Biomass yield in production systems of soybean sown in succession to annual crops and cover crops

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Abstract – The objective of this work was to evaluate the biomass (leaves and stems) production of annual and cover crops sown as second crop, and its effects on soybean yield in succession. The experiment was carried out in the 2014/2015 and 2015/2016 crop seasons. Soybean was sown in the crop season and in the second crop, in a randomized complete block design, in nine production systems (treatments) consisting of annual crops (corn, sunflower, and cowpea) and cover crops (*Pennisetum glaucum*, *Crotalaria breviflora*, *C. spectabilis*, *Urochloa ruziziensis*, *Cajanus cajan*, *Stylosanthes* sp., and *U. brizantha*), which were grown in monocropping or intercropping systems, besides fallow as a control. Monocropped *P. glaucum* and *U. ruziziensis* showed a faster establishment and growth of plants, higher-total biomass and soil cover rate in the 2014 crop season. In 2015, corn intercropped with *U. ruziziensis* and *C. spectabilis*, and sunflower with *U. ruziziensis* stood out for total biomass production during flowering and after harvesting of corn and sunflower grains. Biomass composition in the systems showed greater proportions of stems than of leaves, and *C. spectabilis* stood out after senescence. Sown as a second crop, *C. spectabilis* promotes yield increase of soybean grown in succession in the no-tillage system.

Index terms: grain yield, no-tillage, off-season.

Produção de fitomassa em sistemas de produção de soja em sucessão a culturas e plantas de cobertura

Resumo – O objetivo deste trabalho foi avaliar a produção de fitomassa (folhas e caules) de culturas anuais e plantas de cobertura semeadas em safrinha e seus efeitos na produtividade da soja em sucessão. O experimento foi conduzido nas safras de 2014/2015 e 2015/2016. A soja foi semeada nas safras e nas safrinhas, em delineamento de blocos ao acaso, em nove sistemas de produção (tratamentos) constituídos de culturas anuais (milho, girassol e feijão-caupi) e plantas de cobertura (*Pennisetum glaucum*, *Crotalaria breviflora*, *C. spectabilis*, *Urochloa ruziziensis*, *Cajanus cajan*, *Stylosanthes* sp. e *U. brizantha*), em cultivos solteiros ou consorciados, além de pousio como controle. Os cultivos solteiros de *P. glaucum* e *U. ruziziensis* apresentaram estabelecimento e crescimento mais rápido, maior fitomassa total e taxa de cobertura do solo na safra de 2014. Em 2015, o milho consorciado com *U. ruziziensis* e *C. spectabilis*, e o girassol com *U. ruziziensis* se destacaram na produção de fitomassa total, durante o florescimento e após a colheita dos grãos do milho e do girassol. A composição das fitomassas nos sistemas apresentou maiores proporções de caules do que de folhas, com destaque para *C. spectabilis* após a senescência. Semeada em safrinha, *C. spectabilis* promove aumento de produtividade de soja em sucessão, no sistema plantio direto.

Termos para indexação: produtividade de grãos, plantio direto, safrinha.

Introduction

Agricultural systems with soybean crops in Midwestern Brazil, in the Cerrado region, have contributed to the production of 99 million tonnes of grains every year, which has consolidated Brazil as the second largest grain producer worldwide (Acompanhamento…, 2016). Mato Grosso state, Brazil, stands out for showing the largest area of planted soybean (9.1 million hectares), and for being the region with the highest-soybean production (28 million tonnes) (Acompanhamento…, 2016).

Oxisols and Quartzarenic Entisols are the predominant soil classes in the Cerrado region, which require the use of management systems that favor the increase of organic matter in the soil (Pragana et al., 2012). Therefore, the no-tillage farming system (NTS) has been recommended, in order to improve the chemical, physical, and biological fertility of soil by the sowing of annual crops and soil cover crops after soybean harvest (Carneiro et al., 2008). One of the greatest challenges in the use of this system in soybean crop areas is the assessment of option for the sowings of species that may favor biomass production and allow of increased soybean yield in succession planting. In addition, considering that the succession planting of soybean in the crop season, and corn in the off-season, has been the production model in these regions, for economic reasons and because of the available infrastructure (Calegari, 2002), it is important to evaluate intercropping systems between annual grain-yielding crops and soil-cover plant species that produce biomass to promote the wide-spreading use of these systems.

Grasses such as *U. ruziziensis* and *U. brizantha* are species that can produce high amounts of biomass; besides, they decompose slowly and are resistant to water stress (Pacheco et al., 2011), which makes them potential cultures to be used in production systems between harvests in the Cerrado region. The use of legumes to promote soil fertility and soybean yield in succession planting needs to be investigated (Araújo et al., 2015). Carvalho et al. (2015) detected 93.74 and 91.02 kg ha^{-1} N, in the biomass of *Mucuna pruriens* and *Crotalaria juncea*, respectively, that could be incorporated into the system. In addition, the use of soil cover crops intercropped with grain crops – such as corn and sunflower – may favor the diversification of cultures sown as the second crop in soybean production systems, and result in higher production efficiency and in biomass quality added to the soil.

