used equipped with a spray boom 24.0 m in length with hollow conical nozzles spaced every 0.35 m. The spray hollow conical nozzles used were of the JA-1 and JA-2 type, operated at working pressures of 690 and 828 kPa respectively. The spray displacement speed was 15 km h^{-1}, usually practiced by farmers in the Brazilian mid-western region (Cerrado). This sprayer operated with or without air assistance on the spray boom (conventional) combined with electric charge transference to the spray droplets in turn-on or turn-off mode. For air supply into the sleeve boom, two axial fans were positioned on the central point of the boom and operated at the maximum rotation speed. For the quantification of spray deposits, a tracer dye (Brilliant Blue) was used at a concentration of 0.3%, according to qualitative and quantitative evaluation studies of spray deposits validated by Palladini et al. (2005). The spraying of the tracer dye was performed in the R5.1 growth stage, 80 days after sowing. The average values of height and foliar area were respectively 0.92 m and 0.158 m^2 at this growth stage. The mean values of

spray deposits with different application technologies on soybean plants of the Monsoy 8757 variety are shown in Tables 4 and 5. Greater spray deposits were obtained with air assistance and this spray technology combined with electrically charged droplets in relation to conventional spraying at 100 L ha^{-1} on leaflets positioned at the top part of soybean plants (Table 4). At a low volume rate, there was no observed difference in deposit levels with the different spray technologies. With the higher spray volume using air assistance combined with electric charge transference to the droplets, it was possible obtain greater spray deposits when compared to low spray volume. The best spray deposits on leaflets at the bottom position of soybean plants was obtained with air assistance combined with electric charge transference technology at a volume of 100 L ha^{-1} (Table 5). With this spray volume, air assistance technology combined with electrically charged droplets was better when compared the other two spraying technologies. There was no significant difference between the spraying techniques on tracer deposits using the volume of 50 L ha^{-1} (Table 5). These results obtained with a new spray technology, employing air assistance combined with electric charge transference to droplets, is very promising in disease management in this culture, especially for Asian soybean rust management.

Spray technique	Volume (L ha^{-1})		LSD values (p< 0.05)
	100	**50**	
Air-assistance + electric charge	0.744 Aa	0.352 Ba	
Air-assistance	0.684 Aa	0.480 Aa	0.350
Conventional	0.254 Ab	0.313 Aa	
LSD values (p< 0.05)	0.427		
CV (%)	11.27		

Original means and data transformed in root square of x + 0.5 for analysis.
Means followed by the same letter, smaller in the column and bigger in the line, did not differ by Tukey's test at the 5% significance level.

Table 4. Mean values of Brilliant Blue tracer deposits (µL cm^{-2}) on leaflets at the top position of soybean plants after spraying with different techniques. Botucatu, SP, Brazil, 2009/10.

Spray technique	Volume (L ha^{-1})		LSD values (p< 0.05)
	100	**50**	
Air-assistance + electric charge	1.166 Aa	0.016 Ba	
Air-assistance	0.215 Ab	0.029 Aa	0.622
Conventional	0.033 Ab	0.115 Aa	
LSD values (p< 0.05)	0.758		
CV (%)	21.11		

Original means and data transformed in root square of x + 0.5 for analysis.
Means followed by the same letter, smaller in the column and bigger in the line, did not differ by Tukey's test at the 5% significance level.

Table 5. Mean values of Brilliant Blue tracer deposits (µL cm^{-2}) on leaflets at the bottom position of soybean plants after spraying with different techniques. Botucatu, SP, Brazil, 2009/10.

4. Considerations of ASR management

Despite new techniques and equipment available for the application of fungicides targeting Asian soybean rust management, other factors such as climate conditions, varieties, disease severity, plant architecture, fungicide characteristics, sowing in the same season and application time are important in ensuring culture productivity. Associated with chemical control, plant disease resistance and the adoption of the period of sowing interruption (inter-season) in most Brazilian states have contributed to decreasing the severity of Asian soybean rust. Disease monitoring time of application and choice of fungicide are important factors for the success of Asian soybean rust control. Beforehand sowing and choosing an early variety can also contribute to the control of this disease. Nowadays, multidisciplinary research development is necessary to achieve suitable management of Asian soybean rust. Only knowledge of pesticide application techniques is not sufficient to improve control of the *P. pachyrhizi* pathogen.

