



## Article

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## STICKY NIGHTSHADE INFESTATION AND DISPERSION ON AN INTEGRATED SOYBEAN-EUCALYPTUS SYSTEM AT SUBTROPICAL BRAZIL

*Infestação e Dispersão de Joá em Sistema Integrado de Produção de Eucalipto e Soja no Subtropical Brasileiro*

**ABSTRACT** - Trees in integrated crop-livestock systems can reduce infestation and dispersion of weeds because of a negative interference promoted by competition for light, water and nutrients. The objective of this study was to evaluate the infestation and dispersion of sticky nightshade (*Solanum sisymbriifolium*) in soybean in different positions between eucalyptus (*Eucalyptus dunnii*) double rows [20 m x (4 m x 3 m)] in an integrated crop-livestock system at Subtropical Brazil. The experiment was conducted in a randomized block design, with nine replications, and five equidistant positions between double rows (n=45) as treatments. Sticky nightshade was evaluated for infestation through biomass, plant density (reproductive and vegetative plants), and for dispersion by the flower, fruit, seeds per fruit, and 100 seed weight. Soybean was analyzed for grain yield. Eucalyptus promoted a negative interference in sticky nightshade infestation and dispersion as well as in soybean yield, to a greater extent closer to the tree component.

**Keywords:** integrated crop-livestock systems, weed, alley cropping, ecophysiology, agroforestry.

**RESUMO** - Em sistemas agroflorestais, a interferência negativa do componente arbóreo sobre a disponibilidade de luz, água e nutrientes pode reduzir a infestação e dispersão de plantas daninhas. O objetivo do estudo foi avaliar a infestação e dispersão do joá (*Solanum sisymbriifolium*) em diferentes posições entre renques de linhas duplas [20 m x (4 m x 3 m)] de eucaliptos (*Eucalyptus dunnii*) em sistema agroflorestal no subtropical brasileiro. O experimento foi delineado em blocos ao acaso, com nove repetições, possuindo como tratamentos cinco posições equidistantes entre renques de árvores (n=45). A infestação do joá foi avaliada pela biomassa e densidade de plantas (plantas reprodutivas e vegetativas). Para a avaliação da dispersão do joá, foram analisados a produção de flores, frutos e sementes, como também os componentes de rendimento (número de sementes por fruto e peso de 100 sementes). A soja foi analisada quanto ao rendimento de grãos. O eucalipto influenciou negativamente a infestação e dispersão do joá, bem como o rendimento da soja, aumentando essa interferência quanto mais próximo do componente arbóreo.

**Palavras-chave:** sistemas integrados de produção agropecuária, planta daninha, cultivo em aléias, ecofisiologia, agrofloresta.

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## INTRODUCTION

Stick Nightshade (*Solanum sisymbriifolium*) is an infesting plant with many undesirable features, such as the presence of thorns, which may hurt people and animals. Furthermore, its fruits and seeds have a toxic glucoside that can provoke hemolysis on red blood cells (Kissmann and Groth, 2000). Both features make this plant more harmful in integrated crop-livestock systems (ICLS).

This species is original from South America (Timmermans et al., 2007a) and it is present in fields, open forests with *Araucaria angustifolia*, in secondary forests, *capoeiras* (*Hevea brasiliensis*), road margins, dunes, sandbanks, dirty fields, crops, and rice fields (Mentz and Oliveira, 2004). Many *Solanum* species, including sticky nightshade, can negatively interfere in crops yield and harvest, reducing the quality and quantity of fiber and food (Bryson et al., 2012). On the other hand, SNS has been studied as a biological control to potato crop nematodes (Timmermans and Stomph, 2009).

Weed dispersion occurs as the diaspore is removed or released from plants. The diaspore is or contains the dispersion units. For the sticky nightshade, the dispersion units are the seeds released after the diaspore (fruits) falls and decompose on the soil surface (Kissmann and Groth, 2000).

Stick Nightshade can be classified by its primary dispersion type as barochory, although, once on the ground, the fruits containing the seeds or only the seeds can be transported actively by the water; therefore, its secondary dispersion is denominated as *hydrocoria*. The barochory dispersion syndrome is the one where the diaspore separation from the mother plant takes place through the action of its weight (Almeida-Cortez, 2004).

The tree components in an ICLS can change the weed and crop interactions. The interaction among species in these systems includes aspects of water and nutrient cycles, microclimate, and biodiversity (Quinkenstein et al., 2009). In this context, integrated weed management in an ICLS must consider the interaction between species in the herbaceous community and tree interaction with them. The net yield between the antagonistic and synergistic interactions among the system components results in the system's productivity (Jose et al., 2004).