Some studies have highlighted that only high-biomass production may not result in increased soybean yield (Brancalião et al., 2015). In the literature, there is a lack of results for the effects of annual cultures and soil cover crops on biomass production and grain yield during the second crop season. In addition, little is known about the biomass allocation in the stems and leaves of soil cover crops, a fact that may be important when evaluating biomass quality and understanding the dynamics of its decomposition and release of nutrients to soybean crop in succession.

The objective of this work was to evaluate the biomass (leaves and stems) production of annual and cover crops sown as second crop, and its effects on soybean yield in succession.

Materials and Methods

The experiment was conducted in the 2014/2015 and 2015/2016 crop seasons, at the experimental station of Universidade Federal de Mato Grosso, at the university campus in Rondonópolis, MT, at 16°27'41.75"S, 54°34'52.55"W, and 292 m altitude. The local soil is a Latossolo Vermelho distrófico (Oxisol) Santos et al. (2006) with a flat soil surface, and it was previously occupied by a native vegetation of the Cerrado region. According to the Köppen-Geiger's classification, the local climate is Aw – tropical climate with dry winter season. Precipitation and average maximum and minimum temperatures during the study period are presented in Figure 1.

Previously to the experiment, the area was cleaned, which was followed by plowing and harrowing, and roots were manually removed. Soil sampling was performed for chemical and textural characterization (Table 1). On October 8, 2013, liming (4,000 kg ha^{-1}) was performed with limestone filler (PRNT: 99.02%) using a leveling disc harrow.

A randomized complete block experimental design was carried out with nine production systems (treatments), and four replicates. Soybean was cultivated in all production systems in the crop season (November to March), in the two agricultural years. After harvest, when second crop period (late March to October) begun, the following species were cultivated: annual grain cultures, as corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), and cowpea (*Vigna unguiculata*); and the soil cover crops *Pennisetum glaucum*, *U. ruziziensis*, and *U. brizantha* – of the *Poaceae* family, and *C. breviflora*, *C. spectabilis*, *Cajanus cajan*, *Stylosanthes capitata* and *S. macrocephala* – of the *Fabaceae* family. Some soil cover crops were used as single crops, and others were intercropped with annual cultures, as indicated in Table 2. Some treatments (S4, S7, S8, and S9) consisted of cropping rotation of species sown between the second crops in 2014 and 2015. The treatments in fallow (S1 and S2) were the controls. Each study unit was 7 m wide and 9 m long. Sowing of second crops was performed in furrows of 0.45 m spacing between the lines.

In November 2013, soybean for the 2013/2014 crop season was sown with a tractor and fertilizer-sower using the conventional soil preparation system (CP). Soybean was harvested on February 18, 2014, and soon after, the second crop for 2014 was sown (Table 2). On October 27, 2014, all production systems were desiccated using glyphosate (1,920 g a.i. ha^{-1}), and then, soybean was sown again for the 2014/2015 crop season in all systems, using the no-tillage farming system or conventional preparation system. The soybean harvest of 2014/2015 occurred on 3/2/2015 and, subsequently, the second crops were sown. On September, 22, 2015, the area was desiccated in all systems, except for those with *U. ruziziensis*, in which desiccation occurred 30 days before the other systems, only for the 2015/2016 crop season. Soybean was sown on 10/29/2015, in the 2015/2016 growing season, and it was harvested on 2/16/2016.

The soybean cultivar used for the 2013/2014 and 2014/2015 crop season was ANTA 82 RR and, for the 2015/2016 crop season, TMG 1179 RR; both cultivars were sown in 0.45 m spacing between lines, with a population of 400,000 plants per hectare. Soybean in the three harvests was fertilized using 120 kg ha^{-1} P_2O_5, and 22 kg ha^{-1} N, via monoammonium phosphate in the sowing furrow, and 100 kg ha^{-1} K_2O via potassium chloride, half of which was casted during the pre-sowing, and the remainder was applied on soybean at the V_4 phenological stage. In the 2014/2015 and 2015/2016 crop season, soybean was sown using the no-tillage farming system in all production systems, except for soybean with fallow in

