Integration mulches with atrazine for weed management in corn

Eli Danieli Marchesan[1], Michelangelo Muzell Trezzi[1], Marcos Vinícius Jaeger Barancelli[1], Sorhaila Camila Batistel[1], Fortunato De Bortoli Pagnoncelli Junior[1], Ribas Antonio Vidal[2]

[1] Universidade Tecnológica Federal do Paraná, Campus Pato Branco, Rua Via do Conhecimento, km 1, Fraron, CEP 85503-390, Pato Branco-PR, Brasil. E-mail: elidanieli_marchesan@yahoo.com.br; trezzim@gmail.com; marcos.v.jb@hotmail.com; sc.batistel@hotmail.com; fpagnoncelli@outlook.com
[2] Universidade Federal do Rio Grande do Sul, Faculdade de Agronomia, Departamento de Plantas de Lavoura, Av. Bento Gonçalves, 7712, Agronomia, CEP 91501-000, Porto Alegre-RS, Brasil. Caixa Postal 15100. E-mail: ribas.vidal@gmail.com

ABSTRACT

The use of cover crops can contribute to the reduction of the dose required for weed control. The aim of this work was to assess the growth of weeds and productivity of corn from different degrees of black oat cover and velvet bean and atrazine doses. Two experiments were conducted in the experimental area, both was conducted in randomized blocks in a split plot design with four replications. In the main plots were randomized, four straw levels (0, 0.75, 1.5 and 3 times the amount originally produced) oat (Exp 1) or velvet bean (Exp 2). In the subplots were randomized to four doses of atrazine (0, 2100, 4200 and 8400 g ha^{-1}). It was evaluated the weed density and crop yield. The utilization of straw species coverage on the ground, even at high levels, was not enough to exercise total control of weeds. Atrazine was not effective in weed control only in the treatment with 2100 g ha^{-1} of the herbicide and no velvet bean straw on the ground, but the straw of this species realized suppressive effect, supplementing the effect of the herbicidal dose. Levels in 2775 and 5550 kg ha^{-1} of velvet bean straw reduce the productivity of corn. Integrating the use of oat or velvet bean straw with low dose of atrazine (2100 g ai ha^{-1}), results in effective weed control systems and more suitable cropping systems in the environmental aspect, both by reducing the use of herbicides as taking advantage of the benefits of no-till system.

Key words: Avena strigosa, integrated weed management, Stilozobium aterrimum

Integração de coberturas mortas com atrazina para manejo de plantas daninhas na cultura do milho

RESUMO

O uso de plantas de cobertura do solo pode contribuir para a redução da dose necessária para o controle de plantas daninhas. O objetivo deste trabalho foi avaliar o desenvolvimento de plantas daninhas e a produtividade da cultura do milho a partir de diferentes níveis de cobertura de aveia preta e mucuna preta e doses de atrazina. Dois experimentos foram realizados a campo, em delineamento de blocos ao acaso, em parcelas subdivididas, com quatro repetições. Em ambos experimentos, nas parcelas principais foram alocados quatro níveis de palha (0, 0,75, 1,5 e 3 vezes a quantidade originalmente produzida). O primeiro experimento foi constituído de palha de aveia preta e o segundo de palha de mucuna preta. Nas subparcelas de ambos experimentos foram alocadas quatro doses de atrazina (0, 2100, 4200 e 8400 g ha^{-1}). Foram avaliadas a densidade de plantas daninhas e a produtividade da cultura. A utilização da palha das espécies de cobertura sobre o solo, mesmo em níveis elevados, não foi suficiente para exercer o controle pleno das plantas daninhas. A atrazina não foi eficiente no controle das plantas daninhas apenas no tratamento com 2100 g ha^{-1} do herbicida e ausência de palha de mucuna preta sobre o solo, mas a palha desta espécie de cobertura exerceu efeito supressor, complementando o efeito desta dose de herbicida. Os níveis de 2775 e 5550 kg ha^{-1} de palha de mucuna preta reduzem a produtividade do milho. A integração do uso de palha de aveia preta ou de mucuna preta com a utilização de dose baixa de atrazina (2100g ia ha^{-1}), resulta em sistemas de cultivo eficazes no controle de plantas daninhas e mais adequados quanto ao aspecto ambiental, tanto pela redução do uso de herbicidas quanto pelo aproveitando dos benefícios do sistema de plantio direto.

