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CONSTRUCTION AND PRACTICAL APPLICATION OF A CANOPY OPENER DEVICE

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ABSTRACT: Accurate application of pesticides is difficult for crops with dense leaves, such as soybean crops. To improve spray deposits on the lower leaves of soybean plants, the aim of this study is to build a canopy opener (CO) from a previously developed prototype and to assess its practical application and efficiency on soybean crops. Laboratory experiments were conducted to determine the amount of spray deposits on the top and the lower leaves using a Brilliant Blue dye. The influence of the CO device on the number of flowers knocked down during spraying was also investigated. The data showed that the use of the CO attached to the spray boom enabled more spray deposits on the lower leaves and less spray deposits on the upper leaves compared with conventional spraying. The CO device did not influence the falling of flowers or the damage to the soybean plants. The construction of the CO device proved to be a feasible alternative, which could be used primarily by small-scale soybean producers, with the goal of obtaining larger spray deposits on the lower leaves of soybean plants.

KEYWORDS: Application technology; soybean, spray deposit.

INTRODUCTION

In most cases, crop protection against pathogens is efficient only when the desired dose of the pesticide is applied in a timely manner, with equipment that is calibrated and operating correctly, directly to the affected area of the plants. Among the pesticides that are used to protect crops of economic interest, fungicides and insecticides have greater difficulty reaching their targets than herbicides because insects and fungi are often present in regions of the plant where the spray droplets cannot readily penetrate the barriers created by the top leaves. The penetration of droplets through the leaf canopy is more difficult as the leaf area indices increase (OZKAN et al., 2006; HANNA et al., 2009).

Certain diseases, such as Asian soybean rust (ASR), which is caused by *Phakopsora pachyrhizi*, and white mold (WM), which is caused by *Sclerotinia sclerotiorum*, are difficult to control because of their location in the plant (in the lower region), which hampers adequate fungicide deposition and coverage (ZHU et al., 2008b).

Insects, such as defoliating caterpillars, have a habit of feeding on the lower plant parts, which makes them less vulnerable to attack by pesticides. PRADO et al. (2010c) observed that *Anticarsia gemmatalis* larvae of the first instar sat soybean V10 growth stage (FEHR et al., 1971) preferentially fed on the lower leaves of the soybean canopy and that sprayers with air assistance (AA) on the spray boom obtained better insect control by delivering a larger amount of active ingredient to the lower regions.

For more successful phytosanitary control of diseases such as ASR and WM, adequate spray coverage of the leaves of the entire soybean plant is necessary. The lower leaves in particular must be sprayed because they provide a favorable environment for the development of disease.

The use of AA in the spray boom can increase the efficiency of controlling diseases and insects in crops with high leaf densities because it increases the penetration of the mixture into the

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crop canopy (OZKAN et al., 2006; DERKSEN et al., 2006; CHRISTOVAM, et al., 2010a; CHRISTOVAM, et al., 2010b; CHRISTOVAM, et al., 2010c; PRADO et al., 2010a; PRADO et al., 2010b). Although this technique has shown satisfactory results for pesticide deposition in the lower regions of crops with greater leaf densities, it is a relatively expensive technology and is thus restricted to large producers only.

According to ZHU et al. (2008b), the use of (non-air assisted) conventional sprayers coupled with a device whose purpose is to open the crop canopy (CO) in the spraying direction can be an economic and effective alternative for small- and medium-sized producers.

If attaching a CO on the spray boom can produce spray deposition results that are similar to those obtained with the use of AA in the spray boom (ZHU et al. 2008b) and if the CO technology is more economical than the AA technology, the use of a CO will likely improve the control of fungi and pests with major economic advantages. Therefore, the purpose of this study was to build and optimize a crop CO device based on previously published works, assess its practical application and efficiency with respect to spray deposits on the lower leaves, and assess the potential damage to soybean plants.

MATERIAL AND METHODS

Construction of the CO

To construct the device to open the crop canopy, referred to as the CO, the papers published by ZHU et al. (2008a, b) were used as references. In those tests, the horizontal (length) and vertical (depth) distances between the device (iron pipe) and the spraying nozzles on the spray boom were estimated to provide a better deposition of the droplets in the middle and lower leaves of the soybean plants.