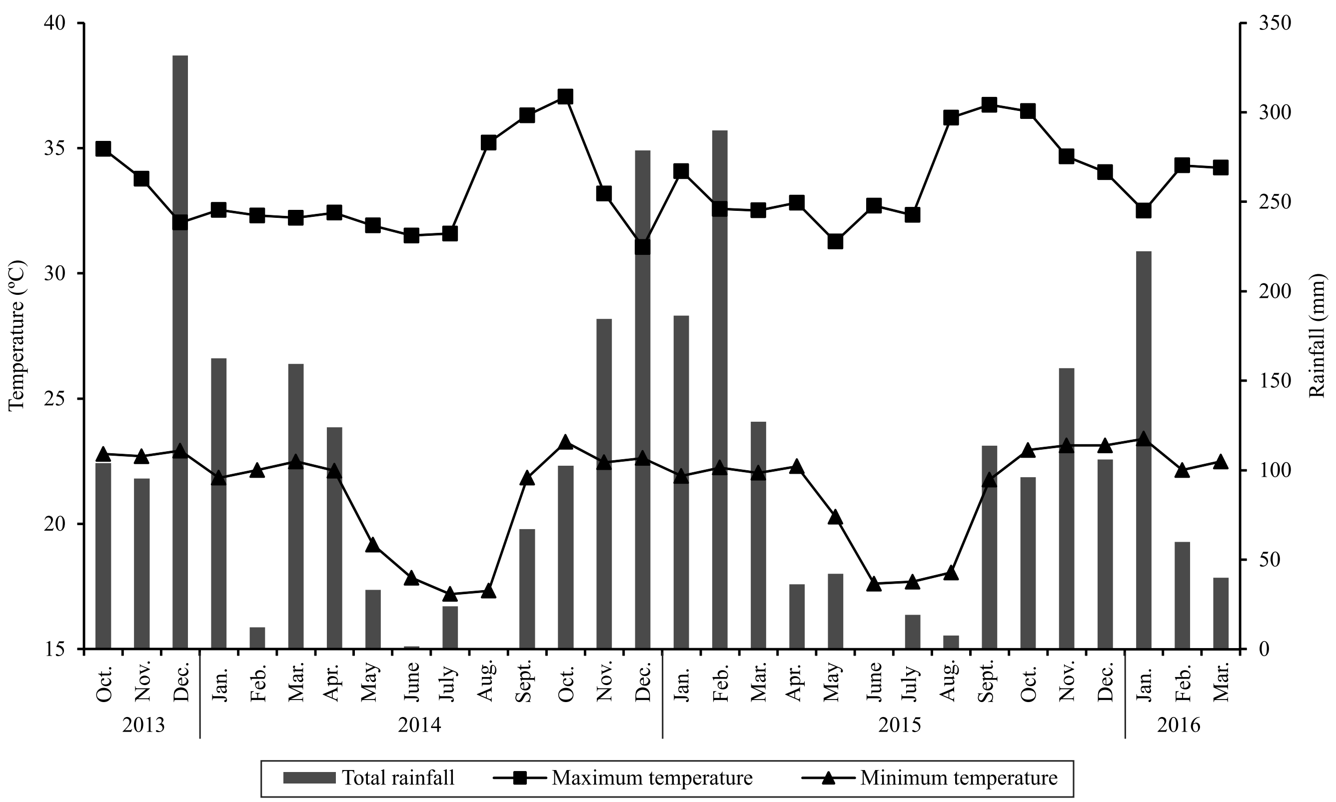

Figure 1. Monthly precipitation, and minimum and maximum air temperatures during the experiment conduction, in Rondonópolis, MT, Brazil.

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CP, in which the plot was subjected to two plowings (for leveling and harrowing) 30 days before sowing. For the annual cultures sown as second crops (corn, cowpea beans, and sunflower), fertilization was done according to the recommendations of Sousa & Lobato (2004), while for the soil cover crops, no fertilizer was used. In the intercropping treatments, soil cover crops were manually sown between the lines of the annual cultures, one week after the sowing of the annual crops.

Plant dry matter was evaluated according to Crusciol et al. (2005), and the soil coverage rate promoted by the crops was evaluated according to Sodré Filho et al. (2004). For the second crop in 2014, these evaluations were performed at 60, 90, and 156 days after sowing (DAS). For the second crop in 2015, these evaluations were conducted in the flowering stage (April 2015), and after the grain harvest of the cultures (June to July 2015). The grain yields of soybean and of the cultures sown in second crops were evaluated by sampling from 2 m^2 (kg ha^{-1}), and standardized at 13% humidity.