5. References

Adam, A.V. (1977). Importance of pesticide application equipment and related field practices in developing countries. In: *Pesticide management and insect resistance*, D.L. Watson & A.W. Brown, (Ed.), 217-225, Academic Press, New York

ANDEF – Associação Nacional de Defesa Vegetal. (2004) *Manual de tecnologia de aplicação de produtos fitossanitários*. Línea Creativa, Campinas, 50p

Antuniassi, U.R. (2010). Tecnologia de aplicação de defensivos: Conceitos básicos de tecnologia de aplicação de defensivos, In: *Boletim de Pesquisa de Soja 2010*, Vol.1, No.14, Fundação Mato Grosso, (Ed.), pp. 347- 372, Mato Grosso, Brazil, ISSN 1807-7676

Antuniassi, U.R. (2005). Tecnologia de aplicação para o controle da ferrugem da soja, *Proceedings of 1rst Workshop brasileiro sobre a ferrugem asiática,* pp. 193-219, UDUFU, Uberlândia, Minas Gerais, Brazil

Antuniassi, U.R.; Camargo, T.V.; Bonelli, M.A.P.O. & Romagnole, E.W.C. (2004). Avaliação da cobertura de folhas de soja em aplicações terrestres com diferentes tipos de pontas, *Proceedings of 3rd Simpósio internacional de tecnologia de aplicação de agrotóxicos*, pp. 48-51, FEPAF, Botucatu, São Paulo, Brazil

Bauer, F.C. (2002). *Distribuição e deposição da pulverização sob diferentes condições operacionais na cultura da soja [Glycine max (L.) Merrill]*. 130p. Tese (Doutorado em Agronomia / Proteção de Plantas) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil

Bauer, F.C. & Raetano, C.G. (2000). Assistência de ar na deposição e perdas de produtos fitossanitários em pulverizações na cultura da soja. *Scientia Agricola*, Vol.57, No.2, pp. 271-276, ISSN 0103-9016

Barros, A. L.M.B. & Menegatti, A.L. (2010). Tendências de médio prazo para o mercado de soja no Brasil e no mundo, In: *Boletim de Pesquisa de Soja 2010*, Vol.1, No.14, Fundação Mato Grosso, (Ed.), pp. 25-27, Mato Grosso, Brazil, ISSN 1807-7676

Boller, W. & Raetano, C.G. (2011). *Bicos e pontas de pulverização de energia hidráulica, regulagens e calibração de pulverizadores de barras*, 31p. (Documento no prelo)

Brown-Rytlewski, D. & Staton, M. (2010). *Fungicide application technology for soybean rust – 2006: Field crop advisory alert,* 2p, Michigan State University Extension, Department of Plant Pathology, Michigan, USA

Calaça, H.A. (2007). *Ferrugem Asiática da soja: relações entre atraso do controle químico, rendimento, severidade e área foliar sadia de soja (Glycine max L. Merrill)*. 80p.

Dissertação (Mestrado) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, São Paulo, Brazil

Christovam, R.S. (2008). *Assistência de ar e aplicação em volume baixo no controle da ferrugem asiática da soja. Botucatu*. 68p. Dissertação (Mestrado em agronomia/ Proteção de Plantas) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil

Christovam, R. S.; Raetano, C.G., Aguiar-Júnior, H.O., Dal Pogetto, M.H.F.A., Prado, E.P., Junior, H.O.A., Gimenes, M.J. & Kunz, V.L. (2010a). Assistência de ar em barra de pulverização no controle da ferrugem asiática da soja. *Bragantia*, Vol.69, No.1, pp. 231-238, ISSN 0006-87065

Christovam, R. S.; Raetano, C.G., Dal Pogetto, M.H.F.A., Prado, E.P., Aguiar-Junior, H.O., Gimenes, M.J. & Serra, M.E. (2010b). Effect of nozzle angle and air-jet parameters in air assisted sprayer on biological effect of soybean Asian rust chemical protection. *Journal of Plant Protection Research*, Vol.50, No.3, pp. 347-353, ISSN 1427-4345

