PLANTA DANINHA

SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS

<http://www.sbcpd.org>

ISSN 0100-8358 (print)
1806-9681 (online)

Article

Floating Macrophyte Control with Glyphosate According to Adjuvants and Spray Nozzles

Controle de Macrófita Flutuante com Glyphosate em Função de Adjuvantes e de Pontas de Pulverização

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Received: November 9, 2016
Approved: January 20, 2017

Planta Daninha 2018; v36:e018168125

ABSTRACT - The goals of this study were to evaluate the application of glyphosate plus three adjuvants and three spray nozzles in controlling the macrophyte *Pistia stratiotes*. For this purpose, after an 80 to 90% colonization, the application of 1.5, 3.5 and 7.0 L h^{-1} of isolated glyphosate and with the adjuvants Aterbane® BR, Veget'oil® and Dash® HC (0.5% vv^{-1}) and the spray nozzles (AI 110.02, TTI 110.015 and TT 110.015) was performed, plus a control sample (water). Applications were performed with a pressurized backpack precision sprayer, at the constant pressure of 50 p.s.i. and with mixture consumption of 200 L ha^{-1}. At the dose of 1.5 L ha^{-1}, there was 100% control for the combination glyphosate + Veget'oil + tip AI 110.02 (Gly+V.oil+AI, Gly+Aterb.+TTI and Gly+Dash+TT) 15 days after application (DAA). At 3.5 L ha^{-1}, the greatest control (95%) was with Gly+AI, Gly+Aterb.+TTI, Gly+V.oil+TTI, Gly+Dash+TTI, Gly+Aterb.+TT and Gly+Dash+TT; and at 7.0 L ha^{-1} 100% was observed for Gly+AI, Gly+Aterb.+AI, Gly+V.oil+AI, Gly+Aterb.+TTI, Gly+V.oil+TTI, Gly+Dash+TTI, Gly+TT and Gly+Dash+TT. Thus, it is possible to conclude that at 1.5 L ha^{-1}, the combination of glyphosate plus Dash® and with the nozzle TT 110.015 (Gly+Dash+TT) was the most promising one; at 3.5 L ha^{-1}, it was Gly+Aterb.+TTI and at 7.0 L ha^{-1} the air induction nozzles (AI 110.02 and TTI 110.015), whether with isolated glyphosate or with any of the three adjuvants, were the best at providing control.

Keyword: *Pistia stratiotes*, application technology, effectiveness, surface tension, contact angle.

RESUMO - O objetivo deste estudo foi avaliar a aplicação do herbicida glyphosate acrescido de três adjuvantes e três pontas de pulverização no controle da macrófita Pistia stratiotes. Para isso, após a colonização de 80 a 90%, foi realizada a aplicação de 1,5, 3,5 e 7,0 L ha^{-1} de glyphosate isolado e com os adjuvantes Aterbane® BR, Veget'oil® e Dash® HC (0,5% vv^{-1}) e pontas de pulverização (AI 110.02, TTI 110.015 e TT 110.015) e um controle (água). As aplicações foram feitas com pulverizador costal pressurizado de precisão, à pressão constante de 50 p.s.i. e consumo de calda de 200 L ha^{-1}. Na dose de 1,5 L ha^{-1} houve 100% de controle para a combinação glyphosate + Veget'oil + a ponta AI 110.02 (Gly+V.oil+AI), Gly+Aterb.+TTI e Gly+Dash+TT em 15 dias após aplicação (DAA). Em 3,5 L ha^{-1} o maior controle (95%) foi para Gly+AI, Gly+Aterb.+TTI, Gly+V.oil+TTI, Gly+Dash+TTI, Gly+Aterb.+TT e Gly+Dash+TT, e em 7,0 L ha^{-1} chegou-se a 100% para Gly+AI, Gly+Aterb.+AI, Gly+V.oil+AI, Gly+Aterb.+TTI, Gly+V.oil+TTI, Gly+Dash+TTI, Gly+TT e Gly+Dash+TT. Assim, conclui-se que em 1,5 L ha^{-1} a combinação de glyphosate com o Dash® e a ponta TT 110.015 (Gly+Dash+TT) foi a mais promissora; em 3,5 L ha^{-1} foi Gly+Aterb.+TTI e em 7,0 L ha^{-1} as pontas com indução de ar (AI 110.02 e TTI 110.015), independentemente de o glyphosate estar isolado ou com qualquer um dos três adjuvantes, foram as melhores no estabelecimento do controle.