The following morphophysiological and phytotechnical indices were calculated: grain harvest index (GHI = grain yield / total biomass at flowering), expressed in kg kg^{-1}; use efficiency of the exported biomass to grain yield (UEBY) = [grain yield / (total biomass at flowering - total biomass after senescence)], expressed in kg kg^{-1}; total biomass relation in the intercropping of soil cover crops and annual cultures at flowering (RBCC-F = total biomass of intercropped cover cultures / total biomass of intercropped annual crops); relation of total biomass in the intercropping of soil cover crops and annual cultures after senescence (RBCC-S = total biomass during senescence of soil cover crops / total biomass during senescence of annual cultures); relation between stem and leaf biomass at flowering (RSLB-F = stem biomass at flowering / leaf biomass at flowering); and relation between stem and leaf biomass during senescence (RSLB-S = stem biomass during senescence / leaf biomass during senescence).

The results were subjected to the analysis of variance, and the mean values were compared by the

Table 1. Chemical and textural characteristics of an Oxisol before the installation of the experiment(1).

Depth	pH	P	K	Ca	Mg	H+Al	T	V	MO	Sand	Silt	Clay
(m)	$CaCl_2$	-----(mg dm^{-3})----		---------------(cmol$_c$ dm^{-3})-------------				(%)	-------------------(g kg^{-1})------------------			
0.00-0.10	4.1	5.4	55	0.5	0.2	6.8	7.6	11	17.6	450	125	425
0.10-0.20	4.0	1.4	49	0.2	0.2	7.2	7.6	5.6	19.9	500	100	400
0.20-0.30	4.1	0.2	31	0.3	0.1	6.2	6.7	7.2	13.7	500	100	400

(1)P, available phosphorus (Mehlich 1); exchangeable K^+, Ca^{2+}, and Mg^{2+}; T, cation exchange capacity at pH 7.0; V, base saturation.

Table 2. Characterization of the production systems, with sowing of the 2014 and 2015 off-seasons, after the soybean (*Glycine max*) harvest in the 2013/2014 and 2014/2015 crop seasons, respectively(1).

Off-season 2014	Off-season 2015
S_1: Fallow in NT	S_1: Fallow in NT
S_2: Fallow in CT	S_2: Fallow in CT
S_3: *Crotalaria spectabilis* (15 kg ha^{-1})	S_3: *Crotalaria spectabilis* (15 kg ha^{-1})
S_4: *Stylosanthes capitata+S. macrocephala* (5 kg ha^{-1})	S_4: *Vigna unguiculata* (160.000 plants ha^{-1})
S_5: *Pennisetum glaucum* 'ADR 8010' (18 kg ha^{-1})	S_5: *Pennisetum glaucum* ADR 9010 (18 kg ha^{-1})
S_6: *Urochloa ruziziensis* (15 kg ha^{-1})	S_6: *Urochloa ruziziensis* (15 kg ha^{-1})
S_7: *Cajanus cajan* (40 kg ha^{-1})	S_7: Sunflower (55.000 plants ha^{-1}) + *U. ruziziensis*
S_8: *Crotalaria breviflora* (15 kg ha^{-1})	S_8: Corn (60.000 plants ha^{-1}) + *C. spectabilis*
S_9: *Urochloa brizantha* 'Marandu' (16 kg ha^{-1})	S_9: Corn (60.000 plants ha^{-1}) + *U. ruziziensis*

(1)NT, no-tillage; CT, conventional tillage with the use of harrow + leveling plow.

Scott-Knott's test, at 5% probability, using the software Sisvar, version 4.2 (Ferreira, 2008).

Results and Discussion

The production systems affected the amount of dry matter (DM) produced and soil cover rate at 60, 90, and 156 DAS after the second crop sowing, in 2014 (Table 3). In the beginning of the period between harvests (60 DAS), the systems with *P. glaucum* and *U. ruziziensis* showed setting and faster growth than the other soil cover crop species, resulting in higher DM during this period. However, *P. glaucum* showed a reduced DM on the soil surface at 90 and 156 DAS, possibly due to its short phenological cycle and the start of the decomposition of its residues. *U. ruziziensis* showed an increased DM at 156 DAS due to its perennial growth habit and regrowth after rain, which occurred in July and allowed of the increase of DM until 156 DAS; this helps explain this species potential to promote soil cover with values that reached 100%, at the end of the period between harvests at 156 DAS. These findings were also reported by Pacheco et al. (2011), in studies conducted in the Cerrado region of Goiás state.

Of the two crotalaria species, *C. spectabilis* outstood for the increased DM with approximately 4.0 Mg ha^{-1} at 90 DAS (Table 3). The cover plant *C. breviflora* showed a shorter cycle than *C. spectabilis*, which may be associated with the shorter photoperiod that occurs during the second crop, leading to a stronger induction of plant flowering and reduced potential to accumulate DM at that time (Menezes & Leandro, 2004).