Palavras-chave: Avena strigosa, manejo integrado de plantas daninhas, Stilozobium aterrimum

Introduction

Currently, the use of herbicides is the most disseminated way to control weed in the crop of corn. Atrazine (2-chloro-4-ethylamine-6-isopropylamine-s-triazine) is widely used in this crop in Brazil, either alone or in association with other herbicides (Fleck & Vidal, 2001). Often the inappropriate use of herbicides causes serious impacts to the environment and reducing the use of these products can be obtained with the adoption of preventive and cultural measures (Balbinot Jr. et al., 2007).

The use of cover crops is a major strategy for agricultural systems in southern Brazil, protecting soil and helping on weed management (Altieri et al., 2011). The latter is because most weeds can found secure places for germination and emergence in fallow areas or with low levels of soil coverage (Radosevich et al., 2007). For this reason, cover crops have an important role in weed suppression (Rizzardi & Silva, 2006; Monquero et al., 2009). There are a number of explanations on this matter like physical factors reducing the availability of solar radiation (Gomes et al., 2014) and the thermal amplitude in the topsoil, as well chemical factors as the releasing of allelopathic substances by the cover crops tissues (Gomes Jr.& Christoffoleti, 2008). Experiments had revealed a progressive reduction of weed infestation with the increasing on the cover crops residues amount. However, different responses has been reported resulting from interaction between cover crop species and weeds (Bittencourt et al, 2013).

In conservationists systems can be used many species of ground cover, including the velvet bean (*Stilozobium aterrimum*), but the main species used in cover crop systems preceding the corn crop culture in southern Brazil remains the oat (*Avena strigosa*).

The grasses and leguminous cover crops have contrasting characteristics regarding the decomposition speed of the residues and the nitrogen biological fixation ability. Given that, both can influence to distinct outcomes in weed suppression over time (Silva et al., 2006; Altieri et al., 2011).

The decomposition process of oats residues usually is slower than that of legume species (Aita & Giacomini, 2003) while the rate of decomposition depends majorly on the stage of development of the plants at the time of desiccation. Changes occur in the composition and fragmentation of crop remains as decomposition progresses, which can modify the dynamics of the herbicides. An increase on the straw surface area due to the enrichment of lignin, and the fragmentation increase the adsorption of herbicides. Recently cutted residues allowed 32% of the total atrazine applied reach the soil surface, while with dry residues the value increased to 52% (Sigua et al., 1993).

Therefore, despite its positive direct effect on weed suppression, cover crops residues can decrease herbicide effectiveness due to interception and adsorption. The scientific information on the interaction between herbicides and cover crops is scarce. This preclude a more efficient weed management when cover crops and herbicides are used together. The objective of this work was to evaluate the join effect of black oat or velvet bean residues with doses of atrazine on weed incidence and corn yield.

Material and Methods

Two field experiments were carried out in the Universidade Tecnológica Federal do Paraná Experimental Station, located in Pato Branco (PR), Brazil (26007'S and 52041'W). The soil is an oxisol (Embrapa, 2006) and the climate is humid subtropical with hot summers (Cfa), according to the Koppen classification. The experiments consisted in the use of black oat (*Avena strigosa*) and velvet bean (*Stilozobium aterrimum*) mulches as winter and summer cover crops, respectively.

The cover crops were cultivated previously, but in the same area used for corn cultivation. Black oats was sown in May 2012, while the velvet bean in October of the same year. Cover crops management was made using an agricultural rotavator (triton) when black oat plants reached full flowering in August and velvet bean the beginning of flowering in February. The obtained mulch was gathered, separated by weight according to respective dose and distributed in the plots.

The corn and weed experiment had a split-plot randomized blocks design, with four replications. This totalized 128 subplots in a 2418 m² area. Main plots received four levels of black oat (0, 3037, 6075 and 12150 kg ha⁻¹) or velvet beans straw (0, 1387, 2775 and 5550 kg ha⁻¹) on the soil surface. The mulch amounts correspond to 0, 0.75, 1.5 and 3 times the amount originally produced from the aerial parts of those species (4050 kg ha⁻¹ for oats and 1850 kg ha⁻¹ for velvet beans). On the subplots were designed four doses of atrazine (0, 2100, 4200 and 8400 g i.a. ha⁻¹).