Palavra-chave: *Pistia stratiotes*, tecnologia de aplicação, eficiência, tensão superficial, ângulo de contato.

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Doi: 10.1590/S0100-83582018360100027

INTRODUCTION

Anthropogenic activities contribute to the accentuated growth of macrophyte colonizations from various ecological groups, due to the release of nutrients into water bodies (Chambers et al., 2008). These colonizations also lead to serious consequences for navigation, water collection, alterations in the natural standards of water quality, water collection for public supply, generation of electric power, evapotranspiration and sheltering for disease vector organisms (Martins et al., 2002; Gettys et al., 2014).

Among the main problematic macrophytes, it is possible to mention *Pistia stratiotes*, *Eichhornia crassipes* and *Salvinia* spp. (Martins et al., 2002; Brundu et al., 2012; Gettys et al., 2014). *P. stratiotes* (water lettuce), belonging to the Araceae family, is a species with high vegetative propagation capacity and ability to regenerate starting from small plant portions (Brundu et al., 2012).

In order to reduce the damages caused by macrophytes, it is necessary to use control measures and, among the options (physical, biological, mechanic and chemical), the chemical management has been evaluated due to its high effectiveness and the good cost/benefit relation (Martins et al., 2002; Marcondes et al., 2003; Gettys et al., 2014). It is worth highlighting that the use of chemical control as a macrophyte management tool presents great potential in Brazil, mainly with its regulation by the Resolution n. 467, dated July 16th 2015. Published on the Brazilian Federal Register n. 137, dated July 17th, 2015, it rules about the use of products or processes for the recovery of water environments (Conama, 2015).

The effectiveness of some herbicides - such as imazapyr (Sellers et al., 2008); triclopyr and 2,4-D in mesocosm condition (Wersal et al., 2010); fluridone (Cheshier et al., 2011); endothal in mesocosm condition (Poovey et al., 2013); penoxsulam (Christopher, 2013); imazamox (Christopher, 2013); diquat (Christopher, 2013) and glyphosate (Sellers et al., 2008; Cruz et al., 2015) – has been demonstrated in many studies.

Glyphosate is one of the most widely used herbicides in agriculture (Rodrigues and Almeida, 2011). Its action mechanism is given by the inhibition of the EPSPs enzyme (5 enolpyruvylshikimate-3-phosphate synthase), which catalyzes the reactions of aromatic amino acid synthesis in plants, fungi and bacteria (Rodrigues and Almeida, 2011; Palaro et al., 2013). The evaluation of this molecule in controlling the macrophytes: *Salvinia molesta* (Nelson et al., 2001; Fairchild et al., 2002), *Urochloa mutica* (Chaudhari et al., 2012), *Alternanthera phyloxeroides*, *Eichhornia crassipes*, *Pistia stratiotes*, *Ludwigia grandiflora*, *Myriophyllum aquaticum* e *S. molesta* (Emerine et al., 2010), *E. crassipes* (Campos et al., 2013) e *E. crassipes*, *P. stratiotes*, *S. molesta*, *S. herzogii* and *U. subquadripara* (Cruz et al., 2015) has been described by various authors in controlled condition.

In order for the herbicide to be effective, it is necessary to adapt to the application technology that provides the proper placement of the product on the target, minimizing the environmental impacts (Decaro-Júnior et al., 2015) that may occur with the contact of phytosanitary products on non-target organisms. The fundamental steps for this adaptation go through the selection of spray nozzle and by the adjustment of the equipment to produce drops with the correct size to reach targets with the necessary quantity and the minimum environmental contamination.

The use of the proper nozzle, associated to the adjuvant, results into the increase of drop spreading over the treated surface (Miller and Butler-Ellis, 2000; Calore et al., 2014). Starting from these characteristics, the behavior of drops, from the formation on the nozzles until the arrival and permanence on the target, may provide higher or lower evaporation, drainage, spreading, adherence, among other aspects, so that they help the effectiveness of spraying control (Mendonça et al., 2007; Maciel et al., 2010).