The device was built with an iron frame, which comprised two horizontal bars with square cross-sections, two vertical holders with bearing housings at one end, an iron pipe, and two brackets. The two vertical holders were used to attach, through the bearing housing, the two ends of the iron pipe. The two horizontal bars were used to hold the vertical holders in place and attach the spray boom. The brackets connected the horizontal bars with the vertical holders, which provided mobility (length and depth) to the vertical holders (Figure1).

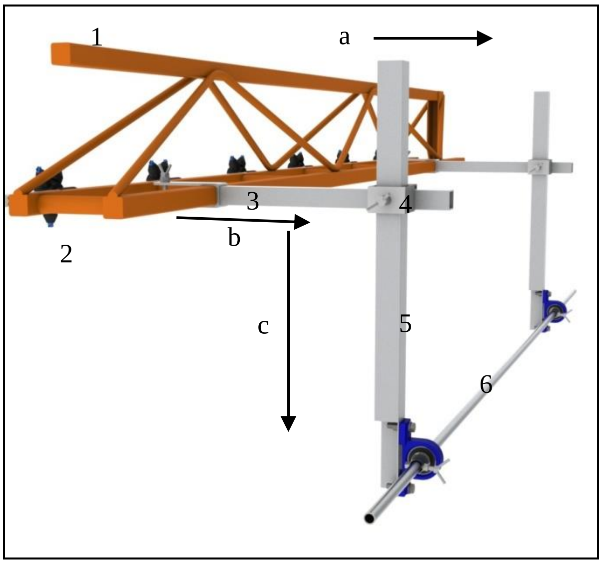

FIGURE 1. Schematic representation of the CO, which shows the displacement direction (a), length (b), and depth (c) between the iron pipe and the spray nozzles: 1- spray boom; 2- spray nozzle; 3- horizontal bar attached to the spray boom; 4-bracket; 5- vertical holder attached to the bearing housings; and 6-iron pipe.

The horizontal bars were built with two equal-sided iron angle bars joined together by a weld bead. They were welded at one end to an iron plate folded in a U shape. On both parts of the distal region of this holder, symmetric holes were drilled, and a hexagonal nut was welded over one of the holes on the outside of the horizontal holder. To affix the horizontal bar to the spray boom, it was attached to the U-shaped holder by passing a bolt through both holes and screwing the bolt to the hexagonal nut (Figure 2a).

To hold the iron pipe in place, two vertical holders were built by attaching two equal-sided angle bars with a weld bead. A bearing housing (Powell P206) was attached at the end of each holder to support, provide mobility to, and allow rotation of the iron pipe (Figure 2b). The bearing housings were joined to the vertical holders by the pressure exerted by the nuts and the washers screwed onto the two bolts. A steel tube with a hole at the end was welded to the inside of each bearing, and a hexagonal nut was welded over the hole (externally) to screw in the bolt. The iron pipe was attached to the bearing housing by the pressure exerted by the tip of the bolt on the rod (Figure 2c).

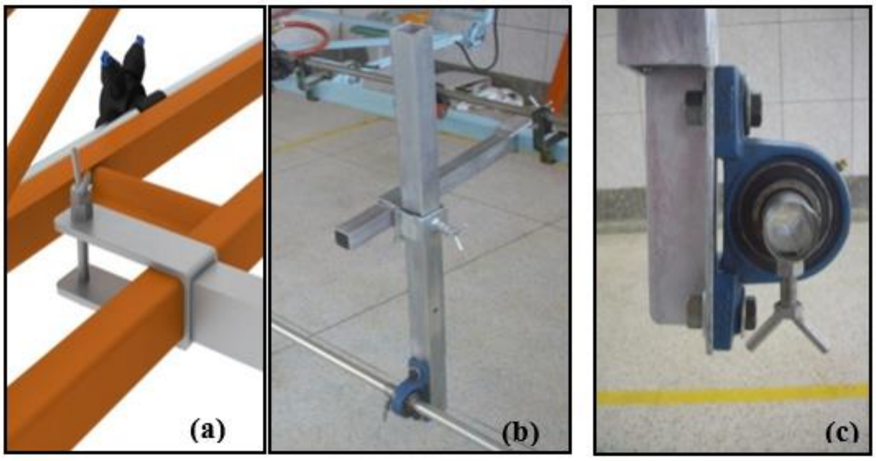

FIGURE 2. Detailed view of the horizontal bar attached to the spray boom (a), vertical holder with the iron pipe (b), and the bearing housing with a steel pipe welded to the inside of the bearing and hexagonal nut welded to the outside of the steel pipe with bolt (c).