The subplots had six lines of corn, spaced 0.70 m from each other of and with 4.5 m in length, totaling 14.8 m² of evaluable area. The single cross corn hybrid (Pioneer 32R48H) was sown in two different moments, first for using oat mulch and later for velvet bean mulch. Black oat seeding was made on the second fortnight of September 2012 and velvet bean in February 2013. A precision seeder was used to obtain 67,000 plants of corn per ha⁻¹.

The area was fertilized with 24, 60 and 60 kg ha⁻¹ of N, P_2O_5 and K_2O, respectively, with a 8-20-20 formulation, attending corn needs. 130 kg ha⁻¹ of N (urea) was used for corn nitrogen topdressing divided in two applications, between the stage V_2 and V_3 and between V_{15} and R_1. Atrazine was applied as post-emergence, approximately 25 days after corn sowing when the weeds were presenting from 2 to 4 fully expanded leaves. The herbicide was sprayed using backpack sprayer pressurized with CO_2 (pressure kept constant). Fan type nozzles 110.02 were used, spaced 0.50 m from each other in a 2.5 m wide bar, totaling a spray volume of 200 L ha⁻¹.

The weed density was evaluated at 7, 21, 28 and 35 days after herbicide application (DAA) in two pre-defined locations on each subplot. The samples were obtained counting all plants present in a 0.45 x 0.45 m square. For the fresh weight of weeds (FW) determination, all weeds plants present inside the 0.45 x 0.45 m square were cut at 1 cm from soil surface on the 50th day after application (DAA). The gathered weeds were separated according to gender or species and then dried

in a stove at 60 °C until constant weight to determine the dry weight (DW).

Corn grain yields were determined at 126 days after sowing when using black oat mulch and 146 days when using velvet beans. Corn was harvest manually and then grain-trashed. The grain was then weighted and the moisture was adjusted for 13%.

The data were submitted to ANOVA ($p < 0.05$), using the statistical software Winstat. Regression analyses was performed between levels of quantitative factors, adjusting to quadratic or linear models when appropriate.

Results and Discussion

Experiments with *Avena strigosa* – the most prevalent weed infestations on corn were from populations of turnip (*Raphanus sativus L.*) and black oat (*Avena strigosa*). For all evaluation periods of time, there was a significative interaction between doses of atrazine and black oat mulch levels. In all evaluations, weed infestations occured only in the absence of atrazine independent from its level (Figure 1).

Weed species densities in plots without both, mulch and atrazine, were increasing until 28 DAA, reaching a maximum of 191 plants m^{-2}. At 35 DAA, the density was lower than in previous periods, which can be explained by the exacerbation of competition for resources among weeds.

Without atrazine, weed density was reduced in response to the levels of black oat straw deposited on the soil surface (Figure 1 A, B, C, D). That is, the presence of oat mulch on the soil surface by itself reduced the emergence of weeds. The use of 3037 kg ha^{-1} of oat straw reduced in 39% the weed infestation, while the levels of control obtained by use of 6075 and 12150 kg ha^{-1} of oat straw reaching 61% and 48%, respectively. Even the highest mulch amount (12,150 kg ha^{-1}) was not sufficient to completely inhibit the emergence of weed species (Figure 1 A, B, C, D).