Thus, the greatest knowledge about the changes in the physical-chemical characteristics of mixtures promoted by the adjuvants and the physical-mechanic alterations with the use of spray nozzles, may contribute to the control and management of water macrophytes and to the best decision-making. The goal of this study was to evaluate the application of the herbicide glyphosate (Rodeo®), with the addition of three adjuvants and with three spray nozzles, in controlling the macrophyte *P. stratiotes*.

MATERIAL AND METHODS

The cultivation of plants was performed in 1,000 liter capacity boxes, with substrate formed by coarse sand, organic fertilizer and soil (1:1:2 vv^{-1}), and continuous water flow. Plants were transplanted to 2.5 L capacity plastic boxes, filled with a similar substrate as the one described for the cultivation, in a growth oven (temperature between 28.1 and 30 ^{o}C and air relative humidity between 60 and 75%).

After occupying 80 to 90% of the plastic boxes, glyphosate was sprayed (480.0 g L^{-1}), in the Rodeo® (Monsanto do Brasil LTDA) formulation, and so were the adjuvants Aterbane® BR (mixture of alkylphenol polyglycol ether ionic surfactant - 466.0 g L^{-1}), Veget'oil® (fatty acid esters of plant origin - 930.0 g L^{-1}) and Dash® HC (mixture of methyl esters, aromatic hydrocarbon, unsaturated fatty acid - 933.0 g L^{-1}). The use of Dash® HC was due to its action in breaking the surface tension; Veget'oil® and Aterbane® BR are adhesive spreaders.

For that, there was the application of 1.5, 3.5 and 7.0 L ha^{-1}, equivalent to 720, 1,682 and 3,360 g a.e. of glyphosate ha^{-1} with no adjuvant and added with 0.5% vv^{-1} of Aterbane® BR, Veget'oil® and Dash® HC, with three types of spray nozzles (AI 110.02, TTI 110.015 and TT 110.015) and the control sample (with no application), all with seven replications. The treatments followed a 3 x 4 x 3 factor scheme, with three herbicide doses, four situations (three adjuvants + one with no adjuvant) and three types of spray nozzles.

Applications were performed with a precision pressurized backpack sprayer with constant pressure maintained by 50 p.s.i. CO_2, composed by an application bar spaced 0.5 m apart and with a spray volume of 200 L ha^{-1}. The environmental conditions during applications were: temperature between 28.1 and 30 ^{o}C, wind speed of 0.5 and 1.5 km h^{-1} and air humidity from 64 to 65%. The spray nozzles were chosen due to the formation of different drop sizes, with a pressure of 50 p.s.i. (3.5 bar); TT 110.015 was medium, AI 110.02 was extremely thick and TTI 110.015 was ultra thick (Spraying Systems, 2016).

After the application of the herbicide, the macrophyte was moved to a greenhouse (with temperature between 28.1 and 30 ^{o}C and air relative humidity from 60 to 65%), where visual evaluations of control effectiveness were performed on day 3, 7 and 15 after application (DAA), following the grade scale recommended by the Associacion Latino Americana de Malezas (ALAM, 1974) and the Sociedade Brasileira de Ciência das Plantas Daninhas (SBCPD, 1995). The grades used a control percentage corresponded to the average of three evaluators that measured individually.

On day 15 DAA, tests were dismantled and plants were placed in a forced air circulation oven for three days at 70 ^{o}C; after that, the dry biomass was weighed on a semi-analytical scale.

Evaluation of surface tension and contact angle

In order to evaluate the surface tension of the mixtures, a Dataphysics tensiometer (Contact Angle System OCA) was used, equipped with a high speed and definition digital camera, and also the SCA20 software, for the automation of the equipment and the manipulation of the obtained images. With the same equipment, the contact angle of the drops applied on the leaf surface of *P. stratiotes* was evaluated according to the methodology by Decaro-Júnior et al. (2015).

Data analysis

For the effectiveness in visual control and dry biomass, the average values were used, and for surface tension and contact angle, the analysis of variance by F test was performed, and the averages were compared by Tukey's test at 5%.