Our hypothesis was that eucalyptus in an ICLS could reduce the infestation and dispersion of SNS because of a negative interference promoted by competition for light, water and nutrients. The objective was to study SNS infestation and dispersion on the herbaceous area of an ICLS intercropped with soybean in the subtropical Brazil, in different positions between 4.5-year old eucalyptus double rows.

## MATERIAL AND METHODS

Sticky nightshade and soybean samples were collected in a long-term experiment established since 2006 in Ponta Grossa, Parana, Brazil, located in 25°06'19" S latitude and 50°02'38" O longitude. According to Köppen, the climatic classification is Cfb, Subtropical Humid Meso-thermal, found in the highest portions of the Second Plateau of Parana. The annual average precipitation ranges from 1600 to 1,800 mm, with 500 to 600 mm in the rainiest quarter (December, January, and February) and 250 to 350 mm in the driest quarter (June, July, and August). The average annual temperature ranges between 17 and 18 °C, ranging from 23 to 24 °C in the hottest quarter (December, January, February) and 12 to 13 °C in the coldest quarter (June, July, and August).

According to Embrapa (2013), the soil classification of the study area is a typical dystrophic red-yellow Latosol, with a moderate, mild medium texture and a wavy soft relief phase (4-8% slope).

The ICLS was composed by *Eucalyptus dunnii* Maiden double rows, planted on contour (i.e. to promote soil and water conservation, Porfirio-da-Silva et al., 2009), with 20 meters between double rows, 4.0 meter between rows and 3.0 meters between plants in the row, aligned in a predominantly East-West orientation following the contour. The cropped area amounted to 18 m, because crop implements required at least one meter of distance from trees. The area was previously a rangeland composed by an association of a variety of C3 and C4 species.

At the sampling moment, trees were 4.5 years old and had nine-meter height. The weed sampling was made 15 days before the soybean harvest (*Glycine max*), which occurred on March 2010. Black oat (*Avena strigosa*) was the previous winter cover crop. Glyphosate (0.9 kg acid equivalent ha<sup>-1</sup>) was applied to eliminate weeds and desiccate oat and no herbicides were applied during soybean cycle. Soybean was sown with a no-tillage system and fertilized to achieve a target of 4.0 Mg ha<sup>-1</sup> yield, as recommended by the Local Soil Fertility Committee (CQFSRS/SC, 2004).

The experiment was arranged in a randomized blocks design, with nine replications, and five positions between double rows as treatments (n=45). Each experimental unit measured 7.2 m<sup>2</sup> (3.6 m x 2 m). As the trees were planted on contour, the positions determination started from the double row with inferior elevation between double rows. The positions were: A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m. Each position covered 3.6 m perpendicularly to double rows and 2 m in parallel to double rows. Samples were collected in the center of each experimental unit covering 1 m<sup>2</sup> (1 m x 1 m).

The following stick nightshade infestation parameters were measured: biomass accumulation and total plant density. As dispersion parameters, density of reproductive plants, vegetative plants (plants without flower and fruits), plants with flower and fruit, plants with only flower, and plants with only fruit were considered. Flowers and fruits on the ground were quantified in the area corresponding to the sampling area (1 m<sup>2</sup>). Plants were collected – excluding roots – and were dried in an oven with forced air-circulation at 60 °C, for biomass quantification.

Stick Nightshade reproduction parameters were assessed through the 100 seed weight and the number of seeds per fruit, both determined in 10 fruits (or between 4 and 10 fruits, when the sample did not have enough fruits). The seeds were sun dried, up to a constant weight during two weeks. Finally, seed production per area (m<sup>2</sup>) was determined.