The bearing housings, apart from allowing free rotation of the pipe when in contact with the soybean plants, which enables easy movement of the device attached to the spray boom, also allows movement of the pipe inside the bearings in relation to the spray boom. Thus, the iron pipe is not necessarily fixed by its ends because the horizontal bars are not attached at any points on the spray boom, which thereby facilitates the assembly and operation of the set (spray boom plus CO).

Although the pipe can freely rotate around its axis, the necessary force required by the tube to rotate was not exerted by the soybean plants. The iron pipe, which is a simple hollow tube 3.0 m long, bends the soybean plants in the spraying direction.

Finally, the two brackets were built by welding two U-beams together (attached to the vertical holders). These were joined by combining two equal-sided dangle bars (attached to the horizontal bars) (Figures 3a and 3b). The brackets connected the vertical holders to the horizontal bars and provided mobility to the holders. The vertical distance between the spraying nozzles and the pipe was defined as the CO depth, and the horizontal distance between the spraying nozzles and the pipe was defined as the CO length.

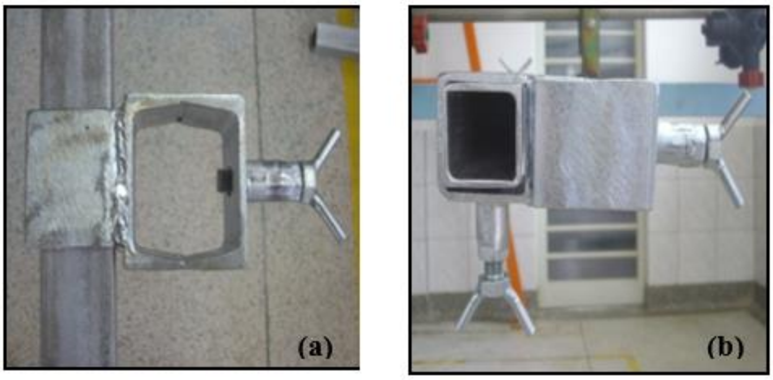

FIGURE 3. Detailed view of the brackets built by joining two U-beams with a nut and bolt (a and b) and the bracket connecting the vertical holder to the horizontal bar.

The CO was made of iron and 1020 carbon steel to provide strength to the assembly and to avoid any bending during operation caused by the resistance from plants that could displace the device. With the exception of the iron pipe (3.0 m), all parts of the device could be easily transported.

All the parts of the assembly were galvanized by immersion to preserve the material because the device will likely be used in field operations. The wings were welded to the heads of all the bolts of the device to facilitate the equipment assembly operations and to reduce the need to transport tools. However, this practice was not feasible to the bolts of the brackets because it was necessary to tighten them with tools to ensure they were tightly fastened during operation.

The device provides a minimum working length of 0.25 m and a maximum length of 0.975 m for both segments, CO length (horizontal distance from the iron pipe to the spraying nozzles) and CO depth (vertical distance from the iron pipe to the spraying nozzles). These lengths were measured from the base where the device was attached to the spray boom of the tractor-mounted sprayer (brand Jacto®, model Advance Vortex 2000), which can vary with the brand and the model of the sprayer.

Growth of the soybean plants in planters

The soybean seeds were sown in rectangular planters, fabricated from asbestos, with dimensions of 1.0 x 0.20 x 0.20 m^3 to represent the sowing conditions in the field, including the spacing between the sown rows. For planting, 3.0 m^3 of substrate was prepared with equal proportions of dark red latosol, cattle manure, and coarse washed sand. The substrate was boosted with 0.95 g of thermo-phosphate BZ, 0.85 g of single superphosphate, and 0.195 g of potassium chloride per liter of substrate, mixed for perfect homogenization, and then distributed in the planters.

