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Levels and phases of defoliation affect biomass production of pearl millet ADR 300

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The aim of this study was to assess biomass production of pearl millet as a function of levels and phases of defoliation. The experiment was carried out in a protected environment at the Fazenda União experimental farm in the municipality of Nova Xavantina, MT, Brazil, in 8 dm^3 capacity pots in soil classified as dystrophic red Latosol. The experimental design used was randomized blocks in a 5 × 3 + 1 factorial arrangement, with five phases of defoliation (three expanded leaves, six expanded leaves, flag leaf, booting, full flowering), three levels of defoliation (33, 66 and 99%), and an additional treatment without defoliation, with three replications. The pearl millet cultivar ADR 300 was used. Plant height, number of tillers, total dry biomass of the seed heads, and total dry biomass of the plants during the leaf rolling phase was assessed. It was observed that plant height at all levels and phases of defoliation was greater than the control. For number of tillers, a reduction was observed in the booting phase and full flowering phase at all levels of defoliation; and three expanded leaves and flag leaf phases for the levels of 66 and 99% defoliation. Total biomass of the panicle at all levels and phases of defoliation was less than the control. For total dry biomass, there was a statistical difference in relation to the control when the plants were subjected to 33% defoliation in the booting phase and full flowering phase, and 66 and 99% defoliation in all the phases. A fall in production of total dry biomass of the plant greater than 53% was observed with total elimination of the leaves during the flag leaf phase.

Key words: Leaf area, damage level, *Pennisetum glaucum*, no-till planting.

INTRODUCTION

Brazil stands out on the agricultural scene as a producer of soybean, common bean, corn, cotton, and dryland rice. Most of the agricultural areas of these crops are concentrated in the Cerrado (Brazilian tropical savanna) biome. Nevertheless, in Cerrado soils, such as Latosols, Neosols, Argisols, most of the time, fertility is restricted to the surface soil layer, and the loss of organic matter from this layer reduces the productive potential of these soils (Petter et al., 2013). Thus, advances in these areas are ensured with the introduction of the No-Till Planting System (NTP). This management technique has been used especially in the soybean crop.

The NTP is characterized by crop rotation and by allowing crop litter and plant residues to remain on the

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Table 1. Chemical composition of the soil dystrophic red Latosol (0-0.20 m) before setting up the experiment at the Fazenda União experimental, Nova Xavantina, MT, Brazil.

pH $CaCl_2$	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^{+}+Al^{3+}$	SB	CEC	P	K	OM	V
	------------------ $cmol_c\ dm^{-3}$ ------------------						--mg dm^{-3}--		g kg^{-1}	%
5.40	1.14	0.60	0.00	2.90	1.90	4.80	42.00	65.00	6.40	39.70

H + Al: potential acidity; SB: sum of bases; CEC: cation exchange capacity at pH 7.0; OM: organic matter; V: base saturation.

soil surface, which are subsequently turned over only in the crop row for depositing seed and fertilizer (Reis et al., 2007). It is based on four basic requirements: crop rotation, maintaining plant residue on the soil, not turning the soil over, and integrated management of pests and diseases.

In the literature, there are studies on diverse species of cover crops with a view toward biomass production (Pacheco et al., 2008; Torres et al., 2008; Menezes et al., 2009; Pacheco et al., 2011). In these studies, pearl millet [*Pennisetum glaucum*] has been seen as the best crop since it exhibits high biomass production between crop seasons, as well as greater resistance to water deficit (Pacheco et al., 2013; Petter et al., 2013), and it is recommended for growing between crop seasons under low rainfall conditions.

Since pearl millet is a between-season crop for the purpose of creating biomass in this period, there is a lack of interest on the part of farmers in controlling defoliating insects, among which the following stand out: lesser cornstalk borer *(Elasmopalpus lignosellus)*, sugarcane borer *(Diatraea saccharalis)*, fall armyworm *(Spodoptera frugiperda)*, and greenbug *(Schizaphis graminum)*, which may compromise biomass production.

Attacks from defoliating insects directly lead to reduction in photosynthetic area, which may reduce biomass production and also yield. Since the production of photoassimilates arises from the photosynthesis generated by the leaves, any factor that affects leaf area may affect plant development.