Christovam, R. S.; Raetano, C.G., Prado, E.P., Dal Pogetto, M.H.F.A., Aguiar-Junior, H.O., Gimenes, M.J. & Serra, M.E. (2010c). Air-assistance and low volume application to control of Asian rust on soybean crop. *Journal of Plant Protection Research*, Vol.50, No.3, pp. 354-359, ISSN 1427-4345

Cooke, B.K. et al. (1990). Air-assisted spraying of arable crops in relation to deposition, drift and pesticide performance. *Crop Protection*, Vol.9, No.4, pp. 303-311, ISSN 0261-2194

Cunha, J.P.A.R.; Reis, E.F. & Santos, R.O. (2006). Controle químico da ferrugem asiática da soja em função de ponta de pulverização e de volume de calda. *Ciência Rural*, Vol.36, No.5, pp. 1360-1366, ISSN 0103-8478

Hislop, E.C.; Western, N.M. & Butler, R. (1995). Experimental air-assisted spraying of a maturing cereal crop under controlled conditions. *Crop Protection*, Vol. 14, No. 1, pp. 19-26, ISSN 0261-2194

Jorgensen, M.K. & Witt, K.L. (1997). Spraying technique in relation to approval and use of pesticides in Northern Europe, *Proceedings of 14th Danish Plant Protection Conference: Pesticides and Environment*, SP-report No.7, 1997

Jorgensen, M.K. & Witt, K.L. (2000). Spraying and the impact on the environment: Spraying technique in relation to approval and use of pesticides in Northern Europe, *Proceedings of Hardi international application technology course*, Vol.1, Chap.1, pp. 4-16, Taastrup, September, 2000

Koch, H. (1997). The evolution of application techniques in Europe, *Proceedings of 1rst Simpósio Internacional de Tecnologia de Aplicação de Produtos Fitossanitários*, pp. 30-38, Águas de Lindóia, São Paulo, Brazil, March 26-29, 1996

Kunz, V.L. (2010). *Dinâmica do ar em barra pulverizadora, com saída única e dupla, deposição da calda e controle da ferrugem asiática da soja*. 48p. Tese (Doutorado em agronomia/ Proteção de plantas) - Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil

Matthews, G.A. (1992). *Pesticide application methods* (2nd. ed.), Longman, ISBN 0-470-21818-5, London, England

Matthews, G.A. (2000). *Pesticide application methods*, (3rd. ed.), Blackwell Science, ISBN 9780632054732 , Oxford, UK

Matuo, T. (1990). *Técnicas de aplicação de defensivos agrícolas*, FUNEP, Jaboticabal, 139p.

Miller, P. (1997). Engineering research and development related to ground-based crop sprayers, *Proceedings of 1rst Simpósio Internacional de Tecnologia de Aplicação de Produtos Fitossanitários*, pp. 102-109, Águas de Lindóia, São Paulo, Brazil, March 26-29, 1996

Monteiro, M.V.M. (2006). BVO Terrestre, In: *Manual de Operação Para Aplicações Terrestres em BVO,* 9 p., Centro Brasileiro de Bioaeronautica, Sorocaba, São Paulo, Brazil

Navarini, L.; Dallagnol, L.J.; Balardin, R.S.; Moreira, M.T.; Meneghetti, R.C. & Madalosso, M.G. (2007). Controle químico da ferrugem asiática (*Phakopsora pachyrhizi* Sidow) na cultura da soja. *Summa Phytopathologica,* [online], Vol.33, No.2, pp. 182-186, ISSN 0100-5405

Nordbo, E. (1992). Effects of nozzle size, travel speed and air assistance on artificial vertical and horizontal targets in laboratory experiments. *Crop Protection*, Vol.11, N o.3, pp. 272-277, ISSN 0261-2194

Ozkan H. E. (2005). Best spraying strategies to fight against Soybean Rust. Available from: http://www.jacto.com/soybean_rust. html.

Ozkan, H.E. (2010). Spraying Recommendations for Soybean Rust. Available at Ohio State University Extension's web site "Ohionline" (http://ohionline.usu.edu).

