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Biomass, nutrient accumulation, and weed suppression by mix of cover crops

Biomassa, acúmulo de nutrientes e supressão de plantas daninhas por mix de plantas de cobertura

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ABSTRACT - Cover crops, isolated or mixed, provide several benefits to agricultural systems, such as nutrient cycling and weed control. The present study aimed to determine the biomass production and nutrient accumulation of a cover crop mix and its effects on weed suppression (biomass production), in the off-season, in a no-tillage area in the Cerrado region. The experimental design was in randomized blocks with six treatments and eight replications. Treatments comprised five cover crop mixes plus the control treatment (fallow). Mixes of cover crops, cultivated between grain harvests in a no-tillage system in the Cerrado region, efficiently reduced weed shoot biomass in the three evaluation periods, 30, 70, and 210 days after sowing. Additionally, it is concluded that the mixes 5 (Black oats, Buckwheat, Millet, Piatã grass, and *Crotalaria ochroleuca*) and 4 (*C. spectabilis*, Buckwheat, Pearl millet, and *Crotalaria breviflora*) are the best among those evaluated for Cerrado conditions because they produce more biomass in the off-season, due to the greater availability of nutrients to the soil, in addition to providing less biomass of weeds compared to fallow.

Keywords: Intercrop. Off-season. Sustainable development. Cerrado.

RESUMO - As plantas de cobertura, isoladas ou em mix, proporcionam diversos benefícios aos sistemas agrícolas, como ciclagem de nutrientes e controle de plantas daninhas. O presente estudo teve como objetivo determinar a produção de biomassa e o acúmulo de nutrientes de mixes de plantas de cobertura e seus efeitos na supressão de plantas daninhas (produção de biomassa), na entressafra, em uma área de plantio direto na região do Cerrado. O delineamento experimental foi em blocos casualizados com seis tratamentos e oito repetições. Os tratamentos consistiram em cinco mix de plantas de cobertura mais o tratamento controle (pousio). Os mixes de plantas de cobertura, cultivadas na entressafra de grãos em sistema plantio direto na região do Cerrado, reduziram eficientemente a biomassa da parte aérea das plantas daninhas nos três períodos de avaliação, 30, 70 e 210 dias após a semeadura. Adicionalmente, conclui-se que os mixes 5 (Aveia preta, Trigo mourisco, Milheto, Capim Piatã e *Crotalaria ochroleuca*) e 4 (*C. spectabilis*, Trigo mourisco, Milheto e *Crotalaria breviflora*) são os melhores dentre os avaliados para condições de Cerrado, pois produzem mais biomassa na entressafra, devido à maior disponibilidade de nutrientes ao solo, além de proporcionarem menor biomassa de plantas daninhas em comparação ao pousio.

Palavras-chave: Consórcio. Entressafra. Desenvolvimento sustentável. Cerrado.

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INTRODUCTION

In the Brazilian Cerrado region, agricultural areas with a rainy period of less than six months normally carry out only one crop per year. The areas remain fallow until the next harvest. In this way, the existing species flourish and produce seeds and, therefore, the incidence of weeds in these areas can be high, leading to an increase in the seed bank in the soil and contributing to the infestation of these plants in the next crop (REDIN et al., 2022). In addition, low vegetation cover on the land can cause the loss of nutrients by fixation, surface carry-over, leaching, and volatilization, which can significantly affect crop yield (CARVALHO et al., 2022).

Given this, the adoption of a cultivation system, such as the no-tillage system (NTS), with the use of cover crops in periods without commercial cultivation, is an option to improve soil quality due to the production of phytomass that will be incorporated to the soil after its desiccation, extraction, and release of nutrients by straw decomposition and breaking the cycles of diseases, pests, and weeds (BOER et al., 2007; CORDEIRO JUNIOR et al., 2017; OLOGINI et al., 2022). The off-season period (autumn/winter) is the appropriate time to sow the cover crops, as these areas generally remain fallow; they would not compete with plants of economic interest (WEIRICK; VALANDRO, 2021).