Beside not being able to cause complete weed suppression, cover crops can suppress the development of weeds as it has been already being reported on previous works (Monquero et al., 2009; Altieri et al., 2011). The suppression of weed germination can be attributed to mulching physical and chemical factors. The reduction on solar radiation and thermal
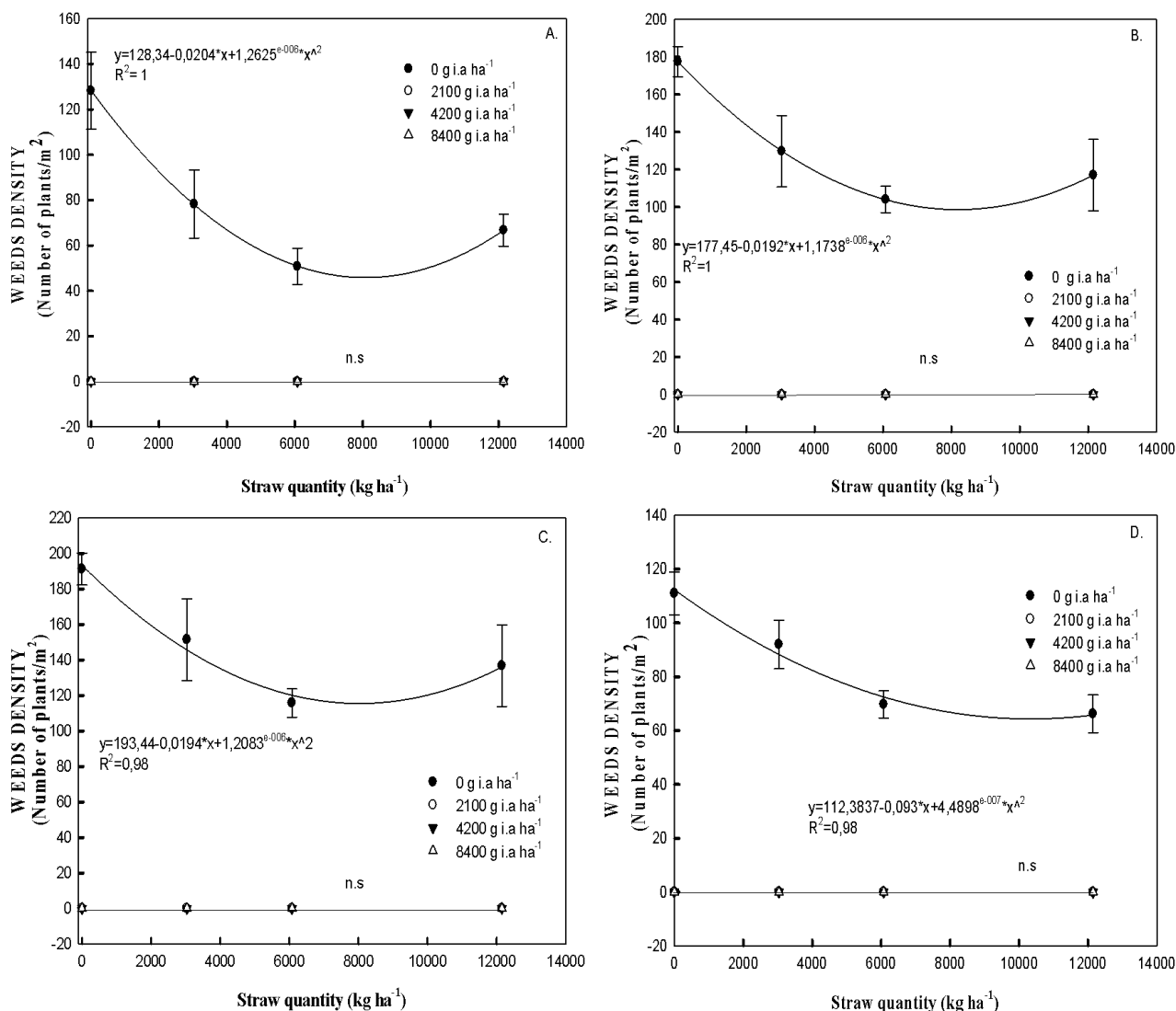
Figura 1. Total number of weed plants per m^2 in function of black oat mulch and atrazine levels, at 7 (A), 21 (B), 28 (C) and (D) and 35 days after application (DAA). UTFPR, Pato Branco, 2014. Bars indicate standard error of average

amplitude in topsoil are major physical factors for reducing of many weed species seed germination. On the other hand, chemicals released from residues can also inhibit germination and/or emergence (Souza et al., 2006). Several studies already demonstrate reduced weed density with increasing mulch levels (Trezzi et al., 2006). Some mulches, even in low amounts (1.5 to 1.7 t ha^{-1}) can reduce by 50% the alexandergrass (*Urochloa plantaginea*), beggarticks (*Bidens* spp.) and sida (*Sida rhombifolia*) infestations.