Even so, chemical control of defoliating insects should be avoided since this results in environmental pollution and an increase in the final cost of production; therefore, identification of the period(s) of greater crop sensitivity to defoliation arising from the attack of insect pests will result in a decrease in the number of applications of agricultural chemicals and will consequently reduce environmental damages and production costs (Barros et al., 2002).

Studies on this theme have found that defoliation reduces plant development, which directly affects production. These effects have been observed in soybean (Barros et al., 2002; Costa et al., 2003; Zuffo et al., 2015), corn (Alvim et al., 2010), sunflower (Lima Junior et al., 2010), rice (Bertoncello et al., 2011), and sorghum (Fonseca et al., 2013). Nevertheless, there are no studies on the phases and levels of defoliation in the pearl millet crop.

Thus, the aim was to assess biomass production of pearl millet as a function of levels and phases of defoliation.

MATERIALS AND METHODS

The experiment was carried out at the Fazenda União (experimental farm) in the municipality of Nova Xavantina, MT, Brazil (14° 50' 41" latitude South, 52° 22' 49'' longitude West, with a mean altitude of 290 m) in the period from June to August 2013.

The soil used in the experiment was collected in a soybean production area from the 0-0.20 m layer. The following physical characteristics were found in soil analysis: 500, 100, and 400 g kg^{-1} of sand, silt, and clay, respectively. Chemical composition of the soil in the experimental area is shown in Table 1.

Climate in the region is Aw, according to the Köppen global climate classification, with two well-defined seasons: a dry season from May to September and a rainy season from October to April. Climate data were collected at the meteorological station of the Instituto Nacional de Meteorologia – INMET and are shown in Figure 1.

A randomized block experimental design was used in a 5 × 3 + 1 factorial arrangement, with five phases of defoliation [three expanded leaves (10 days after plant emergence - DAE), six expanded leaves (20 DAE), flag leaf (30 DAE), booting (40 DAE), full flowering (50 DAE)], three levels of defoliation [33, 66, 99%], and an additional treatment without defoliation, making for a total of 16 treatments, with three replications. Defoliation was characterized by random removal of leaves from the plant with the aid of a scissors.

The pearl millet was grown in 8 dm^3 capacity pots. Five seeds were sown per pot at a sowing depth of 1 to 2 cm and afterwards thinned, leaving only one plant. The fertilizer applied was 3 g of limestone and 10 g of the formulate NPK 02-20-20 per pot. At 30 DAE, 2.0 g of urea per pot was applied in topdressing. During the time of the experiment, the plants were irrigated daily to replenish water lost through evapotranspiration and to maintain soil field capacity.

During plant development, the following management practice was used: (i) two applications of insecticide, thiamethoxam + lambda-cyhalothrin (Platinum Neo®) at the rate of 200 mL c. p. (commercial product) ha^{-1}, applied at 20 and 45 DAE; ii) one application of fungicide pyraclostrobin + epoxiconazole (Opera®) at the rate of 500 mL c. p. ha^{-1}, applied at 40 DAE. Weeds were removed manually so as to eliminate the effect of weed competition on pearl millet. A CO_2 pressurized backpack sprayer coupled to a spray boom with four XR 110.02 spray nozzles was used for application, applying a volume of the mixture of 200 L ha^{-1}.

In the leaf rolling phase, which is characterized by grain filling and maximum accumulation of dry biomass, the following were determined: a) plant height - determined from the soil surface to the tip of the seed head with the aid of a ruler, in millimeters; b) number