Cover crops, when sown in the off-season, are capable of absorbing nutrients in subsurface layers, accumulating them in their plant material, and later releasing them into the soil through the decomposition and mineralization of their residues (PACHECO et al., 2011; NASCENTE et al., 2013). All these events make it possible to maintain and improve the chemical and biological quality of the soil and contribute to reducing the amount of synthetic fertilizers used to obtain high yields of annual crops sown in succession (FAVARATO et al., 2015; MUHAMMAD et al., 2021; KOUDAHE; ALLEN; DJAMAN, 2022).

The sowing and cultivation of cover crops in the off-season, with known cycles and phenological characteristics, also helps to prevent resistant weeds, preventing their development, flowering, and seed dispersal throughout the area and facilitates their mechanical or chemical control in the pre-sowing of the main crop (MONQUERO; HIRATA, 2014; TADIELLO et al., 2022). In other words, the use of cover crops in the off-season allows the main crop to start its development with greater availability of nutrients and less competition with weeds (ADEUX et al., 2021; KOUDAHE; ALLEN; DJAMAN, 2022).

The use of a mix of cover crops, which consists of mixing seeds from different plant species, can be even more effective than using only one species of cover crop (single crop) since species diversification can increase the production of plant biomass, providing greater weed control and producing higher quality straw in terms of better nutritional performance (MICHELON et al., 2019; KOUDAHE; ALLEN; DJAMAN, 2022). The use of mix can be a viable alternative to maximize the quality of the formed straw, leaving it closer to the ideal, being possible to optimize the release of N and the decomposition of the straw on the soil, which occurs more slowly, maintaining the soil covered for a longer time favoring better crop development (MICHELON et al., 2019). In tropical conditions, such as Cerrado, they have been an interesting alternative to ensure the formation of straw and increase the levels of organic matter in the soil (WULANNINGTYAS et al., 2021).

However, there are few studies in the literature with the use of a mix of cover crops in the off-season for grains, requiring more consistent information on the use of this practice in the Cerrado. This work hypothesizes that the use of cover crop mixes provides higher weed control and accumulation of nutrients in the straw compared to fallow. Thus, this study aimed to determine the biomass production and nutrient accumulation in different mixes of cover crops cultivated in the off-season, and their effects on weed suppression, in a no-tillage area in the Cerrado region.

MATERIAL AND METHODS

The experiment was conducted at Capivara Farm, Embrapa Rice and Beans (Embrapa Arroz e Feijão), in Santo Antônio de Goiás-GO, at 16º28’00” S, 49º17’00” W, and an altitude of 823 m, in the 2020/2021 crop season. According to the Köppen classification, the region’s climate is Tropical Aw -type with an average temperature of 23.3 °C and average rainfall of 1428 mm. The minimum, average, and maximum temperature and precipitation were monitored during the experiment from March to October 2021 (Figure 1).