The soybean seeds, cultivar FTS Campo Mourão RR (semi-determinate growth habit), were inoculated with *Bradirhizobium japonicum* (Nitragin Optmize©, BASF S/A) using 150 mL of the commercial product, 50 kg^{-1} of seeds, treated with a carboxin fungicide mixture combined with thiram (Vitavax Thiram 200 SC, Chemtura Indústria Química do Brasil Ltda.) at a dosage of 50 g + 50 g of active ingredient, i.e., 100 kg^{-1} of seeds, sown at a depth of 0.02 m. The planters were kept in a natural environment with daily irrigation. The excess plants were eliminated 14 days after emergence, maintaining a population of 12 plants per meter. After 20 days, top-dressing fertilizing was performed using 100 g of the formula 08-28-16 (N-P-K) per planter. This practice was adopted because of the visual observation of nutritional deficiency of the plants, which was most likely from nutrient leaching caused by daily irrigation. This cultivar was selected because of its adequate development for cultivation in the region of Botucatu, São Paulo (SP), its large size, high leaf area index, and large leaves, which makes it prone to the development of diseases such as ASR and WM.

Effect of the CO on the falling of flowers and damage to the soybean plants

Based on the hypothesis that the metal pipe could knock down soybean flowers when spraying with the CO during the reproductive stages (RS) R2 (flowering) and R3 (pod formation) (FEHR et al., 1971), additional tests were performed in the laboratory with spray boom speeds of 1.4 m s^{-1} and 2.5 m s^{-1} on planters containing 12 soybean plants each. Two runs were performed (forward and backward) of the spray boom with the *CO* attached at two heights (metal pipe), 0.1 m and 0.2 m. The experiment was performedin a randomized block design with four treatments and five replicates (each replicate was represented by one planter).

Practical application of the CO on soybean plants

The experiment testing the practical use of the CO was conducted in a randomized block design with three treatments and seven replicates. Three scenarios were compared based on the spray configuration, i.e., conventional spraying, spraying with the CO at a 0.10-m depth, and spraying with the CO at a 0.20-m depth. There were a total of 21 planters.

The depths of 0.10 m and 0.20 m refer to the distance between the iron pipe of the device and the top of the soybean plants. The length of 0.25 m refers to the distance between the spraying nozzles and the pipe, as shown in Figure 4a. The purpose of this device is to bend the soybean plants in the direction of the spray, which opens a space in the crop canopy, thus facilitating penetration of the spray droplets to the middle and lower leaves of the soybean plants (Figure 4b).

At the RS R3, the planters were taken to the laboratory, and three planters were placed side by side, in such a way that the distance between the sowing rows was 0.45 m and the density was 24 plants m^{-2}. With this arrangement, the edges of each plant came into contact with the plants in the adjacent planters, which provided a better approximation to field conditions. At the RS R3, the plants were of medium height, i.e., 0.60 m relative to the soil of the planter.

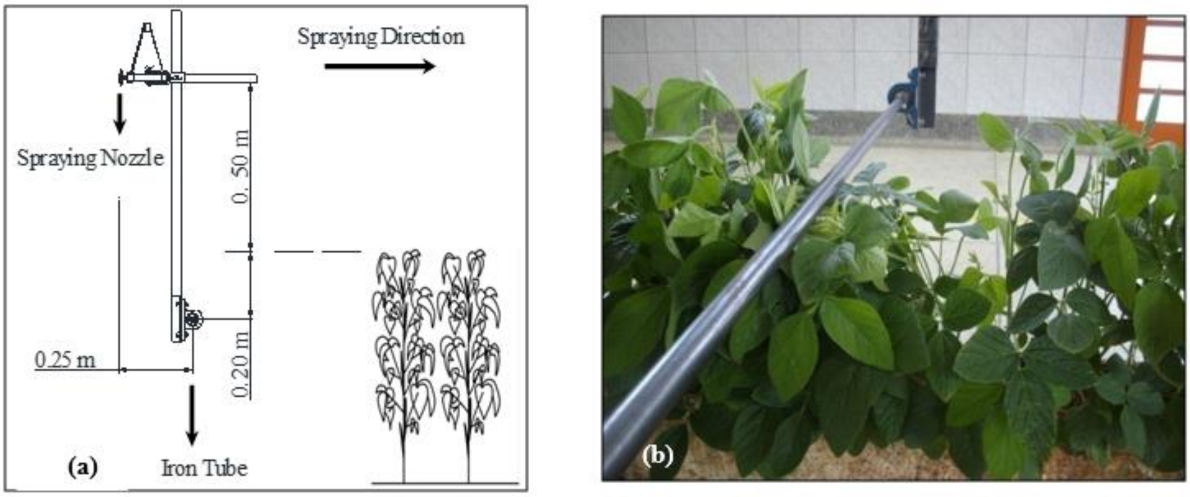

FIGURE 4. Depth and length between the iron pipe relative to the spraying nozzles (a) and CO bending soybean plants (b).