The species *C. cajan* promoted DM accumulation above 6.0 Mg ha^{-1} and increased the soil cover rate to 75% at 156 DAS (Table 3). Similar results were obtained by Pereira et al. (2012). According to Pacheco et al. (2011), this species shows slow initial growth; however, rainfalls occurring between harvests (July) are sufficient for the regrowth and for the plant DM accumulation until the end of the period between

Table 3. Phytomass production and soil cover rate promoted by the plants sown in the off-season, after the soybean (*Glycine max*) harvest in 2013/2014[(1)].

Production system	Harvest (DAS)		
	60	90	156
	Biomass (kg ha^{-1})		
S_1: Fallow in NT	2,200C	2,575C	1,062D
S_2: Fallow in CT	2,250C	1,945D	943D
S_3: *Crotalaria spectabilis*	2,900C	4,175B	3,244C
S_4: *Stylosanthes capitata* + *S. macrocephala*	1,925C	1,960D	2,498C
S_5: *Pennisetum glaucum*	6,550A	3,905B	3,737B
S_6: *Urochloa ruziziensis*	5,850A	5,561A	7,852A
S_7: *Cajanus cajan*	3,900B	4,293B	6,110B
S_8: *Crotalaria breviflora*	3,300B	3,003C	3,248B
S_9: *Urochloa brizantha*	3,200B	3,083C	5,315B
Coefficient of variation (%)	16.62	16.58	17.33
	Soil cover rate (%)		
S_1: Fallow in NT	66.1B	63.2B	30.5E
S_2: Fallow in CT	66.1B	60.6B	24.8E
S_3: *Crotalaria spectabilis*	74.8B	72.2B	41.6D
S_4: *Stylosanthes capitata* + *S. macrocephala*	55.5B	63.5B	55.3C
S_5: *Pennisetum glaucum*	69.4B	72.0B	58.3C
S_6: *Urochloa ruziziensis*	91.6A	94.4A	100.0A
S_7: *Cajanus cajan*	79.8A	70.0B	74.9B
S_8: *Crotalaria breviflora*	80.5A	69.4B	55.5C
S_9: *Urochloa brizantha*	83.3A	80.4A	80.5B
Coefficient of variation (%)	16.38	15.02	15.60

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott´s test, at 5% probability. DAS, days after the sowing in the 2014 off-season, held after the soybean harvest in the 2013/2014 crop season.

harvests because of the presence of vegetative buds on the stems of *C. cajan*.

Effects of the production systems were observed on the stem dry matter (SDM), leaf dry matter (LDM), and total dry matter (TDM) of the cultures sown for the second crop in 2015 (Figure 2). In the full flowering stage, the production systems of corn intercropped with *U. ruziziensis* and *C. spectabilis* showed the highest accumulation of SDM, LDM and TDM, with values close to 9.0 Mg ha^{-1}, 5.0 Mg ha^{-1}, and 14.0 Mg ha^{-1}, respectively. Similar results were obtained by Pereira et al. (2012), who reported an overall mean value of 10.4 Mg ha^{-1} DM for *C. spectabilis*, and by Torres et al. (2008), who obtained 10.3 Mg ha^{-1} DM with millet in 2000, in a study conducted in the municipality Uberaba, MG, Brazil.

After grain senescence and harvest, the corn plants showed the highest reductions (almost 50%) of the remaining dry matter, in comparison with the accumulation at flowering. These results are explained by the high production of grains – of over 8.0 Mg ha^{-1} (Table 4) –, which resulted in a significant export rate of biomass photoassimilates to the grains.

It should be noted that, in the evaluations performed during the full flowering period, the soil cover crops intercropped with corn did not significantly contribute to DM accumulation. However, the analysis of SDM, LDM, and TDM during corn senescence and grain harvest (Table 3), and the relation of total biomass in soil cover crops intercropped with the annual cultures after senescence (RBCC-S) (Table 4), showed that *U. ruziziensis* and *C. spectabilis* intercropped with corn have contributed significantly to the production of biomass due to the resumed development of the plants, favored by the solar radiation and final summer rains after corn senescence, which reinforces the findings reported by Pacheco et al. (2013).

Sunflower intercropped with *U. ruziziensis* showed intermediate results for LDM, SDM, and TDM at the full flowering, with values of 7.7 Mg ha^{-1}, 4.1 Mg ha^{-1}, and 11.0 Mg ha^{-1}, respectively (Figure 2). A significant result was observed for biomass, during the period after sunflower grain harvest, which practically showed no reduction in the values. Sunflower had low rates of photoassimilate exsport to the grains, which can be confirmed by the value of use efficiency (0.95) of biomass exported to grain yield (UEBY) (Table 4). This occurs because only a small portion of nutrients is exported to the grains, causing nutrient retention in the plant aerial parts, and allowing the fast cycling and availability of nutrients to subsequent cultures (Silva & Oliveira, 2011).