The total weed control obtained from the association of atrazine regardless the mulching level indicates that the mulch was not a barrier for atrazine. The high effectiveness of weed control occurred, probably due to precipitation (60 mm) that occurred 4 days after application of the herbicide, which allowed atrazine to get into the soil. It may also have contributed to the high herbicide sensitivity observed for black oat and turnip, which were fully controlled even with the lowest dose of atrazine used.

These results are supported by those obtained by Rodrigues et al. (2000), which report that even with a 85% of atrazine interception by oat straw, the herbicide was identified in soil after a 20 mm precipitation. The fact that it was not observed weed infestation in any evaluation period (up 2100 to 8400 g i.a ha^{-1}) (Table 1) after application of atrazine also indicates a herbicide action as both post and pre-emergence.

Corn yield showed significance for mulch x herbicide interaction. There was a good fit between levels of productivity and levels of straw through the quadratic polynomial model (Figure 2). High yields of corn (when compared to the region average) were achieved, ranging from 12,500 to 15,300 kg ha^{-1}.

There were not found differences in yield in function of atrazine dose in the absence of straw and with 3037 kg ha^{-1} and 6075 kg ha^{-1} of straw. However, at the highest straw level (12150 kg ha^{-1}) the largest atrazine dose has increased corn yield. This yield was higher than without atrazine and with 2100 g i.a. ha^{-1} dose (Figure 2). In principle, the increase in productivity with the use of higher doses was not due to reduced weed interference (competition or allelopathy) generated because low doses of atrazine were enough to generate adequate levels of control (assessments conducted up to 35 DAA). However, it is possible that the presence of weeds in later stages (during the reproductive stage of culture) in treatments without atrazine or with lower levels of the herbicide can promote negative interactions of pathogens or pests with culture, especially with higher straw levels, thereby reducing grain yield.

Small decreases corn yield have been identified at intermediate levels of oat straw, when compared to his absence (Figure 2). This can be attributed to the immobilization of nitrogen. Immobilization of N by biomass constitutes an important drain of N. Although, appropriate management practices of cover crop mulches can avoid it (Cabezas et al.,
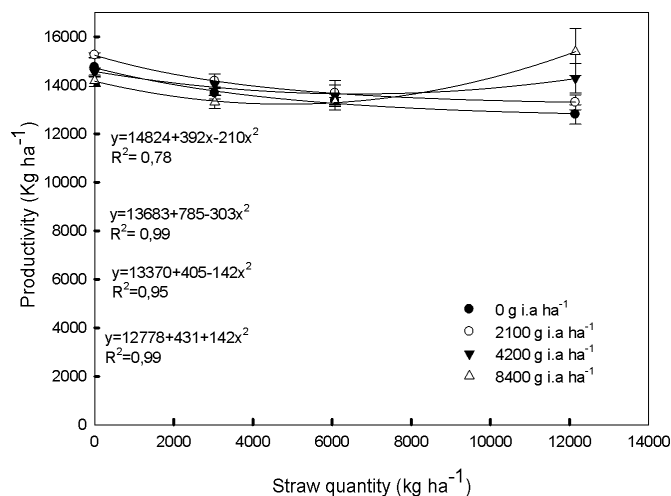
Figure 2. Corn grain yield, depending on the amount of oat straw and the doses of atrazine. UTFPR, Pato Branco, 2014. Bars indicate standard error of average

2005). However, it is not possible to identify why this effect was not observed in the highest straw level and the intermediate and higher doses of atrazine.

Experiments with *Stilozobium aterrimum* - several weeds occurred on velvet bean mulch, highlighting turnip (*Raphanus sativus L.*), oats (*Avena sativa*), hairy beggarticks (*Bidens pilosa*), morning glories (*Ipomoea* sp.), Horconyza (*Conyza* spp.) and wild poinsettia (*Euphorbia heterophylla*).

It was observed interactions between dose of atrazine and velvet bean mulch level for all evaluations of weed density (Figure 3). Weed density assessments performed at 7, 21, 28 and 35 days after herbicide application (DAA) show similar behavior among treatments over time. The greatest weed infestations were observed in the absence of both atrazine and mulch. The variation of 45 (7 DAA) to 78 plants m^{-2} (35 DAA) (Figure 3), whereas the absence of atrazine combined to the higher level of straw on the soil (5550 kg ha^{-1}) resulted in variation of 13 plants per m^2 (7 DAA) to 40 plants per m^2 (35 DAA) (Figure 3), which is equivalent to an increase over time of 73% in the condition without straw and 307% with the use of higher level of straw, both without atrazine.