RESULTS AND DISCUSSION

The highest glyphosate doses promoted an increase in the control effectiveness and a higher reduction in the dry biomass, surface tension and contact angle.

At the dose of 1.5 L ha^{-1}, on day 7 DAA, control was between 7.5 and 15%, and on day 15 DAA, the treatments Gly+TTI (glyphosate with the TTI 110.015 nozzle) and Gly+AI presented 85 and 90% control, whereas Gly+V.oil+AI (glyphosate - 0.5% Veget'oil with AI 110.02 nozzle), Gly+Aterb.+TTI and Gly+Dash+TT promoted 100% control (Table 1). The mentioned control effectiveness was higher than what was evaluated (76.7%) on day 14 DAA for *Salvinea molesta*, at the dose of 8.97 kg ha^{-1} of glyphosate+0.5% Cide-Kick® adjuvant, as verified by Nelson et al. (2001), and 66% control with glyphosate (2.8 L ha^{-1}) + 0.25% of the surfactant Optima®, 52% with Kinetic®, 58% with Cygnet Plus®, 61% with LI-700® and 25% with the surfactant Mon 0818® for *S. molesta* on day 14 (Fairchild et al., 2002).

Table 1 - Relation among control effectiveness over *P. stratiotes* exposed to the herbicide glyphosate (Rodeo®), adjuvants and spray nozzles

Treatment	1.5 L ha^{-1}			3.5 L ha^{-1}			7.0 L ha^{-1}		
	DAA (days after application)								
	3	7	15	3	7	15	3	7	15
Control sample	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gly+AI	0.0	10.0	90.0	5.0	70.0	75.0	20.0	85.0	100.0
Gly+Aterb.+AI	0.0	10.0	85.0	12.5	80.0	95.0	25.0	90.0	100.0
Gly+V.oil+AI	0.0	10.0	100.0	2.5	75.0	85.0	20.0	85.0	100.0
Gly+Dash+A'I	0.0	10.0	95.0	5.0	75.0	80.0	20.0	90.0	95.0
Gly+TTI	0.0	12.5	85.0	0.0	70.0	80.0	20.0	85.0	95.0
Gly+Aterb.+TTI	0.0	15.0	100.0	10.0	80.0	95.0	25.0	90.0	100.0
Gly+V.oil+TTI	0.0	10.0	95.0	5.0	80.0	95.0	25.0	90.0	100.0
Gly+Dash+TTI	0.0	15.0	97.5	2.5	85.0	95.0	20.0	95.0	100.0
Gly+TT	0.0	7.5	90.0	2.5	75.0	80.0	20.0	75.0	100.0
Gly+Aterb.+TT	0.0	10.0	97.5	10.0	85.0	95.0	30.0	90.0	95.0
Gly+V.oil+TT	0.0	7.5	95.0	5.0	80.0	85.0	15.0	90.0	95.0
Gly+Dash+TT	0.0	10.0	100.0	5.0	85.0	95.0	20.0	95.0	100.0

At the dose of 3.5 L ha^{-1}, on day 3 DAA, the effectiveness was 0.0% for glyphosate with the nozzle TTI 110,015 (Gly+TTI), and the highest was 12.5% for glyphosate added with Aterbane® and the nozzle AI 110.02 (Gly+Aterb.+AI); on day 7 DAA, it was 70% for Gly+AI and Gly+TTI and 85% for Gly+Dash+TTI, Gly+Aterb.+TT and Gly+Dash+TT; and on day 15 DAA the lowest control was 75% for Gly+AI and the highest one was 95% for Gly+Aterb.+AI, Gly+Aterb.+TTI, Gly+V.oil+TTI, Gly+Dash+TTI, Gly+Aterb.+TT and Gly+Dash+TT (Table 1).

At 7.0 L ha^{-1}, control varied between 15 and 30% on day 3 DAA for the treatments Gly+V.oil+TT and Gly+Aterb.+TT, respectively. On day 7 DAA, the highest control occurred with the nozzles TTI and TT and the use of the adjuvant Dash® (Gly+Dash+TTI and Gly+Dash+TT), and the lowest one with TT and no adjuvant (Gly+TT).