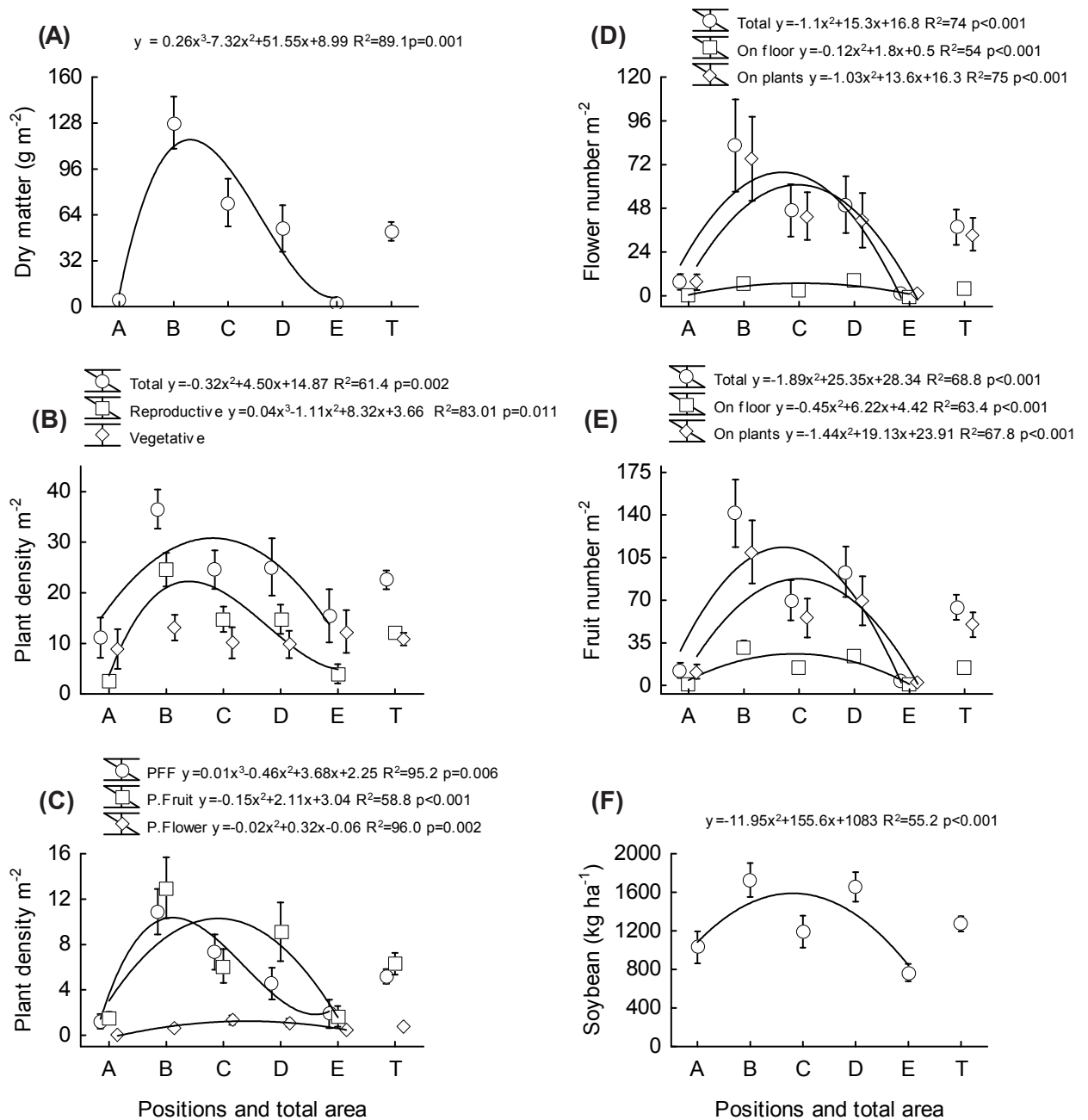
At the same experimental units, soybean was harvested and grain yield was determined after drying (the oven at 60 °C) and weighing the grains. Grain yield was determined by correcting the data to 13% grain moisture.

The statistical analyses were performed using the randomized block design framework, in the General Linear Models procedure of Statistica 8.0 for Windows (StatSoft, Inc., Tulsa, OK, USA). Residual normality was analyzed by the Shapiro-Wilk test and the data was submitted to the analysis of variance. When the position effect was significant, variables were submitted to a simple regression analysis, for the linear, squared, and cubic degrees. The mathematic models were selected according to those that best fitted the data, confirmed by the higher coefficient of determination and significance. Pearson's correlation test was performed between all SNS variables versus the soybean yield.

## RESULTS AND DISCUSSION

The stick nightshade infestation was analyzed by biomass accumulation and plant density. SNS biomass accumulation at the end of the soybean cycle was greater in the intermediate position B between double rows (p<0.01) (Figure 1A). In positions closer to the eucalyptus (i.e., positions A and E), there was a severe reduction of biomass accumulation. The stick nightshade total plant density was also negatively affected by the tree components (p<0.01) (Figure 1B). Therefore, the eucalyptus negatively affected the stick nightshade infestation, based on the biomass accumulation and density parameters.