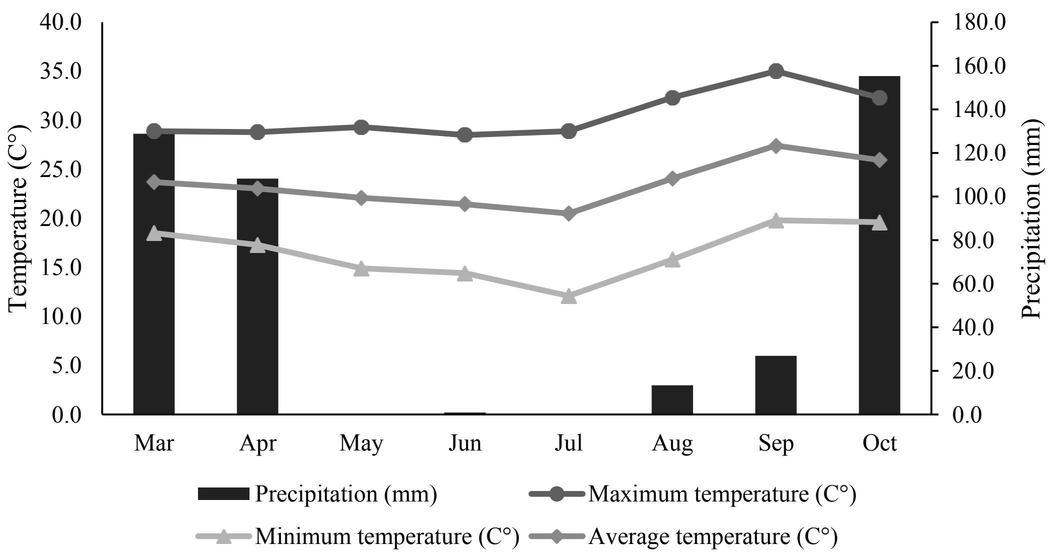

Figure 1. Temperature (°C) and rainfall (mm) during the growing season of cover crop mixes. Santo Antônio de Goiás, GO, Brazil.

The predominant soil in the region is classified as Acric Red Latosol (SANTOS et al., 2018). Before installing the experiments, chemical analyses of the soil were carried out, according to the methodology described by Donagema et al. (2011), with the following results: pH (H_2O) = 6.0; Ca^{2+} = 29.7 $mmol_c$ dm^{-3}; Mg^{2+} = 12.8 $mmol_c$ dm^{-3}; H + Al^{3+} = 16.0 $mmol_c$ dm^{-3}; P = 14.6 mg dm^{-3}; K^+ = 117.2 mg dm^{-3}; Cu^{2+} = 1.5 mg dm^{-3}; Zn^{2+} = 4.8 mg dm^{-3}; Fe^{3+} = 15.9 mg dm^{-3}; Mn^{2+} = 28.1 mg dm^{-3}, and organic matter = 32.0 g kg^{-1}.

The experimental design was randomized blocks with six treatments and eight replications. Treatments comprised five mixes of cover crops and a control treatment: 1. Mix 1 (Mix Ultra) – White lupin (*Lupinus albus*), Buckwheat (*Fagopyrum esculentum*), White oats (*Avena sativa*), Black oats (*Avena strigosa)*, *Crotalaria ochroleuca*, *Crotalaria juncea*, Forage turnip (*Raphanus sativus*), and Finger millet (*Eleusine coracana*); 2. Mix 2 (Mix Vitale) – Buckwheat, *Crotalaria spectabilis*, Forage turnip, and Black oats; 3. Mix 3 (Mix forrageiro) – Pearl millet (*Pennisetum glaucum*), *Crotalaria ochroleuca*, Black oats, White oats, Buckwheat, and Finger millet; 4. Mix 4 (Mix Reduct) *Crotalaria spectabilis*, Buckwheat, Pearl millet, and *Crotalaria breviflora*; 5. Mix 5 – Black oats, Buckwheat, Pearl millet, Piatã grass (*Uruchloa brizantha*), and *Crotalaria ochroleuca;* 6. Weeds/fallow (control). The names of cover crop mixes in parentheses refer to the commercial names of those mixes.

The plots had a dimension of 5.40 m x 10 m in length, and the useful area of each plot was composed of the three central rows, disregarding 0.50 m on each side. The cover crops were sown after the soybean harvest, grown in the summer, in March 2021. A spacing of 0.45 m was used between rows, a depth of 2 cm, using 50 kg ha^{-1} of seeds from each cover crop mix for each treatment.

Evaluations of plant biomass production for all treatments (mixture of cover crops and weeds (fallow) were carried out three times: 30 days after sowing of cover crops (DAS), 70 DAS, and 210 DAS (before desiccation up to sowing of the subsequent summer crop). To collect cover crops and weeds, a metallic square with an area of 1 m^2 was used, placed randomly in each plot. In the square area, the shoot of all cover crops and weeds was collected, then dried in an oven with forced air circulation at 65 °C for 72 hours until it reached constant mass. In the square area, the shoot of all cover crops and weeds was collected, then dried in an oven with forced air circulation at 65 °C for 72 hours until it reached constant mass. The material collected at 210 DAS was also ground in a Willey-type mill to determine the macronutrient content: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) and micronutrients: boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and molybdenum (Mo) from the shoot of cover crops and weeds (fallow), following methodology proposed by Claessen (1997) in the laboratory of Agro-environmental Sciences at Embrapa Rice and Beans (Embrapa Arroz e Feijão). The material collected at 210 DAS was also ground in a Willey-type mill for analysis to determine the macronutrient content: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) and micronutrients: boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and molybdenum (Mo) from the shoot of cover crops. The amount of nutrients per hectare was calculated by multiplying dry biomass production at 210 DAS by nutrient contents following the methodology proposed by Claessen (1997) in the Agro-environmental Sciences of Embrapa Rice and Beans laboratory.