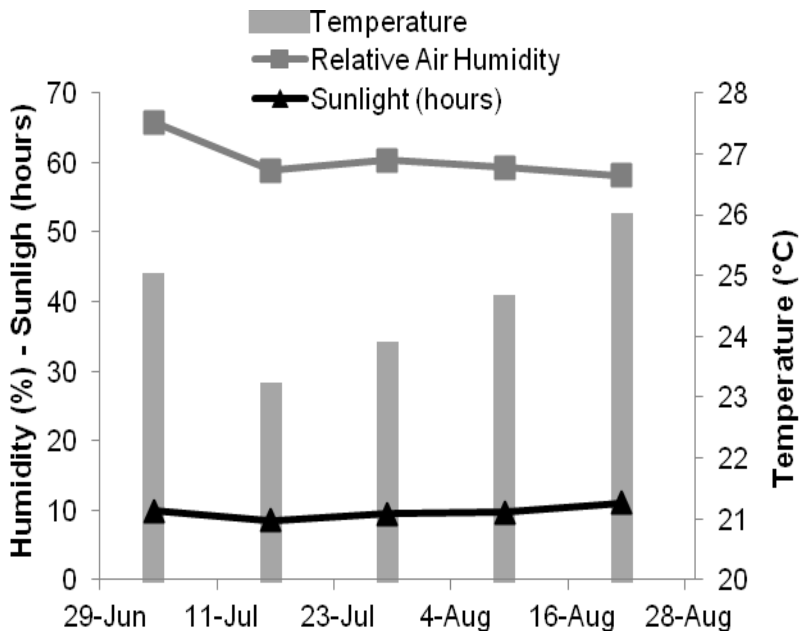

Figure 1. Mean temperature, relative air humidity, and sunlight hours over the period of the experiment (data from INMET – Nova Xavantina station, MT, Brazil).

Table 2. Summary of analysis of variance of the data related to plant height (PH), number of tillers (NT), total dry biomass of the panicle (DBPA), and total dry biomass of the plant (DBPL) obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Sources of variation	DF	Mean squares			
		PH	NT	DBPA	DBPL
		cm	unit	- - - - - - g - - - - - -	
Blocks	2	285.14	6.08	1.49	21.83
Defoliation (D)	2	1472.57**	8.86**	6.92**	4461.74**
Phase (E)	4	578.65*	7.20**	5.54**	1085.45**
D x E	8	118.98^{ns}	0.86^{ns}	0.96^{ns}	386.10**
Factorial *vs* Additional	1	1593.11**	10.51**	132.16**	2526.00**
Treatments	15	520.11**	4.26**	8.99**	1258.67**
Residues	30	192.34	0.92	0.68	64.02
Corrected Total	47				
CV (%)		8.20	17.11	14.59	9.38

** and * significant at the level of 1 and 5% probability by the F test, respectively. ^{ns} – not significant; DF – degree of freedom; CV – coefficient of variation.

of tillers - measured in a manual way in the pot; and c) total dry biomass of the panicle and total dry biomass of the plant, with the aid of a forced air circulation laboratory oven at 60°C for 72 h until obtaining constant weight, and after that the plant residues were weighed on a precision balance (0.001 g).

After collecting and tabulating the data, analysis of variance was carried out of the data obtained in all the parameters evaluated. Comparison of the defoliation treatments and the comparison of each mean value of the defoliation treatment versus the additional treatment (control) were made by the Scott-Knott test at 5% probability. The statistical program Sisvar (Ferreira, 2011) was used to carry out the analyses.

RESULTS AND DISCUSSION

The summary of analysis of variance of the data obtained is shown in Table 2. It may be observed that for plant height (PH), number of tillers (NT), total dry

Table 3. Mean values of plant height obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Plant height - PH (cm)			
Three expanded leaves	194.50*	162.00	158.66	171.72^{B}
Six expanded leaves	192.33*	184.00*	175.66*	184.00^{A}
Flag leaf	179.00*	164.00	162.33	168.44^{B}
Booting	173.00*	169.33	165.33	169.22^{B}
Full flowering	172.00*	161.33	153.16	162.16^{B}
Mean	182.16^{a}*	168.13^{b}	163.03^{b}	171.11

In the column, the mean values followed by the same uppercase letter, and, in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (147.33 cm) by the Scott Knott test at 5% probability.