Our results followed a broad trend that trees in the ICLS have the potential to reduce weed infestation. When evaluating 21 studies on weed abundance, Pumariño et al. (2015) found that non-parasitic weeds and, to a lesser extent, parasitic weeds were affected by the presence of trees when compared to annual cropping systems without trees. The authors attributed the negative effect of the trees on the weeds to improvements in the availability soil nutrients and microclimatic conditions that benefited the crop in the suppression of weeds. Adding to that, weeds can be negatively affected because of other effects promoted by trees such as increased soil covering with litter and reduced weed germination due to lower soil temperatures (Pumariño et al., 2015).



T represents the average of positions (A-E). Vertical bars indicate standard error.

**Figure 1** - Sticky nightshade (*Solanum sisymbriifolium*) biomass accumulation (A) total, reproductive and vegetative plant density (B), density of plants with flower and fruit (PFF) and only with fruit (P. Fruit) or flower (P. Flower) (C) number of flowers (D) and fruits (E) per plant and on the ground, and soybean grain yield (F) in positions between double rows [20 m (4 m x 3 m)] with 4.5 year-old eucalyptus (*Eucalyptus dunnii*), at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the double row positioned in the lower elevation between double rows, in an agroforestry system located in Ponta Grossa, PR - Brazil.

The presence of tree rows implies biophysical alterations relative to the dynamics of wind, temperature, solar radiation, nutrients, and water, as well as the interaction among these factors (Jose et al., 2004; Tsonkova et al., 2012). The tree rows behave as a permeable windbreaker and their porosity determines wind speed; tree height determines efficiency and planting orientation regarding the predominant wind direction, exert important influence on the wind characteristics inside the ICLS (Quinkenstein et al., 2009). The amplitude of soil temperature variation is lower throughout the day under the treetops (Feldhake, 2001), and lower soil temperatures were observed in arborized systems when compared to systems without trees (Clinch et al., 2009).

Moreover, air temperature is different in distances from the trees in arborized systems, and in comparison to arborized ICLS with treeless sites (annual cropping systems without trees) (Pezzopane et al., 2015).

Additionally, solar radiation incidence on the cropped area depends on the architecture and size of trees, spatial distribution of trees (e.g., on contour), and slope of the area. It is also a result of the constant change in the sun elevation and consequently, the radiation incidence angle, which interacts with the wind-induced treetop movement, thus promoting fluctuations of radiation incidence inside these systems (Kohli and Saini, 2003). Another characteristic is that trees deposit leaves, branches, and bark closer to tree rows, and they can intercept nutrients at greater depths, altering the nutrient cycling when compared to sole-cropped systems (Jose et al., 2004). Finally, treetops intercept and redistribute rainwater (Ghazavi et al., 2008; Poppenborg and Hoelscher, 2009) through the water flow of trunks and canopies (Siles et al., 2010). Consequently, these factors could have contributed to variations in growth and development of the SNS, in the different positions between double rows, and justifying, thus, a possible squared or cubic polynomial adjustment in this dynamic system.

According to the literature, factors known to affect SNS growth are light and temperature. In monocultures (without trees), SNS accumulated more biomass as the photosynthetic active radiation interception increased between 0 and 500 MJ m<sup>-2</sup>, resulting in a radiation use efficiency of 1.76 g MJ<sup>-1</sup> (Timmermans and Stomph, 2009). Reductions in solar radiation incidence combined with low temperatures are strong co-limiting factors to SNS growth (Timmermans et al., 2007a). Timmermans and Stomph (2009) verified that SNS increases its relative growth rate of leaves as air temperature increases, which was attributed to the increase in the transportation of photosynthetic electrons. The biomass accumulation of SNS occurs exponentially up to 400 °C degrees day and then linearly after this thermal period, increasing leaf biomass during the exponential growth phase, which turns to be constant during the linear growth phase (Timmermans et al., 2007a). Therefore, since light and temperature are factors that can be altered by the presence of trees in an ICLS, they could have contributed to the responses observed for SNS infestation, and consequently for dispersion.

Moreover, for other *Solanum* weed species, there is evidence of the interactive effect of water limitation and shade (Tan and Weaver, 1997) and only shade or light quality alteration on weed growth (Crotser et al., 2003). In brief, under reduced light availability, there was a lower snap flow rate per unit of leaf area when compared to full light availability, as the water availability increased for *S. ptycanthum* and *S. sarrachoides* (Tan and Weaver, 1997). As shade increased from 0 to 71%, *S. ptycanthum* decreased shoot weight, and this decrease was associated with lower stem weight, but shade did not reduce leaf weight or leaf area (Crotser et al., 2003). Furthermore, exposure of *S. ptycanthum* and *S. nigrum* to low red: far-red ratio radiation increased portioning of resources to stem tissue, resulting in taller plants; however, it did not affect branching and total biomass production (Crotser et al., 2003).