Data were subjected to analysis of variance and significant means compared by Fisher's least significant difference (LSD) at 5% probability. The R software version 3.5.0 (R CORE TEAM, 2017) was used.

RESULTS AND DISCUSSION

At 30 DAS, the mixes 2 (buckwheat, *Crotalaria spectabilis*, fodder radish, and black oat) (1.02 Mg ha^{-1}), 4 (*Crotalaria spectabilis*, buckwheat, millet, and *Crotalaria breviflora*) (1.10 Mg ha^{-1}), and 5 (Black oats, Buckwheat, Pearl millet, Piatã grass, and *Crotalaria ochroleuca*) (1.28 Mg ha^{-1}) showed the highest biomass production of cover crops but did not differ significantly from the biomass production of weeds (1.25 Mg ha^{-1}) (Table 1). At 70 and 210 DAS, mixes 4 and 5 showed the highest biomass production (3.61 and 3.61 Mg ha^{-1}; 3.07 and 3.55 Mg ha^{-1}, respectively), not differing from each other and superior to the other mixes and fallow. Mix 4 had a biomass production of 160% at 70 DAS and 68% at 210 DAS, higher than fallow, and mix 5 of 160% and 94%, respectively. Mixes 1, 2, and 3 were superior to fallow at 70 DAS (86%, 80%, and 78%, respectively); however, they were inferior to mixes 4 and 5.

Table 1. Shoot dry matter of mixes of cover crops cultivated in the off-season and of the control treatment (weeds/fallow), evaluated at 30, 70, and 210 days after sowing (DAS).

Treatments[1]	Shoot dry matter (Mg ha^{-1})		
	30 DAS	70 DAS	210 DAS
Mix 1	0.84 b	2.57 b	1.99 b
Mix 2	1.02 ab	2.49 b	1.65 b
Mix 3	0.92 b	2.46 b	2.14 b
Mix 4	1.27 a	3.60 a	3.07 a
Mix 5	1.10 ab	3.60 a	3.55 a
Fallow	1.25 a	1.38 c	1.82 b

Means followed by the same letter in the column do not differ by Fisher's LSD test at 5% significance. [1]Mix 1: (Ultra Mix) White lupine, Buckwheat, White oats, Black oats, *Crotalaria ochroleuca*, *Crotalaria juncea*, Forage turnip, and Finger millet; Mix 2: (Mix Vitale) Buckwheat, *Crotalaria spectabilis*, Forage turnip, and Black oats; Mix 3: (Forage mix) Millet, *C. ochroleuca*, Black oats, White oats, Buckwheat, and Finger millet; Mix 4: (Mix Reduct) *C. spectabilis*, Buckwheat, Millet, and *Crotalaria breviflora;* Mix 5: Black oats, Buckwheat, Millet, Piatã grass, and *C. ochroleuca*.

The most frequent weeds in the studied area were common purslane (*Portulaca oleracea*), sourgrass (*Digitaria insularis*), beggar's Tick (*Bidens pilosa*), Mexican fireplant (*Euphorbia heterophylla*), common morning-glory (*Ipomoea purpurea*), white mouth dayflower (*Commelina erecta*), southern sandbur (*Cenchrus echinatus*), and common sowthistle (*Sonchus oleraceus*). Although these plants in fallow areas had biomass production close to the production of some treatments with mixes at 30 and 210 DAS, this is not advantageous for the system. Thus, even though weed biomass is also added to the soil with its decomposition, all these weed species have a competitive potential with commercial crops. If no control method is adopted, a seed bank can be formed in the area, making it difficult to control and reduce the production and grain quality of the crops of interest. According to Pires et al. (2008), even if the fallow area with high weed density presents high biomass production, this is usually lower than that produced by cover crops (as observed with mixes 4 and 5). Even when production is not lower, as observed at 30 DAS and 210 DAS with mixes 1, 2, and 3, the presence of several invasive species provides an increase in the seed bank and problems in controlling them later.