Ozkan, H.E.; Zhu, H.; Derksen, R.C.; Guler, H. & Krause, C. (2006). Evaluation of various spraying equipment for effective application of fungicides to control Asian soybean rust. *Aspects of Applied Biology*, Vol.77, pp. 1-8

Palladini, L.A.; Raetano, C.G. & Velini, E.D. (2005). Choice of tracers for the evaluation of spray deposits. *Scientia Agricola*, Vol.62, No.5, pp. 440-445, ISSN 0103-9016

Prado, E.P. 2009. *Assistência de ar em pulverização no manejo fitossanitário na cultura da soja [Glycine max (L.) Merrill.].* 94p. Dissertação (Mestrado em agronomia/ Proteção de Plantas) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista. Botucatu, São Paulo, Brazil

Prado, E. P.; Raetano, C.G.; Aguiar-Junior, H.O.; Dal Pogetto, M.H.F.A.; Christovam, R.S.; Gimenes, M.J. & Araújo, D. (2010). Velocidade do ar em barra de pulverização na deposição da calda fungicida, severidade da ferrugem asiática e produtividade da soja. *Summa Phytopathologica*, Vol.36, No.1, pp. 45-50, ISSN 0100-5405

Prado, E.P. (2011). Different fungicides application technologies to control of Asian rust in the soybean culture, 120p. (Not published)

Raetano, C.G. (2002). Assistência de ar em pulverizadores de barra. *O Biológico*, Vol.64, No.2, pp. 221-225, ISSN 0366-0567

Raetano, C.G. & Bauer, F.C. (2003). Efeito da velocidade do ar em barra de pulverização na deposição de produtos fitossanitários em feijoeiro. *Bragantia,* Vol.62, No.2, pp. 329-334, ISSN 0006-8705

Raetano, C.G. & Bauer, F.C. (2004). Deposição e perdas da calda em feijoeiro em aplicação com assistência de ar na barra pulverizadora. *Bragantia*, Vol.63, No.2, pp.309-315, ISSN 0006-8705

Raetano C.G. & Merlin A. (2006). Avanços tecnológicos no controle da ferrugem da soja, In: *Ferrugem Asiática da Soja*, L. Zambolim, (Ed.), 115–138, UFV, ISBN 85-60027-14-9, Viçosa, Minas Gerais, Brazil

Robinson, T.H. (1993). Large-scale ground-based application techniques, In: *Application technology for crop protection*, G.A. Matthews & E.C. Hislop, (Eds.), 163-186, CAB International, ISBN 0-85198-834-2, Wallingford, Oxon, UK

Sartori, S. (1997). Equipamentos tratorizados para culturas de baixo fuste: situação no Cone–Sul, *Proceedings of 1rst Simpósio Internacional de Tecnologia de Aplicação de Produtos Fitossanitários*, pp. 110-112, Águas de Lindóia, São Paulo, Brazil, March 26-29, 1996

SCudeler, F. & Raetano, C.G. (2004). Assistência de ar e angulação da barra pulverizadora na deposição e perdas da pulverização na cultura da batata. Depto. de Produção Vegetal, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil, 35p. (Relatório Científico)

Silva, M. A. S. (2001). *Depósitos da calda de pulverização no solo e em plantas de tiririca (Cyperus rotundus L.) em diferentes condições de aplicação*. 53p. Tese (Doutorado em Agronomia / Agricultura) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, São Paulo, Brazil

Soares, R.M.; Rubin, S.A.L.; Wielewicki, A.P. & Ozelame, J.G. (2004). Fungicidas no controle da ferrugem asiática (*Phakopsora pachyrhizi*) e produtividade da soja. *Ciência Rural*, Vol.34, No.4, pp.1245-1247, ISSN 0103-8478

Taylor, W.A. & Andersen, P.G. (1991). Enhancing conventional hydraulic nozzle use with the Twin Spray System. *British Crop Protection Council Monograph*, No.46, pp. 125-136, UK

Taylor, W.A. & Andersen, P.G. (1997). A review of benefits of air assisted spraying trials in arable crops. *Aspects of Applied Biology*, Vol.48, (January 1997), pp. 163-174, ISSN 0265-1491, Wellesbourne, Warwick, UK

Taylor, W.A.; Andersen, P.G. & Cooper, S. (1989). The use of air assistance in a field crop sprayer to reduce drift and modify drop trajectories, *Proceedings of 3rd Brighton Crop Protection Conference Weeds*, p.631, ISBN 0948404361, British Crop Protection Council, Brighton, Farnham, UK, November 20-23, 1989