On day 15 DAA, control exceeded 91% in all treatments (Table 1), and it was higher than what was evaluated by Cruz et al. (2015), with the same test-plant, with 80% on day 15 DAA at the dose of 7.0 L ha^{-1}, and similar to what was obtained for *E. crassipes* (100%) at the same dose (7.0 L ha^{-1}) and during the same exposure period with the use of glyphosate (Rodeo®) + 0.5% Aterbane®. This effect may be due to the interspecies difference in the sensitivity to the herbicide and/or to seasonality, since the studies were conducted in different periods of the year.

The effectiveness in controlling *P. stratiotes* at 1.5 L ha^{-1} was higher than the one obtained at 3.5 L ha^{-1}; the greatest visual control effectiveness at the lowest dose may be due to the use of a more sensitive plant lot.

The surface tension was statistically similar to the isolated glyphosate (Gly) (51.36 mN m^{-1}) and with the adjuvant Veget'oil (Gly+V.oil) (52.55 mN m^{-1}) at the dose of 1.5 L ha^{-1}; it was similar to Gly+Dash at the doses of 3.5 (36.57 mN m^{-1}) and 7.0 L ha^{-1} (34.99 mN m^{-1}). Among the other products and doses, there was significant difference ($p<0.05$) (Table 2).

Glyphosate added with Aterbane (Gly+Aterb) at the dose of 3.5 L ha^{-1} was the one most reducing the surface tension (21.49 mN m^{-1}) (Table 2). This result was similar to what was observed in the association of the herbicide glyphosate and clorimuron-ethyl, which presented a surface tension of 42.5 and 35.7 mN m^{-1}, respectively; when mixed to 0.5% of the surfactant Nimbus®, the tension decreased to 27.0 and 26.5 mN m^{-1}, and for Joint Oil® it was 28.8 and 26.7 mN m^{-1}, respectively (Maciel et al., 2010).

Cunha and Souza-Alves (2009) also observed the reduction of the surface tension with the use of the surfactant alkyl phenol polyglycol ether, but these authors compared with the control sample (distilled water). According to Mendonça et al.(2007), the action of the adjuvant on the surface tension is determined by the capacity to reduce it to the minimum, as in this study with Gly+Aterb. (21.49 mN m^{1}).

Table 2 - Relation between surface tension and contact angle with the adjuvant combinations and the herbicide glyphosate

Formulated product	Surface tension (mN m^{1})		
	1.5	3.5	7.0
	(L ha^{-1})		
Gly	51.36 Ac	64.31 Ab	73.42 Aa
Gly+Aterb.	32.62 Cb	21.49 Dc	43.87 Ba
Gly+V.oil	52.55 Aa	41.97 Bc	49.02 Cb
Gly+Dash	36.93 Bb	36.57 Ca	34.99 Da
	Contact angle (degrees)		
Gly	125.58 Bb	126.62 Ca	124.19 Cc
Gly+Aterb.	87.76 Ca	76.27 Db	69.20 Dc
Gly+V.oil	144.49 Ab	134.94 Bc	150.72 Aa
Gly+Dash	145.51 Ab	159.55 Aa	138.50 Bc

Averages followed by letters, distinct capital letters in the columns and lowercase letters on the lines, differ statistically among themselves by Tukey's test ($p<0.05$).

In the analysis of the contact angle, there was similarity ($p<0.05$) only with glyphosate added with Veget'oil (Gly+V.oil) with 144.49° and with Dash® (Gly+Dash) with 145.51°; with the other products and herbicide doses, there was significant difference ($p<0.05$) (Table 2). Glyphosate added with Aterbane® (Gly+Aterb.) was the one promoting the greatest contact angle reduction, regardless of the dose, compared to the other adjuvants (Veget'oil® and Dash®), with an emphasis on the dose of 7.0 L ha^{-1} (69.20°) (Table 2).