All cover crop mixes tended to accumulate greater dry matter mass at 70 DAS than at 210 DAS. This can be explained by the fact that most of the cover crops that make up the mixes are already in the senescence and defoliation period at 210 DAS and enter the dry period, while at 70 DAS, in the off-season, still with rain, the coverage was in full development. Machado and Assis (2010), for example, found that pearl millet, used as a cover crop, presents rapid initial development; however, its maximum point of plant mass production reduces at the moment when leaf senescence begins and, around 110 DAS of its cultivation, re-infestation of the area by the crop may already occur.

Another important point to be considered is the occurrence of a high decomposition rate of plant remains in regions with a tropical climate, such as the Cerrado, even when the straw is made up of grasses (TORRES et al., 2014). In addition, Timossi, Henchen and Lima (2021) reported that plants with a short life cycle and rapid straw mineralization may not be the best option for long off-season periods. However, the use of a mix of cover crops, such as those used in this study, can be a viable alternative since species with different morphophysiological characteristics can minimize such effects. By corroborating this statement, Holmes, Thompson, and Wortman (2017) reported that the success of combining cover crop species (mix) is closely linked to the morphological and functional characteristics of each species since the more divergent characteristics, the better for the system.

In general, mix 5 stood out concerning the greater accumulation of macronutrients, N, P, K, Ca, Mg, and S, being significantly superior to the other mixes and fallow (Table 2). This mix had an accumulation of 218% (N), 383% (P), 391% (K), 63% (Ca), 150% (Mg), and 184% (S) higher than the content found in weeds (fallow). Mix 4 provided significant levels of all macronutrients compared to fallow; however, the contents of N, P, K, Mg, and S were lower than those of mix 5. Mix 4 had an accumulation of 93% (N), 143% (P), 139 % (K), 50% (Ca), 46% (Mg), and 95% (S) higher than the content found in weeds (fallow). Mix 2 also had an N content of 24%, significantly higher than fallow. There were no significant differences concerning weeds (fallow) for the other mixes and macronutrients.

Table 2. Content of macronutrients (kg ha^{-1}) added to the soil through mixes of cover crops cultivated in the off-season, and the control treatment (weeds/fallow), at 210 days after sowing (DAS).

Treatments[1]	N	P	K	Ca	Mg	S
Mix 1	21.35 c	1.50 bc	8.65 bc	15.99 c	4.83 c	1.64 c
Mix 2	23.87 b	1.43 bc	10.27 bc	16.00 c	4.30 c	1.58 c
Mix 3	26.01 bc	1.77 bc	14.37 bc	16.98 bc	5.80 bc	1.85 c
Mix 4	37.09 b	2.21 b	18.92 b	21.02 ab	7.97 b	2.65 b
Mix 5	61.24 a	4.40 a	38.86 a	22.87 a	13.65 a	3.86 a
Fallow	19.25 c	0.91 c	7.91 c	14.00 c	5.46 c	1.36 c

Means followed by the same letter in the column do not differ by Fisher's LSD test at 5% significance. [1]Mix 1: (Ultra Mix) White lupine, Buckwheat, White oats, Black oats, *Crotalaria ochroleuca*, *Crotalaria juncea*, Forage turnip, and Finger millet; Mix 2: (Mix Vitale) Buckwheat, *Crotalaria spectabilis*, Forage turnip, and Black oats; Mix 3: (Forage mix) Millet, *C. ochroleuca*, Black oats, White oats, Buckwheat, and Finger millet; Mix 4: (Mix Reduct) *C. spectabilis*, Buckwheat, Millet, and *Crotalaria breviflora;* Mix 5: Black oats, Buckwheat, Millet, Piatã grass, and *C. ochroleuca*.