The soybean plants were sprayed using an indoor boom track sprayer such that the spraying was completely adjustable to control all the parameters of the selected configuration and calibration of the equipment. Flat fan spraying tips XR 11002 (Spraying Systems of Brazil Ltda.©), spaced 0.50 m apart, with a working pressure of 250 kPa, provided fine droplets according to the manufacturer’s specifications (SPRAYING SYSTEM, 2011). The flow rates of all the nozzles were verified prior to spraying. The equipment moved along the plant rows at a speed of 1.7 m s^{-1} and applied an approximate spray volume of 144 L ha^{-1}. These conditions simulated the small grower’s conditions in Brazil. The operational conditions were the same for the three scenarios tested in the experiment. The spray boom was maintained at a height of 0.50 m relative to the top of the soybean plants. The movement of the spray boom began at a distance of 2.0 m from the first planters to standardize the spraying speed, which was kept constant for all treatments.

The ambient temperature changed from 23°C to 25°C and the relative humidity changed from 48% to 52% (Thermohygrometer Lutron, model HT-3003, Accuracy ± 2%) from the beginning to the end of the test.

Quantification of the spray deposit

Brilliant Blue (FD&C Blue n.1) was used as the dye at a concentration of 1.5 g L^{-1}. According to CERQUEIRA et al. (2012), this marker exhibits an extraction coefficient in natural targets of 93% when measured in leaves of *Phaseolus vulgaris* and *Brachiaria plantaginea*. After the spraying and drying, the central planter was isolated by carefully removing the planters at the two ends. The spray deposition was assessed in the upper portion (top leaves) and in the lower portion (last leaves of the lower part of the plant) to determine the penetration capacity of the spray mixture into the canopy of the plants. Five leaves of the top portion (three leaflets) and five of the lower portion of eight plants of each central planter were collected by cutting the petiole using scissors. The only function of the planters at the ends was to simulate the density of the plants under natural conditions.

The leaves that were removed from the plants were placed individually in plastic bags, washed with 20 mL of distilled water, and stirred for approximately 15 seconds. The solution resulting from the washing step was placed in plastic pots and quantified in a spectrophotometer (Shimadzu UV 1601 PC) at a wavelength of 630 nm (SCUDELER et al., 2004). After tracer extraction, each leaf area measurement was performed using a leaf area meter benchmark (LI-COR 3100, Lincoln, US). With the previously known dye concentrations of 10.0, 5.0, 2.5, 1.25, 0.625, and 0.156 mg L^{-1}, a straight line (R^2= 0.9997) was determined as follows [eq. (1)]:

$$y = 0.2145x + 0.0125 \quad (1)$$

where,

y = the dye concentration (mg L^{-1}), and

x = absorbance detected by the spectrophotometer

With the dye concentration in the mixture, the dye concentration in the leaf, and the dilution volume of the sample, the volume captured by the leaf was calculated using [eq.(2)] as follows:

$$Vi = (Cf \times Vf)/Ci \qquad (2)$$

where,

Ci = the dye concentration in the spray mixture (1500 mg L^{-1});

Vi = the volume captured by the target (mL);

Cf = the dye concentration (mg L^{-1}), and

Vf = the dilution volume of the sample (20 mL).

For a better presentation of the data, the volume retained in each leaf in mL was translated into µL and divided by its respective leaf area, thus obtaining the results in µL cm^{-2}.

Statistical analysis

The spray deposits (µL cm^{-2}) were subjected to an analysis of variance by the F-test, and the means of the treatments, when significant, were compared by Tukey’s test (p = 0.05) through the SISVAR program (FERREIRA, 2011).