This demonstrates that the velvet beans mulch amount can play a key role in the suppression of weed infestations. Nevertheless, the decomposition process allows a crescent weed emergence, even where there are significant levels of mulch on the soil surface.
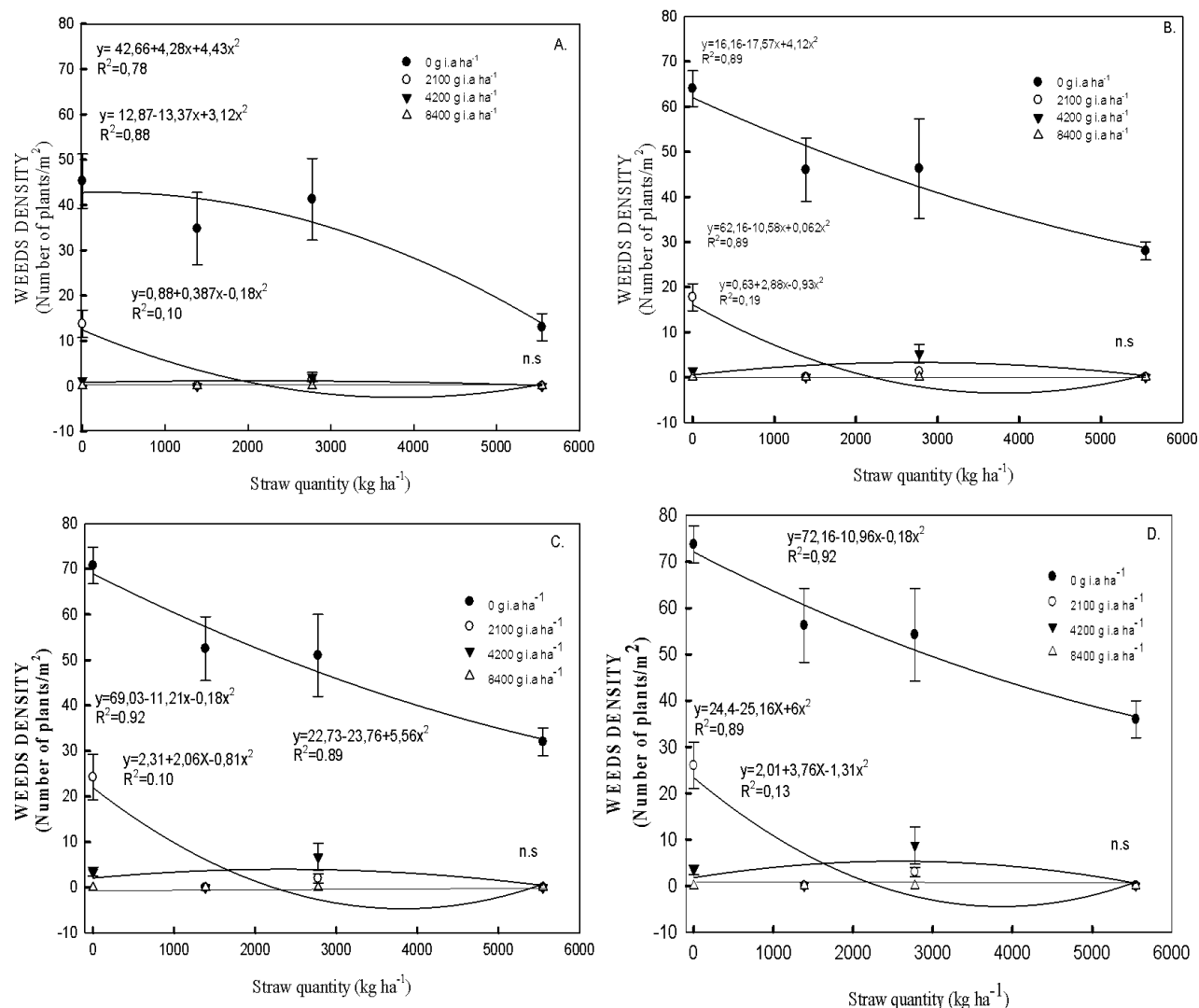
The 4200 and 8400 g ha^{-1} atrazine doses were efficient in keeping the weed population at very low densities. The herbicide was effective regardless the presence of the velvet bean mulch (Figure 3). Weed infestations at 21 DAA, resulting from the application of atrazine on dose of 2100 g ha^{-1} in the absence of mulch on the soil surface, was of 17 plants m^{-2}, with small increments at 28 and 35 DAA. The other doses of atrazine in the absence of straw controlled weeds almost completely.