As for the single cultivations of soil cover crops, *P. glaucum, U. ruziziensis*, and *C. spectabilis* showed important results. *P. glaucum* had TDM values at flowering close to 8.0 Mg ha^{-1} (Figure 2). Similar values were obtained by Pacheco et al. (2011) with a single cultivation of *P. glaucum* that showed higher SDM than LDM (RSLB-F, Table 4), which make this crop interesting, as its stems show greater recalcitrance for decomposition, and as it can minimize the biomass loss in the no-tillage farming system of soybean in succession cropping (Torres & Pereira, 2014). However, plant residues with high recalcitrance to the physical and microbiological mineralization process result in a lower rate of nutrient release to the soil.

After the harvest of *P. glaucum* grains, a reduction of 25% was observed in TDM in relation to that observed at the full flowering of the plants. However, the 'ADR 9010' hybrid grain yield (2,586 kg ha^{-1}) resulted in the highest mean value of UEBY (1.97). As no fertilizer was used during sowing, and due to the high potential of the *P. glaucum* root system to explore deeper soil depths and absorb nutrients (Teixeira et al., 2012), this species is an alternative to increase efficiency in the use of nutrients in soybean production systems.

U. ruziziensis cultivated as single crop had no plant flowering, which is showed by the increase of SDM, LDM, and TDM, in the evaluations conducted during the full flowering period and after the grain harvest in the other production systems. The explanation for this fact is the time of sowing that did not favor the flowering and fruiting of *U. ruziziensis* plants. In addition, it should be noted that this species showed an RSLB-S of 2.1 (Table 4), and that its stems are not woody, which explains the high rate of decomposition and release of nutrients after desiccation (Pacheco et al., 2013; Rossi et al., 2013).

The single cultivation of *C. spectabilis* for the second crop in 2015 showed TDM (4.0 Mg ha^{-1} similar to that of the year before (Figure 2). Souza et al. (2008) found values above 8.0 Mg ha^{-1} for this species that stood out among the evaluated legumes by the author. After senescence, no TDM reduction was observed for full flowering, which can be explained by the low-grain