Mixes 4 and 5 also stood out in terms of micronutrients. None of the treatments was superior to the control (fallow) in B accumulation (Table 3). However, for Cu, mixes 4 and 5 did not differ from each other and were significantly superior to the other mixes and fallow. The values were 208% (mix 4) and 231% (mix 5), higher than that accumulated by weeds. Mix 4 was the only one that differed from fallow in Fe accumulation, with a value 262% higher than that found in weeds (fallow). Mix 5 provided higher values of Mn and Zn, significantly higher than fallow (52%

and 290% higher, respectively). Mix 4 was also the treatment with the highest Mo accumulation, 374% higher than fallow, and statistically similar to mix 5, which had Mo content 258% higher than fallow. Mix 3 also provided significant values of Zn and Mo compared to fallow (97% and 195% higher, respectively); however, it was lower than mixes 4 and 5.

Table 3. Content of micronutrients (g ha^{-1}) added to the soil through the shoot of mixes of cover crops cultivated in the off-season, and the control treatment (weeds/fallow), at 210 days after sowing (DAS).

Treatments[1]	B	Cu	Fe	Mn	Zn	Mo
Mix 1	11.20 a	5.99 b	2788.84 b	131.56 bc	22.88 d	0.30 d
Mix 2	12.09 a	8.48 b	3857.78 b	118.68 c	29.48 cd	0.31 cd
Mix 3	13.89 a	8.85 b	4591.01 b	183.81 bc	40.31 c	0.56 bc
Mix 4	16.35 a	15.88 a	10117 a	200.54 ab	63.94 b	0.90 a
Mix 5	13.42 a	17.09 a	4838.88 b	269.75 a	79.69 a	0.68 ab
Fallow	11.81 a	5.16 b	2792.96 b	177.49 bc	20.41 d	0.19 d

Means followed by the same letter in the column do not differ by Fisher's LSD test at 5% significance. [1]Mix 1: (Ultra Mix) White lupine, Buckwheat, White oats, Black oats, *Crotalaria ochroleuca*, *Crotalaria juncea*, Forage turnip, and Finger millet; Mix 2: (Mix Vitale) Buckwheat, *Crotalaria spectabilis*, Forage turnip, and Black oats; Mix 3: (Forage mix) Millet, *C. ochroleuca*, Black oats, White oats, Buckwheat, and Finger millet; Mix 4: (Mix Reduct) *C. spectabilis*, Buckwheat, Millet, and *Crotalaria breviflora;* Mix 5: Black oats, Buckwheat, Millet, Piatã grass, and *C. ochroleuca*.

Therefore, it appears that cover crops, especially those comprising mix 5 (Black oats, Buckwheat, millet, Piatã grass, and *C. ochroleuca*), which had significant biomass production and significant accumulation of N, P, K, Ca, Mg, S, Cu, Mn, Zn, and Mo, followed by mix 4 (*C. spectabilis*, Buckwheat, millet, and *Crotalaria breviflora*), which had statistically similar biomass production to mix 5 and significant accumulation of N, P, K, Ca, Mg, S, Cu, Fe, Zn and Mo are valuable sources of macro and micronutrients which, during their release in the straw decomposition process, enrich the soil with essential mineral elements for the growth and development of the species agronomic crops of economic interest that will be cultivated in the subsequent harvest. As in this study, Pacheco et al. (2011) showed that cover crops had positive and significant effects on phytomass production and N and P contents, reinforcing the contribution of cover crops in straw production and nutrient cycling in the agricultural system. In another study, Wolschick et al. (2016) observed that black oat (*Avena strigosa*), fodder radish (*Raphanus sativus* L.), common vetch (*Vicia sativa*), and the mix with the three species as cover crops had high biomass production and greater accumulation of nutrients in the plant tissue when compared to fallow.