At the 2100 g ha^{-1} atrazine dose it was possible to identify a complementary effect between herbicide and mulch levels. Satisfactory weed control was acquired when this dose was associated to any levels of velvet beans mulch (Figure 3).

Table 1. Aboveground weed mass in function of atrazine level. UTFPR, Pato Branco Campus, 2013

Dose/ g de i.a ha^{-1}	Green mass (g m^{-2})	Dry mass (g m^{-2})
	50 DAA	50 DAA
0	145 A	19A
2100	0 B	0 B
4200	0 B	0 B
8400	0 B	0 B

Figure 3. Total number of weeds per m² depending on quantities of straw of velvet beans and doses of atrazine, at 7 (a), 21 (b), 28 (c), (d) 35 days after application (DAA), UTFPR, Pato Branco, 2014. Bars indicate standard error of average

Nevertheless, this dose was not sufficient to fully suppress the weed infestation in the absence of straw on the soil surface. This leads to the conclusion that, when mulch and herbicide are used together it is possible to reduce the levels of atrazine, demonstrating the effectiveness of integration of these management practices.

Other studies reinforce the importance of complementing the use of mulching with other tools. The use of ryegrass and forage turnip coverage provided partial control of weeds in corn, but the association with nicosulfuron increased productivity of culture, regardless of the coverage used (Moraes et al., 2009; Moraes et al., 2013). The use of rice straw on the soil benefits the species *Mentha arvensis*, since it was obtained a. high oil yield without the need for high doses of diuron (Singh & Saini, 2008).

Velvet bean is known in Brazilian agriculture for its use as green manure, due to advantages of soil protection, nutrient cycling, nitrogen fixation and weed control. The literature reports allelopathic effects of this species on hairy beggarticks (Teixeira et al., 2004), *Ipomoea gradifolia* and *Panicum maximum* (Monquero et al., 2009). It is supposed that both physical and chemical properties can have a positive influence on weed control.

The results on weed density are supported by weed above ground biomass, green (MPAV) and dry (MPAS). Since they confirm the higher development of plants on the plots where it was not used any form of control, be it chemistry, by the use of atrazine, or by the use of straw and also the complementary effect of the straw in the suppression of weeds by using 2100 g ha⁻¹ of atrazine (Figure 4).

Only the mulch level showed significance on corn yield. High grain yields (considering the region average) have been achieved, varying between 13582 and 14469 kg ha⁻¹. Which represents a low amplitude, of only 887 kg ha⁻¹.

The response of grain yields to levels of velvet beans straw was set to a positive quadratic polynomial model. In the regression curve, it is possible to check that the intermediate levels of straw of velvet beans (1397 and 2775 kg ha⁻¹ of straw) provided small increases in corn productivity when compared to the absence of mulch (Figure 5).