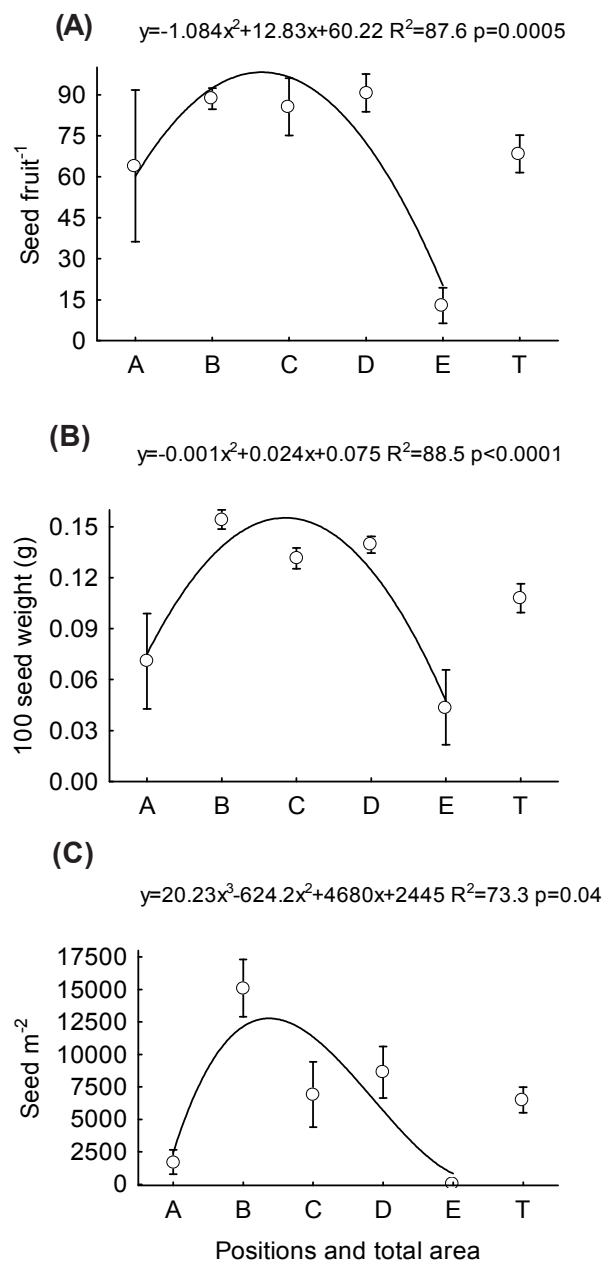
Stick Nightshade dispersion potential was analyzed through the number of reproductive plants and the fruit and also seed production. In general, all variables relative to SNS dispersion were negatively affected by the eucalyptus double rows. The responses of SNS dispersion followed a similar pattern to the one described for SNS infestation, suggesting the factors that negatively affected infestation had a consequence for dispersion. The net results from dispersion was further confirmed by Deiss et al. (2017a), which verified that relative seed density of SNS on the seedbank was greater in positions farther away from the trees.

The density of vegetative plants was lower when compared to the density of reproductive plants at the end of the soybean cycle, and it did not differ among positions between double rows ( $p > 0.10$ ). By contrast, reproductive plants had a strong suppression in the positions closer to the double rows ( $p < 0.001$ ), and occurred at higher densities between positions B and C (Figure 1B). The composition of reproductive plants was given by the plants with flowers and fruits, plants with only flowers or plants with only fruits (Figure 1C). In the ICLS (average of the positions), plants with only fruits predominated, followed by plants with flowers and fruits, and plants with flowers, suggesting that the community was in an advanced reproductive state. All plants that composed the reproductive plant group had a lower density next to the double rows [plants with only fruits ( $p < 0.001$ ), plants with only flowers ( $p < 0.01$ ) and plants with flowers and fruits ( $p < 0.001$ )].