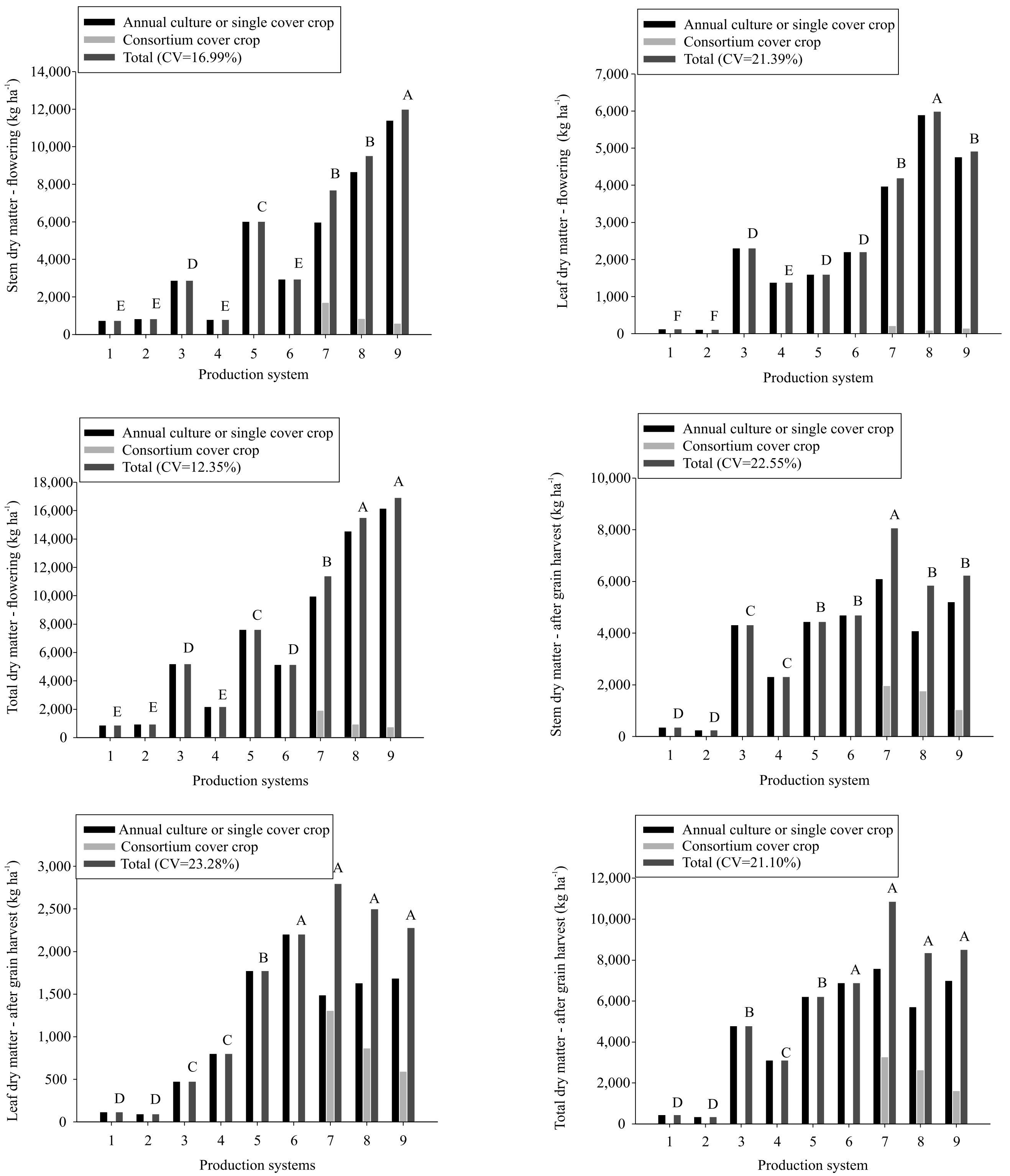

Figure 2. Dry matter production (stems, leaves, and total) in the off-season, after the harvest of soybean (*Glycine max*) in the 2014/2015 crop season, measured during flowering and after grain harvest. Systems: 1, fallow NT; 2, fallow CT; 3, *Crotalaria spectabilis*; 4, cowpea (*Vigna unguiculata*); 5, *Pennisetum glaucum*; 6, *Urochloa ruziziensis*; 7, sunflower (*Helianthus annuus*) and *U. ruziziensis*; 8, corn (*Zea mays*) and *C. spectabilis*; and 9, corn (*Z. mays*) and *U. ruziziensis*. Means followed by equal letters on the bars, do not differ, by the Scott-Knott's test, at 5% probability.

production of 4.0 kg ha^{-1} (Table 4). In addition, when analyzing the constituents of TDM, this species showed an RSLB-S above 9 during plant senescence. These results are explained by the fact that this species shows woody stems with high recalcitrance, and that senescent leaves that were on the soil surface quickly started the decomposition process during plant senescence.

The system that used cowpea and *Stylosanthes* sp. showed low production of biomass for the second crops in 2014 and 2015 (Figure 2). Cowpea plants showed fast initial growth, but with a short phenological cycle, resulting in unsatisfactory biomass yield and soil cover rate. *Stylosanthes* sp. plants showed slow initial growth, which did not allow their use for biomass yield in the second crop. Another negative factor of this species was the difficult control with herbicides used in desiccation, which led to a significant regrowing during soybean grown in succession planting. The low-biomass production of *Stylosanthes* sp. was also observed by Dantas et al. (2015), with DM amount of 97.5 kg ha^{-1}, which was a disadvantage in comparison to the other species.

Regarding soybean grain yield, a significant effect of the production systems was observed only in the 2015/2016 crop season (Table 5). The occurrence of short dry periods (named "veranicos"), in February 2016 (2015/2016 crop), and the effects of the systems over time are factors that may have contributed to statistical differences between the mean values of soybean yield, as reported by Fietz & Urchei (2002). The production systems with the inclusion of *Crotalaria* sp. favored the increase of soybean yield, evidenced by *C. spectabilis* yield in single crop systems in the 2014/2015 and 2015/2016 harvests, and in system 4 (*C. breviflora*/corn + *C. spectabilis*) for the 2014/2015 crop (Table 5). Santos et al. (2010) reported a significant increase of corn yield in succession to *C. spectabilis* (8.105 Mg ha^{-1}) in comparison to the control (spontaneous vegetation) (3.710 Mg ha^{-1}).

Despite the high efficiency in biological nitrogen fixation of soybean, significant effects on soil quality can be attributed to the use of *Crotalaria* sp. in the soybean succession system (Table 5). According to Brancalião et al. (2015), soybean may positively respond to the N availability during the initial stages of growth, as the soybean–*Bradyrhizobium* interaction process is consolidated only 15 days after emergence. Carneiro et al. (2008) observed that soil cover crops associated with crop rotation have positive effects on soil fertility, favoring microbial activity, organic matter incorporation in the soil, and crop productivity.

Fallow (S1 and S2) showed the lower mean values of grain yield, highlighting the 2015/2016 crop, when trial duration and lower-than-average rainfalls intensified these effects. It should be noted that, in fallow, soil inversion favored the initial growth of soybean plants, which can be explained by the oxidation effect of organic matter that momentarily increases the availability of nutrients in the soil solution (Souza et al., 2008). However, these long-term effects may result in reduced organic matter associated with the colloidal and

Table 4. Morphological and phytophysiological indices of the crops sown in the 2015 soybean (*Glycine max*) production system, for the 2014/2015 crop season[(1)].