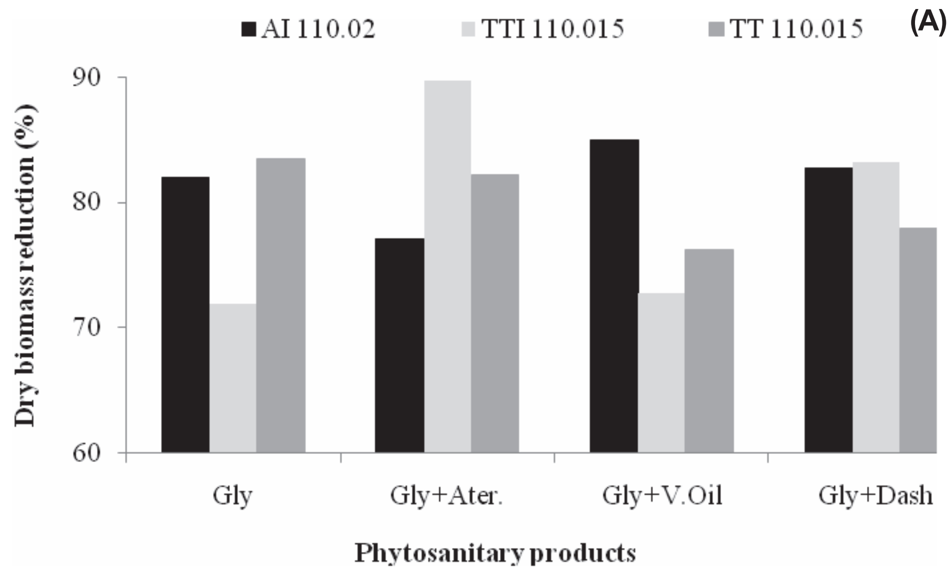
The contact angle values presented in this study were higher than what was evaluated for the adjuvant Silwet L-77® exposed to *Ipomoea grandifolia* (0.0°), *Euphorbia heterophylla* (5.6°) and *Urochloa plantaginea* (2.1°); and for Supersil®, with 1.9°, 4.1° and 5.5° respectively; and they were similar to what was obtained for LI-700®, with 68°, 83.7° and 80° (respectively), to Pronto 3®, with 53.3°, 76.5° and 88.2° (respectively), and to the adjuvant Uno®, with 63.3°, 82.8° and 77° (*I. grandifolia*, *E. heterophylla* e *U. plantaginea*, respectively) (Iost and Raetano, 2010).

The treatment with the adjuvant Aterbane® (Gly+Aterb.) presented the lowest values, due to the fact that the product is an adhesive spreader, which does not mean that Aterbane® is the best adjuvant; moreover, the morphological characteristics of the leaf surface must be taken into consideration, for example, whether it is hydrophobic or hydrophilic, the presence of trichomes and the chemical composition of the epicuticular wax (Mendonça et al., 2007; Iost and Raetano, 2010).

With the use of the 1.5 L ha^{-1} dose and the AI 110.02 nozzle, the reduction percentage of the dry biomass was 77.08 to 84.97% (Gly+Aterb. and Gly+V.oil, respectively); with TTI 110.015, it was 71.88 to 89.73% (Gly and Gly+Aterb., respectively); and with TT 110.015, it was 76.19 to 83.48% (Gly+V.oil and Gly, respectively) (Figure 1A), compared to the control sample treatment. At the dose of 3.5 L ha^{-1} with the 110.02 nozzle, the reduction percentage was between 86.45 and 95.57% (Gly and Gly+V.oil, respectively); with TTI 110.015, it was between 88.08 and 98.06% (Gly and Gly+Dash, respectively); and with TT 110.015, it was between 95.32 and 97.66% (Gly and Gly+Aterb, respectively) (Figure 1B).

With 7.0 L ha^{-1} the dry biomass was not measured, due to the high control effectiveness of glyphosate (Rodeo®), which resulted in the absence of dry biomass to weigh, regardless of the adjuvant and the spray nozzle.

Glyphosate reduced the dry matter above 70% at 1.5 L ha^{-1} regardless of the adjuvants and the spray nozzles. This result is higher than what was obtained for *Pycreus decumbens*, with 60%, and lower than what was obtained for *Alternanthera philoxeroides* (97.8%) and *Enhydra anagallis*, with 90% (14 DAA), with the use of the same herbicide as this study's one + 0.5% of