RESULTS AND DISCUSSION

Effect of the CO on the falling of flowers and damage to the soybean plants

Falling flowers or any other type of damage to the soybean plants were not observed when the CO device attached to the spray boom passed over the soybean plants at heights of 0.1 m and 0.2 m with displacement speeds of 1.4 m s^{-1} and 2.5 m s^{-1} for the studied cultivar and under the conditions tested. The fact that the device did not knock down the flowers is important because falling flowers decreases the number of pods in the soybean plants and consequently reduces yield.

Feasibility of the CO on spray deposition in soybean leaves

The spray deposits in the upper ($p \leq 0.05$) and lower ($p \leq 0.01$) sections of the plants showed significant differences between the different scenarios (Table 1).

TABLE 1. Results of the analysis of variance of the spray deposits in the leaves of the upper and lower portions of the soybean plants under controlled environmental conditions.

Plant section	LSD[a]	CV[b]	F
Upper	0.2056	40.2	15.62**
Lower	0.0456	54.8	4.18*

*Significant (p≤ 0.05); **Significant (p≤0.01)

[a]LSD = least significant difference.

[b]CV = coefficient of variation.

In the upper section of the plants, larger mean values of deposits were observed for the conventional treatment, which differed significantly from the other treatments. The conventional treatment had nearly three times more deposits in the upper leaves of the plants when compared with the treatment when the CO was used (Figure 5a).

In the lower sections of the plants, greater levels of the spray deposits were obtained in the treatments with the CO. In particular, the treatment with the CO operating at a depth of 0.2 m relative to the top of the plants differed from the conventional treatment but did not differ significantly from the treatment with the CO at 0.1-m depth. The treatment with the CO at a 0.2-m depth resulted in mean spray deposits that were 2.8 times greater compared with that of the conventional spraying system in the lower section of the plants.

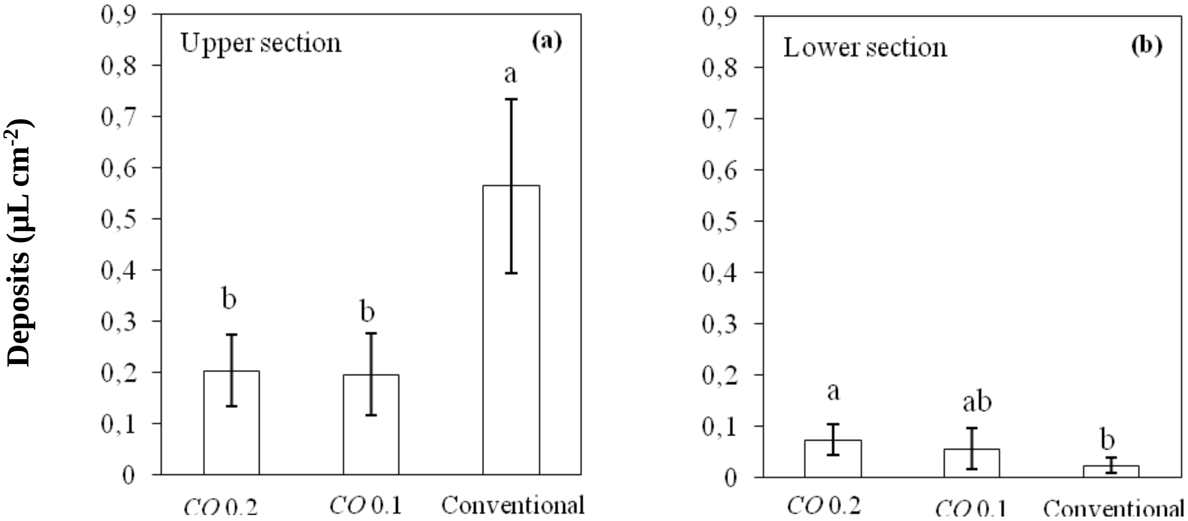

FIGURE 5. Mean spray deposits of the Brilliant Blue dye in two different sections of the soybean plants (upper and lower) (standard deviation of the mean is represented by the vertical lines). CO 0.2: CO at a 0.20-m depth and CO 0.1: CO at a 0.1-m depth from the top leaves.

Deposits with the same letter do not differ according to Tukey's test (p≤0.05).

Similar results to those obtained in this experiment were reported by OZKAN et al. (2006). The authors studied different spraying equipment with the goal of controlling ASR and observed higher spray coverage percentages in the middle and lower leaves of the soybean plants when spraying was performed with the help of the CO device attached to the spray boom.