According to Farmaha, Sekaran and Franzluebbers (2022), the production of dry mass and the accumulation of nutrients in cover crops is variable since it is associated with the type of plant species selected, the chemical composition of the medium, the age of the tissue, the development of the root system in depth, intrinsic management factors, and climatic, edaphic, and phytosanitary conditions. On the other hand, there is no criterion for determining the percentage of seeds of each species selected to compose the mix of cover crops to be used; however, seed proportions can influence the accumulation of biomass and nutrients, as well as their rate of decomposition; since species of the Poaceae (grasses), Fabaceae (legumes), and Brassicaceae (crucifers) families have distinct morphophysiological characteristics (TORRES et al., 2014). Based on this statement, it was found in the present study that the mixes produced variable amounts of dry biomass of shoots and accumulated variable amounts of nutrients.

Like in this study, Araújo et al. (2021) also observed significant differences in dry matter production and nutrient contents in different mixes of cover crops compared to fallow. In the study, millet + *Urochloa ruziziensis* and millet + *Urochloa ruziziensis* + pigeon pea mixes produced the highest amounts of straw (10.15 and 10.93 mg ha^{-1}, respectively), an increase of 132% and 150% of the biomass concerning the fallow, respectively. At the same time, millet + buckwheat and millet + crotalaria mixes produced a similar amount of straw as the control treatment (weeds/fallow) (ARAÚJO et al., 2021).

According to Tempesta (2020), even if, sometimes, the production of biomass and accumulation of nutrients per mix of cover crops is not significantly higher than their isolated use or even does not differ from the biomass production of weeds (fallow), the use of mixes makes it possible to reconcile the benefits of each species and reduce their unwanted factors. The cover crops used in the present study are well known for their excellent biomass production under different conditions, which is important for the intensification of sustainable agriculture, maintenance of no-tillage practice, soil protection, and release of nutrients for the subsequent crop, which contributes to improving soil quality in the Cerrado, which is naturally low in fertility (PACHECO et al. 2011; LACERDA; NASCENTE, 2021).

Additionally, mixes of cover crops grown off-season in a no-tillage system in the Cerrado region efficiently controlled weeds in the three evaluation periods, 30, 70, and 210 DAS (Table 4). Thus, biomass production from the shoot of weeds in the fallow areas was significantly higher than in the areas where the cover crops were grown, indicating that using a mix of cover crops can be an important strategy for weed management in integrated weed control. Likewise, Araújo et al. (2021) verified a reduction in weeds' density and dry matter mass in areas planted with a mix of cover crops, at 30, 75, and 225 DAS, concerning fallow.

Table 4. Shoot dry matter (Mg ha^{-1}) of weeds collected in areas cultivated with mixes of cover crops in the off-season, and control treatment (weeds/fallow), evaluated at 30, 70, and 210 days after sowing (DAS).

Treatments[1]	Dry matter (g m^{-2})		
	30 DAS	70 DAS	210 DAS
Mix 1	0.34 b	0.11 b	0.08 b
Mix 2	0.19 c	0.09 b	0.04 c
Mix 3	0.28 bc	0.04 c	0.04 c
Mix 4	0.29 bc	0.05 c	0.02 c
Mix 5	0.21 bc	0.04 c	0.04 c
Fallow (control)	1.25 a	1.39 a	1.82 a

Means followed by the same letter in the column do not differ by Fisher's LSD test at 5% significance. [1]Mix 1: (Ultra Mix) White lupine, Buckwheat, White oats, Black oats, *Crotalaria ochroleuca*, *Crotalaria juncea*, Forage turnip, and Finger millet; Mix 2: (Mix Vitale) Buckwheat, *Crotalaria spectabilis*, Forage turnip, and Black oats; Mix 3: (Forage mix) Millet, *C. ochroleuca*, Black oats, White oats, Buckwheat, and Finger millet; Mix 4: (Mix Reduct) *C. spectabilis*, Buckwheat, Millet, and *Crotalaria breviflora;* Mix 5: Black oats, Buckwheat, Millet, Piatã grass, and *C. ochroleuca*.