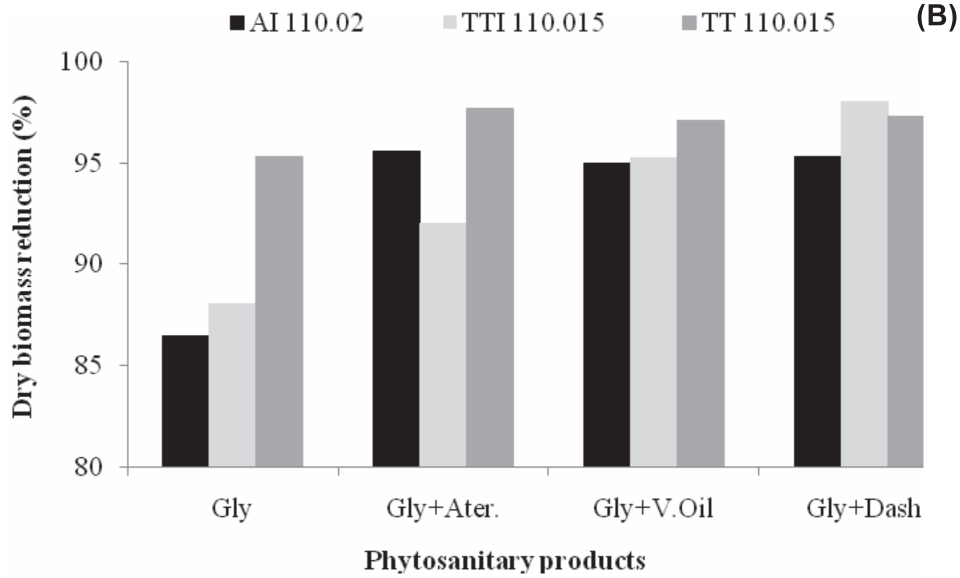


Figure 1 - Reduction of the dry biomass with the adjuvant combinations and spray nozzles at the doses of 1.5 L ha^{-1} (A) and 3.5 L ha^{-1} (B).

Aterbane BR® (Costa et al., 2005). However, at 3.5 L ha^{-1}, the dry matter reduction was above 85%.

When performing the analysis of the sole adjuvants, the one that most contributed with glyphosate in the control effectiveness over *P. stratiotes* was Dash®, with average values of 97.5% at the dose of 1.5 L ha^{-1}; at 3.5 L ha^{-1}, it was Aterbane® with 95%; and at 7.0 L ha^{-1}, all adjuvants presented an average of 98.33%.

When analyzing only the effect of the spray nozzles, at the dose of 1.5 L ha^{-1}, TT 110.015 was the one that most contributed to the greatest average control effectiveness (95.62%); at 3.5 L ha^{-1} it was TTI 110.015 with 91.25%; and at 7.0 L ha^{-1} it was AI 110.02 and TTI 110.015 with 98.75%.

At the greenhouse condition under which this study was conducted, the spray nozzle TT 110.015 was one of those presented a great performance. However, in an on-the-field situation, this nozzle must be indicated with criteria, since it produces medium-sized drops (Spraying Systems, 2016), and it is more prone to drifting, which is the quantity of herbicide diverted outside the target which, when reaching non-target organisms, may cause negative environmental impacts (Berti et al., 2009).

Thus nozzles with air induction started to be the most promising (AI 110.02 and TTI 110.015), mainly the latter, which was the one providing the best control results.

The adjuvant Dash® and the nozzle TTI 110.015 were the ones providing the best visual control effectiveness results and an excellent reduction percentage of the dry biomass at the doses of 1.5 L ha^{-1} (83.18%), 3.5 L ha^{-1} (98.06%) and 7.0 L ha^{-1} (100%).

Thus, it is possible to conclude that at 1.5 L ha^{-1}, the herbicide glyphosate added with Dash® and the nozzle TT 110.015 (Gly+Dash+TT) was the one providing the greatest control; at 3.5 L ha^{-1} it was Aterbane® and the nozzle TTI 110.015 (Gly+Aterb.+TTI); and at the dose of 7.0 L ha^{-1} the nozzles with air induction (AI 110.02 and TTI 110.015), no matter if glyphosate was isolated or with any of the three adjuvants (Aterbane®, Veget'oil® and Dash®), they provided a similar control effectiveness as the one in greenhouse, which demonstrates that glyphosate at the highest dose was effective regardless of the adjuvant and the spray nozzle.

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