Table 4. Mean values of number of tillers obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Number of tillers - NT (unit)			
Three expanded leaves	7.33	5.33*	4.66*	5.77^{B}
Six expanded leaves	8.33	6.66	6.33	7.11^{A}
Flag leaf	6.33	5.66*	5.33*	5.77^{B}
Booting	6.00*	4.66*	5.33*	5.33^{B}
Full flowering	5.00*	5.00*	4.00*	4.66^{B}
Mean	6.60^{a}*	5.46^{b}*	5.13^{b}*	5.73

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (7.66 cm) by the Scott Knott test at 5% probability.

biomass of the panicle (DBPA), and total dry biomass of the plant (DBPL), there was a significant effect of the phases and of the levels of defoliation applied. Significant interaction between both factors occurred for total dry biomass of the plant. With the exception of the parameter of total dry biomass of the plant, the parameters led to an isolated study of the level and phase factors of defoliation.

The mean values of the data obtained for plant height may be seen in Table 3. In general, it was observed that plant heights at all levels and phases of development were greater than the control. There was a significant effect at the lowest level of defoliation and at all levels in the defoliation phase with six expanded leaves. A greater increase in plant height (32.01 and 30.54% in relation to the control) was observed when the plants were defoliated at 33% in the initial phases of three and six expanded leaves, respectively. It is clearly shown that when defoliation is performed, the remaining leaves promote a compensatory effect in which they are able to produce photoassimilates and redistribute them in such a way that the plant develops.

Although, the defoliation levels promote greater plant height, upon analyzing the number of tillers, a different behavior was observed. Upon comparing all the defoliation treatments to the control, significant change was seen in the number of tillers for the booting phase and full flowering phase at all levels of defoliation; and three expanded leaves and flag leaf phases for the levels of 66 and 99% defoliation (Table 4). Such a response may have occurred as a result of the leaves concentrating the structures of the plants with a greater active photosynthetic rate, which may confer a greater amount of photoassimilates accumulated during the cycle (Taiz and Zeigler, 2009).

Defoliation limits the capturing of solar radiation and production of photoassimilates; thus, there is a decline in development of new tillers. Tillering is considered to be an advantageous characteristic because it is directly related to the number of stalks. For Sodré Filho et al. (2004), around 40% of the biomass accumulated in pearl millet is found in the stalk, which is formed by more

Table 5. Mean values of total dry biomass of the panicles obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Total dry biomass of the panicles - DBPA (g)			
Three expanded leaves	5.84*	5.23*	4.52*	5.20^{B}
Six expanded leaves	6.61*	6.72*	5.90*	6.41^{A}
Flag leaf	8.13*	5.62*	6.08*	6.61^{A}
Booting	5.89*	5.52*	5.24*	5.55^{B}
Full flowering	5.66*	5.04*	3.63*	4.78^{B}
Mean	6.42^{a}*	5.63^{b}*	5.07^{b}*	5.71

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (11.40 g) by the Scott Knott test at 5% probability.

Table 6. Mean values of total dry biomass of the plant obtained in the trial of levels and phases of defoliation in pearl millet ADR 300. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)			Mean value
	33	66	99	
	Total dry biomass of the plant - DBPL (g)			
Three expanded leaves	108.00^{Aa}	97.45^{Aa}*	81.45^{Ab}*	95.63
Six expanded leaves	119.42^{Aa}	93.13^{Ab}*	84.98^{Ab}*	99.18
Flag leaf	121.34^{Aa}	69.33^{Bb}*	53.87^{Bc}*	81.51
Booting	94.27Ba*	79.69^{Bb}*	65.41^{Bc}*	79.79
Full flowering	79.67Ca*	73.92^{Ba}*	66.79^{Ba}*	73.46
Mean	104.54	82.70*	70.50*	85.91

In the column, the mean values followed by the same uppercase letter, and in the row, by the same lowercase letter, belong to the same group by the Scott Knott test at 5% probability. * Mean values statistically different from the mean value of the control without defoliation (115.88 g) by the Scott Knott test at 5% probability.

lignified tissues and a greater C/N ratio compared to the other structures of the plant. That way, the greater the number of tillers, the slower the decomposition rate of the straw, resulting in longevity of the residues in establishing the NTP. In addition, the tillers may act as suppliers of photoassimilates in a situation of deficiency of the source, brought about by defoliation of the main stalk, as reported by Pasuquin et al. (2008) in irrigated rice and Sangoi et al. (2012) in corn.