In accordance with this work, ZHU et al. (2008 b) showed significantly higher spray deposition and coverage in the middle and lower sections of the soybean canopies than the conventional boom sprayer treatments without the opener. The same authors concluded that the optimal opener depth range would be from 0.075 m to 0.15 m and the optimal width would be 0.25 m for the 1.06 m soybean plants. These results agree with the present study where the results at a depth of 0.2 m did not differ significantly from the results at a depth of 0.1 m for the plant with 0.7 m at vegetative stage V10.

The ratio between the mean values of the spray deposits retained in the upper and lower sections of the crop canopy were 2.7, 3.4 and 21.5 for the CO treatments at depths of 0.2 m and 0.1 m and the conventional treatment, respectively. CUNHA et al. (2011) studied the distribution of the spray mixture in ground applications using different spraying nozzles and obtained a mean deposition in the upper section of the soybean plants (RS R4) 3.9 times higher than that obtained for the lower section. PRADO et al. (2015) reported spray application deposits at the top of soybean plants approximately six times higher than those at the bottom at RS R2. The high ratio between the values of spray deposits that was obtained with conventional spraying can be related to the absence of wind during spraying, which hinders the movement of the droplets along the crop canopy and the plane of the spatial exposure of the leaves relative to the spraying jet (data not shown).

When comparing the mean values of spray deposits in the leaves of the upper and lower sections of the soybean plants, the data showed that most of the deposits were retained in the upper leaves of the plants when spraying was performed in the conventional manner, and a small amount of deposit was retained in the lower leaves. This small amount of spray deposit in the lower leaves is from the large leaf mass index of the soybean plants, which provided a barrier to prevent the droplets from penetrating the lower section of the plants.

The CO device increased the spray deposits in the lower leaves of the plants by breaking this barrier via plant deflection, which is imposed by the upper leaves, which allows the droplets to reach the leaves of the middle and lower sections.

The construction of the CO device may be a feasible alternative that could primarily be used by small-scale soybean producers to obtain larger spray deposits in the leaves of the lower sections of the soybean plants. The advantage of using the CO is its simple construction, i.e., it can be built by the producers themselves, does not require special tools, and has a low production cost. Special care must be taken with the oscillation of the boom suspension, i.e., it must be less than the opener depth to avoid losing constant contact with the plants that are deflected by the opener (ZHU et al., 2008b).

Another important point is the excessive depth that the CO can reach in the crop canopy, especially when the spraying is done on irregular ground. The excessive depth may be critical to the crop because the pipe may damage the plants. A restrictor height or a height correction sensor in areas where the ground surface is irregular can be adapted for the spray boom to avoid the contact to the CO (iron pipe) to a pre-determined excessive depth.

ZHU et al. (2008 b) reported that the CO could have some potential problems associated with the use of openers on conventional sprayers with long booms. The opener weight and plant resistance may cause excessive stress to long booms and the depth of the opener inside canopies may fluctuate more from a long boom bounce than from a shorter boom. Oscillations of the spray boom are frequent, primarily in sprayers with large-sized booms that do not have height correction sensors and in areas where the ground surface is irregular. Although the CO is a technology shown to have potential for reducing losses caused by ASR, tests must still be performed because the experiments conducted in this work were restricted to a single segment of the spray boom. The use of the CO device along the entire length of the spray boom can damage the soybean crop; however, damage was not observed in this test.

Studies related to the depth of the iron pipe inside the crop canopy, which could provide greater values of spray deposits in the leaves of the middle and lower sections of the plants, should still be conducted because there is a wide range of plant sizes and leaf densities among soybean cultivars. A relation between plant height and depth of the device to promote more deposition on the middle and lower parts of the canopy should be found for a large range of cultivars with different sizes. Experiments evaluating the efficiency of fungicides and insecticides using the CO attached on the spray boom should be done to measure the operating efficiency of this device. Future research should be done to improve this technology to be more practical and more viable to farmers.

CONCLUSIONS

The CO device is a simple piece of equipment that can be built by the producers. In laboratory conditions, the CO, working at a length of 0.25 m and a depth of 0.1 m and 0.2 m, improves spray deposition on the lower leaves of soybean plants compared with conventional spray. The data showed no damage in the flowers or any other structure of the soybean plants.

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