The increase in productivity in the presence of velvet beans mulch can be explained partially by the contribution of nitrogen fixation. Along with N fertilization, it's also possible that weed suppression could also has exerted a positive influence on yield.
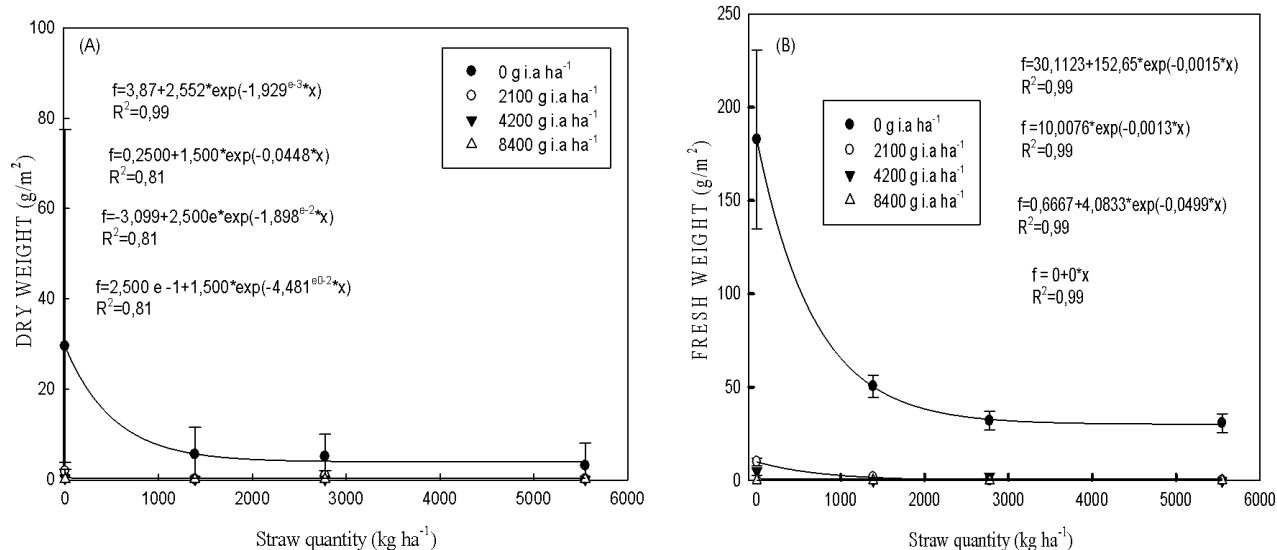
Figure 4. Mass of dry aerial part (A) and mass of green aerial part (B), based on the quantity of oat and the doses of atrazine. UTFPR, Pato Branco, 2014. The bars in the figure indicate the standard error of average
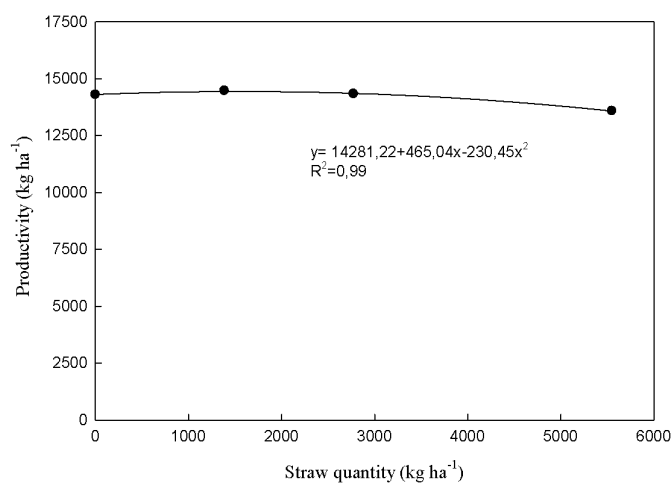
Figure 5. Corn grains yield, according to different levels of velvet beans straw on the soil. UTFPR, Pato Branco, 2014

The causes for the small decrease in productivity with the use of higher level (5550 kg ha^{-1}) of velvet beans (Figure 5) should be better investigated. The hypothesis of allelopathic interference is supported by the scientific literature, since the studies report that some leguminous species like red clover (Liebman & Sundberg, 2006) and the velvet beans (Teixeira et al., 2004) have allelopathic activity, which may interfere with the growth of weeds and crops, including corn.

Therefore, the present work demonstrates the feasibility of integrating methods of weed control in no-tillage systems. This could also allow a decrease in the atrazina dose used, with consequent reduction on the negative effects often caused by adopting the chemical control. However, to achieve this integrated control system there is a need for production of minimum levels of straw, which allow the maximization of physical and allelopathic effects and also the use of herbicides with physicochemical characteristics that allow their migration from the straw to the soil, allowing the suppression and control of weeds.

Conclusions

The use of high amounts of oat straw or velvet beans, alone, are not effective for complete weed control on corn.

The weed control exercised by the 2100 g ha^{-1} atrazine is not efficient for weed control by itself.

The velvet beans mulch exerts a complete weed control when associated to a 2100 g ha^{-1} of atrazine.

High levels of velvet beans mulch reduce the corn yield and the causes of this effect should be better investigated.

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