At 30 DAS, mix 2 (buckwheat, *Crotalaria spectabilis*, Forage turnip, and black oats) provided the lowest weed biomass production (0.19 Mg ha^{-1}) compared to the other treatments and fallow (1.25 Mg ha^{-1}) (Table 4). At 70 DAS, mixes 3, 4, and 5 were significantly lower (lower weed biomass) than mixes 1 and 2 and fallow; however, all mixes had significantly lower biomass than fallow. At 210 DAS, all mixes were significantly lower than fallow, with mix 1 being the only one that provided significantly higher biomass than the other mixes. As verified in this study, Reis and Borsoi (2020) observed a higher incidence of weeds in fallow areas than in areas with isolated or mixed cover crops, verifying a greater presence, mainly, of horseweed (*Conyza sp*.) and sourgrass (*Digitaria insularis*). In another study, Vuicik et al. (2018) also verified that the use of buckwheat, millet, and the mix between them, as cover crops in the off-season were viable alternatives in controlling weeds, increasing dry mass production and soil management when compared to fallow.

Our results align with the goal of achieving sustainable agriculture since weed control is a major challenge in production systems, as they compete with crops of economic interest for environmental resources such as water, nutrients, and light. In addition to releasing allelopathic substances that significantly reduce the productivity of commercial crops. In addition, weeds host insects and diseases, reduce grain quality, and increase production costs (VARGAS; PEIXOTO; ROMAN, 2006; GALON et al., 2018; BASSO et al., 2018). In the present study, it was verified that using a mix of cover crops was efficient in significantly reducing the production of weed biomass, which can help avoid these problems and ensure greater productivity of subsequent commercial crops.

Duarte et al. (2014) reported that a cover crop to be considered effective in weed management must have high phytomass production, a deep root system, and quickly establish itself in the area. Most of the time, weed control by cover crops is achieved through physical barriers, allelopathic and biological effects, and competition for water, light, nutrients, and space (MONQUERO; HIRATA, 2014; KOUDAHE; ALLEN; DJAMAN, 2022). In the present study, control probably occurred through competition for space, water, light, and nutrients since the evaluations were carried out during the development of cover crops and weeds.

Therefore, as observed in this research, it is necessary to pay special attention to soil protection, especially in the off-season, when the soil normally remains fallow after removing the previous crop until the next season. Fallow areas provide a favorable environment for the germination of weed species and other problems for the soil and crops that will come in the next harvest, such as erosion and loss of nutrients. Thus, as was done, the off-season would be the appropriate time to sow cover crop mixes; as these areas generally remain fallow, they would not compete with plants of economic interest, such as corn and soybeans. (WEIRICK; VALANDRO, 2021; KOUDAHE; ALLEN; DJAMAN, 2022). In addition, there would still be a few months of rain that would help the cover crops to grow, develop and stifle weed development, as observed in the present study.

In this study, it was found that mixes 4 (*C. spectabilis*, Buckwheat, millet, and *Crotalaria breviflora*) and 5 (Black oats, buckwheat, millet, Piatã grass, and *Crotalaria ochroleuca*) stood out for having biomass production, nutrient accumulation, and reduction of significant weed biomass compared to fallow and which, from the producer's point of view, should be selected for the benefits they could provide to the production system. However, it can be observed that the cultivation of all mixes evaluated in the off-season provided advantages, as all helped in the significant reduction of weed biomass when compared to the control treatment (fallow).

Therefore, using cover crops in the off-season is a good option to help manage weeds, which can help control and reduce the use of herbicides in agricultural areas. In addition, it can contribute to an increase in the availability of nutrients for crops grown in succession due to the accumulation of nutrients by cover crops and their release in the straw decomposition process, which can help reduce the use of synthetic fertilizers, contributing thus to make Cerrado agricultural systems more efficient and sustainable.

CONCLUSION

The efficiency of using a mix of cover crops to produce biomass and control weeds depends on the species that comprise each mix.

Mixes 5 (Black oats, Buckwheat, Pearl millet, Piatã grass, and *Crotalaria ochroleuca*) and 4 (*C. spectabilis*, Buckwheat, Pearl millet, and *Crotalaria breviflora*) are the best among those evaluated for the conditions of the Cerrado because they produce the highest biomass in the period off-season, due to the greater availability of nutrients to the soil, in addition to providing lower weed biomass compared to fallow.

All mixes provided lower weed biomass in the off-season compared to fallow.

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