Tomazela, M.S.; Martins, D.; Marchi, S.R. & Negrisoli, E. (2006). Avaliação da deposição da calda de pulverização em função da densidade populacional de *Brachiaria plantaginea*, do volume e do ângulo de aplicação. *Planta Daninha*, Vol.24, No.1, pp.183-189, ISSN 1806-9681

Van De Zande; J.C.; Meier, R. & Van Ijzendoorn, M.T. (1994). Air-assisted spraying in winter wheat-results of deposition measurements and the biological effect of fungicides against leaf and ear diseases. *Proceedings of British Crop Protection Conference - pests and diseases*, pp.313-318, BCPC, Brighton, UK, 1994

Zhu, H.; Brazee, R.D.; Fox, R.D.; Derksen, R.C. & Ozkan, H.E. (2008a). Development of a canopy opener to improve spray deposition and coverage inside soybean canopies: Part 1. Mathematical models to assist opener development. *Transactions of the ASABE*, Vol.51, No.6, pp.1905-1912, ISSN 2151-0032

Zhu, H.; Derksen, R.C.; Ozkan, H.E.; Reding, M.E. & Krause, C.R. (2008b). Development of a canopy opener to improve spray deposition and coverage inside soybean canopies: Part 2. Opener design with field experiments. *Transactions of the ASABE*, Vol.51, No.6, pp.1913-1921, ISSN 2151-0032

Yorinori, J.T.; Júnior, J.N. & Lazzarotto, J.J. (2004). Ferrugem asiática da soja no Brasil: Evolução, importância econômica e controle, 36p, EMBRAPA Soja, Londrina, Paraná, Brazil (Documentos, 247)

Yorinori J.T. (2005). A ferrugem asiática da soja no continente americano: evolução, importância econômica e estratégias de controle. *Proceedings of Workshop Brasileiro sobre a Ferrugem Asiática*, pp.21-37, EDUFU, Uberlândia, Minas Gerais, Brazil, 2005

Yorinori, J.T.; Yuyama, M.M. & Siqueri, F.V. (2010). Doenças da soja, In: *Boletim de Pesquisa de Soja 2010*, Vol.1, No.14, Fundação Mato Grosso, (Ed.), pp. 218-274, Mato Grosso, Brazil, ISSN 1807-7676

Yorinori, J.T. (2010). Controle da ferrugem "Asiática" da soja na safra 2006/2007, 3p, EMBRAPA soja, Londrina, Paraná, Brazil
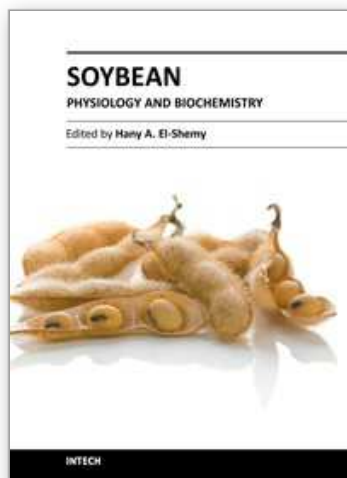
Soybean Physiology and Biochemistry

Edited by Prof. Hany El-Shemy

Worldwide, soybean seed proteins represent a major source of amino acids for human and animal nutrition. Soybean seeds are an important and economical source of protein in the diet of many developed and developing countries. Soy is a complete protein and soyfoods are rich in vitamins and minerals.Soybean protein provides all the essential amino acids in the amounts needed for human health. Recent research suggests that soy may also lower risk of prostate, colon and breast cancers as well as osteoporosis and other bone health problems and alleviate hot flashes associated with menopause. This volume is expected to be useful for student, researchers and public who are interested in soybean.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Carlos Gilberto Raetano, Denise Tourino Rezende and Evandro Pereira Prado (2011). Application Technologies for Asian Soybean Rust Management, Soybean Physiology and Biochemistry, Prof. Hany El-Shemy (Ed.), ISBN: 978-953-307-534-1, InTech, Available from: http://www.intechopen.com/books/soybean-physiology-and-biochemistry/application-technologies-for-asian-soybean-rust-management

INTECH
open science | open minds