The total number of flowers ( $p < 0.001$ ), flowers on plants ( $p < 0.001$ ), and aborted flowers (flowers on floor) ( $p < 0.001$ ) had a severe reduction in the positions closer to the double rows (Figure 1D). The aborted flowers occurred in a smaller proportion than the ones present in plants. The total number of fruits ( $p < 0.001$ ), fruits on the ground ( $p < 0.001$ ), and fruits in plants ( $p < 0.001$ ) had a quadratic response, decreasing the number of fruits closer to the trees (Figure 1E). For *S. ptycanthum* and *S. nigrum*, low red: far-red ratio radiation did not affect the number of flowers and timing of flowering (Crotser et al., 2003). By contrast, fruit weight decreased and fewer fruits were produced as shading increased from 0 to 71% (Crotser et al., 2003). Therefore, shade intensity could have contributed to inhibited SNS fruit production near the trees in the ICLS.

The eucalyptus negatively interfered in the soybean yield ( $p < 0.001$ ), and had a quadratic response with reduction in the positions closer to the eucalyptus (Figure 1F). The response of soybean to tree interference is better known than SNS response. In another investigation, Deiss et al. (2017b) found that soybean yield and its components were reduced between eucalyptus lines when compared with sole-cropping without trees. Grain yield reductions have been reported when soybean was interacting with walnut (*Juglans regia*), plum (*Prunus salicina*) or apple (*Malus pumila*) trees (Peng et al., 2009; Gao et al., 2013). Moreover, Green-Tracewicz et al. (2011) found that low red:far-red ratio in soybean seedlings reduced soybean branching, grain yield and most of its yield components. Soybean yield reduction was possibly alleviated as a result of the severe negative interference of eucalyptus over SNS biomass accumulation. However, other investigation verified that soybean growth and yield were not affected by weed competition within an eucalyptus agroforestry system, while weeds reduced soybean growth and yield in sole-cropping without trees (Deiss et al., 2017b).

Stick Nightshade seed production is the real dispersion potential of this plant. Its persistence in the seed bank will depend, after the dispersion, on persistence, quiescence, dormancy and, by contrast, on the seed bank output sources (germination, deterioration, predation, and pathogenic level). Number of seeds per fruit ( $p < 0.01$ ), 100-seeds weight ( $p < 0.001$ ) and seed production per area ( $p < 0.001$ ) were negatively affected by the eucalyptus interference (Figure 2A, C). The number of seeds per fruit found in our experiment was greater than the ones found in the literature, except for position E (i.e., from 20 to 30 seeds, Kissman and Groth, (2000) and from 18 to 60 seeds, Bryson et al. (2012).



T represents the average of positions (A-E). Vertical bars indicate standard error.

**Figure 2** - Number of seeds per fruit (A), 100 seed weight (B) and seed production (C) of sticky nightshade (*Solanum sisymbriifolium*) in five positions between double rows [20 m (4 m x 3 m)] with 4.5 year-old eucalyptus (*Eucalyptus dunnii*), at A: 2.8 m, B: 6.4 m, C: 10.0 m, D: 13.6 m, and E: 17.2 m from the double row positioned in the lower elevation between double rows, in an agroforestry system located in Ponta Grossa, PR - Brazil.

Among other *Solanum* species, SNS seeds have a faster emergence (i.e., eight days) (Bryson et al., 2012). However, a seedling emergency delay is expected for this species when the temperature accumulation in soil is low (Timmermans et al., 2007a). Between 21.8 °C and 13.0 °C, with a soil water potential of -0,0017 MPa, SNS emergence delay ranged from 12 to 39 days (Timmermans et al., 2007b). However, even considering that SNS produced seeds near the double rows, a lower emergence rate is expected, because of the lower soil temperatures resulting from tree interference. Pezzopane et al. (2015) found lower temperatures nearer the trees when compared to positions further away from the trees in an arborized system. Reductions in weed emergence as a result of lower temperatures promoted by trees in integrated systems has been observed for other species such as striga (Carson, 1989). Therefore, this possible alteration should be taken into account in the integrated management of weeds in an ICLS.

The correlation between soybean yield and SNS variables was significant for almost all variables ( $p < 0.05$ ), except for total plant density, plants with flowers, and vegetative plants. Those variables had a positive correlation ( $P$ ) with soybean yield, ranging between  $P=0.27$  and  $P=0.49$ , evidencing, thereby, the sticky nightshade's importance as a potential competitor with the soybean, because there was a greater soybean grain yield where SNS infestation and dispersion were greater in this ICLS with eucalyptus.

In conclusion, there is a negative interference promoted by eucalyptus in SNS infestation and dispersion in the ICLS. Over the years, SNS infestation and dispersion are expected to decrease because of eucalyptus development.

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