Production system	Grain yield (kg ha^{-1})	GHI (kg grain per kg total dry matter at flowering)	UEBY (kg grain per kg exported biomass)	RBCC-F	RBCC-S	RSLB-F	RSLB-S
S_1: Fallow in NT	-	-	-	-	-	6.44A	4.15B
S_2: Fallow in CT	-	-	-	-	-	8.07A	2.67B
S_3: *Crotalaria spectabilis*	3.95	0.01D	0.06C	-	-	1.25B	9.47A
S_4: *Vigna unguiculata*	825.66	0.26B	-	-	-	0.57B	2.88B
S_5: *Pennisetum glaucum*	2,586.48	0.25B	1.97A	-	-	3.79B	2.51B
S_6: *Urochloa ruziziensis*	-	-	-	-	-	1.34B	2.10B
S_7: Sunflower + *U. ruziziensis*	2,247.90	0.18C	0.95B	0.19A	0.44A	1.86B	2.87B
S_8: Corn + *C. spectabilis*	8,306.49	0.36A	0.94B	0.06B	0.48A	1.60B	2.36B
S_9: Corn + *U. ruziziensis*	8,579.99	0.34A	0.93B	0.04C	0.23B	2.60B	2.74B
Coefficient of variation (%)	15.19	31.21	32.36	31.12	30.05	33.04	31.40

[(1)]Means followed by equal letters, in the columns, do not differ from each other by the Scott-Knott's test, at 5% probability. GHI, grain harvest index; UEBY, use efficiency of biomass exported to grain yield; RBCC-F, relation between total biomass in the intercropping of soil cover crops and annual cultures at flowering; RBCC-S, relation of total phytomass in the intercropping of soil cover crops and annual cultures after senescence; RSLB-F, relation between stem and leaf biomass at flowering; RSLB-S, relation between stem and leaf biomass during senescence.

Table 5. Grain yield of soybean (*Glycine max*) grown in the 2014/2015 and 2015/2016 crop seasons, in succession planting to annual cultures and cover crops sown in the off-seasons in nine production systems[1].

Production system	Soybean yield (kg ha^{-1})	
	2014/2015 crop season	2015/2016 crop season
S_1: Soybean-Fallow NT/ Soybean-Fallow NT	2,763^{ns}	1,889C
S_2: Soybean-Fallow CT/ Soybean-Fallow CT	2,837	2,276B
S_3: Soybean-*Crotalaria spectabilis*/ Soybean -*Crotalaria spectabilis*	4,059	2,686A
S_4: Soybean -*Stylosantes capitata + S. macrocephala*/ Soybean -*Vigna unguiculata*	3,170	2,425B
S_5: Soybean -*Pennisetum glaucum*/ Soybean -*P. glaucum*	3,349	2,347B
S_6: Soybean -*Urochloa ruziziensis*/ Soybean -*U. ruziziensis*	3,373	2,273B
S_7: Soybean -*Cajanus cajan*/ Soybean -Sunflower+*U. ruziziensis*	3,660	2,301B
S_8: Soybean -*Crotalaria breviflora*/ Soybean -Corn+*Crotalaria spectabilis*	4,054	2,155B
S_9: Soybean -*U. brizantha*/ Soybean - Corn+*Crotalaria spectabilis*	2,560	2,051C
Coefficient of variation (%)	24.26	7.67

[1]Means followed by equal letters, in the columns, do not differ by the Scott-Knott's test, at 5% probability. ^{ns}Nonsignificant by the F-test, at 5% probability.

microbial phases of soil which are essential indicators of soil quality in today's agricultural systems.

Conclusions

1. *Pennisetum glaucum* in a single cultivation, and *Urochloa ruziziensis* and *Crotalaria spectabilis* both in single crops or intercropped with corn (*Zea mays*) favor the production of stem, leaf, and total biomass, as well as the soil cover rate in soybean production systems, during the period between harvests, in the Cerrado region of Mato Grosso state, Brazil.
2. Corn intercropped with *U. ruziziensis* and *C. spectabilis* shows the highest reductions of dry matter (stem, leaf and total) between the flowering and senescence stages.
3. Annual cultures and soil cover crops sown in the second crop show higher mass proportions of stem than leaf in their biomass composition, highlighting *C. spectabilis* after senescence.
4. *Pennisetum glaucum* shows the highest efficiency in converting biomass into grain yield during the second crop.
5. *Crotalaria spectabilis* sown in the second crop promotes the grain yield increasing of soybean sown in succession, in the no-tillage farming after three years of this system implementation.

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