In general, it was observed that there was a significant effect for total dry biomass of the panicle at all levels and phases of defoliation, and the mean values were less than those obtained in the control (Table 5). Total dry biomass of the panicle is directly related to production of the pearl millet crop; thus, any level and phase of defoliation affects pearl millet production. Reduction in pearl millet yield (hybrid GHB-30 and MH-179) as a function of the level of defoliation was seen by Josshi et al. (2003). The authors report that removal of a single leaf at the upper part of the stem significantly changed grain production.

Although, pearl millet yield was not assessed in the present study (because of the destruction of the plants for data collection), it may be inferred that as a result of the effects of defoliation in any phenological phase and based on the results of research (Josshi et al., 2003; Fonseca et al., 2014) that deals with the correlation of such characteristics with productive capacity, defoliation results in a decline in pearl millet yield.

For total dry biomass, when the plants were subjected to 33% defoliation in the booting phase and full flowering phase, and 66 and 99% defoliation in all the phases, there was statistical difference in relation to the control (Table 6). These results are partially the same as those obtained by Fonseca et al. (2014); upon studying levels of artificial defoliation in millet, they concluded that only defoliation of 100% in the ED1 (third visible sheet) phase was less than the other levels of defoliation.

The results may be related to a compensatory effect of the remaining leaves; however, the quantity of the photoassimilates is limited, especially in all the reproductive phases and at the defoliation levels of 66

Table 7. Percentage variation of total dry biomass of the plant in relation to the control without defoliation in pearl millet ADR 300, subjected to defoliation levels of 33, 66, and 99% in five phases of defoliation, grown in a greenhouse. Nova Xavantina, MT, Brazil, 2013.

Phases of defoliation	Levels of defoliation (%)		
	33	66	99
	Total dry biomass of the plant - DBPL (g)		
Three expanded leaves	- 6.80	- 15.90*	- 29.71*
Six expanded leaves	+ 3.05	- 19.63*	- 26.66*
Flag leaf	+ 4.71	- 40.17*	- 53.51*
Booting	- 18.64*	- 31.23*	- 43.55*
Full flowering	- 31.24*	- 36.20*	- 42.36*

* Mean values statistically different from the mean value of the control without defoliation according to the mean values shown in Table 6.

and 99%.

Defoliations carried out in all the reproductive phases and at the defoliation levels of 66 and 99% led to reduction in grain production, as seen in the data on percentage variation in total dry biomass of the plant, and of the phases and levels of the defoliation treatments in relation to the control (Table 7).

In general, a greater reduction in total dry biomass of the plant, around 53.51% in relation to the control, was seen when the plants were in the flag leaf phase and were totally subjected to defoliation, underscoring the lower biomass production because this treatment reduces the number of tillers and the total dry biomass of the panicle (Table 4 and 5, respectively). Dry biomass of the plant is correlated to the production of photoassimilates during photosynthesis. Therefore, photosynthetic efficiency in transformation of solar radiation intercepted and transformed into dry biomass (Casaroli et al., 2007) is highly dependent on leaf area (Alcântara Neto et al., 2011). Thus, damages brought about in leaves impede photosynthetic activity (Mondo et al., 2009).

Therefore, defoliation at any level and phase favors plant height. In contrast, it limits the number of tillers and total dry biomass of the plants in all the reproductive phases and at 66 and 99% defoliation levels. However, for the parameter that is directly related to the total dry biomass of the panicle, all the levels and phases of defoliation affected biomass production of pearl millet ADR 300.

According to the results, it is possible to see that small levels of defoliation in the initial phases of plant development of pearl millet do not reduce the total biomass production of the plant, probably because there is an increase in photosynthetic yield brought about by greater penetration of light into the lower layers of the plant. Therefore, there is no need for control in this condition. However, in relation to grain yield, further studies should be undertaken so as to clarify if the trends of decline in the production components found in the present study correlate with plants sown under field conditions.

In light of the results obtained, the different levels and phases of defoliation have a significant effect on all the parameters studied. The total dry biomass of the panicle is reduced when subjected to any level and phase of defoliation. The greatest reduction in production of total dry biomass is observed from the total elimination of leaves in the flag leaf phase.

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Conflict of Interest

The author(s) have not declared any conflict of interests.

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