

Allelochemicals in sorghum (*Sorghum bicolor* [L.] Moench) as bio-inputs for weed control

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ABSTRACT

This study aimed to evaluate and identify the potential herbicidal activity of sorghum plants. The field experiments were done in completely randomized design with Main Plots and sub-plots. The experimental area was divided into two Main plots, in one plot sorghum was cultivated and in second plot corn (*Zea mays* L.) was cultivated under no-till system for straw. After the harvest of sorghum and corn, soybeans were sown in Main Plots, and weed control test was done in sub-plots (1.5 x5.0 m). This study aimed to develop sustainability through the use of renewable resources. The allelochemicals present in sorghum significantly changed the soil microbiology, reduced weed density restricted the growth and development of weeds.

Keywords: Allelochemicals, Bioherbicide, Renewable resource, Sorghum, *Sorghum bicolor*, Sorgoleone, Sustainability, Weed control.

INTRODUCTION

Sorghum (*Sorghum bicolor* [L.] Moench, Poaceae Family), is grown following soybeans in Brazilian Midwest. The plant is allelopathic, and its main allelochemical is sorgoleone, a lipid benzoquinone produced in leaves and roots and constantly exuded through root hairs (25,28). The production and release of allelochemicals occurs throughout the growth of sorghum plants (8). Sorghum has been extensively studied for its allelopathic properties and has potential to reduce the use of chemical herbicides for weed control in cropping systems. This is made possible by sorgoleone, which is excreted from root trichomes and affects the FSII of photosynthesis in weeds upon contact (28). Sorghum has considerable levels of total phenolic compounds that exert effective actions in weed control. The phenols extracted from sorghum have been used as a bioherbicide (cause leaf lesions and impairs plant photosynthesis) to control narrow- and broad-leaved weeds (26,30). Hydroquinone sorgoleone is the main component of sorghum extract and it accounts for about 40 % of root extract and is the main compound to reduce weeds abundance (13,20).

Leaf extracts and root exudates from sorghum plants reduces the shoot growth of weeds and susceptible species such as lettuce and other vegetables by more than 50 % (16,21). The use of sorgoleone as natural herbicide can have several environmental benefits. Sorgoleone alters the soil microbial community by interfering with the nitrification process by blocking the activity of the enzymes ammonia monooxygenase (AMO) and hydroxylamine oxidoreductase (HAO) in nitrifying bacteria, the archaea responsible for converting ammonia to nitrate (29,34,40). The processes of nitrification and denitrification of nitrogen are predictors of environmental pollution due to the leaching of nitrates, which contaminates groundwater, and N₂O gas that enhances the greenhouse effect. The

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agricultural activities contribute more than half of nitrous oxide emitted into the atmosphere (31). Thus, inhibiting the biological nitrification in soil by sorgoleone could be of great environmental significance.



Image 1. Photograph of weed *Ipomoea nil* (L.) from cultivated fields in Brazilian Cerrado.

The weeds have high competitive potential and reduces agricultural productivity and increase crop production costs (22,23,24). Hence, it is important to study sustainable alternatives to control invasive plants. Allelochemicals are potential alternative that supports biorational and lower-cost of agricultural production. This study aimed to evaluate and identify the potential herbicidal activity of sorghum plants.

MATERIALS AND METHODS

The study was conducted at the Experimental Farm, State University of Goiás, South Campus, Ipameri (Lat. 17° 43' 19" S, Long. 48° 09' 35" W, Alt. 773 m). This region has humid tropical climate with a rainy summer and dry winter (1). An area left uncultivated for 2-years, followed by 12-months without herbicides, was used for experiment. The soil in experimental area is Dystrophic Red-Yellow Latosol with a medium texture (12). Following soil chemical analysis (Table 1), fertilization was done as per the technical recommendations for soybean cultivation (27).

Table 1. Soil chemical analysis of the experimental area at a depth of 0 to 20 cm in the years 2021 (1st) and 2022 (2nd) in Ipameri, GO.

Depth/Year	pH	O.M.	P ⁽¹⁾	K ⁽¹⁾	Ca ⁽¹⁾	Mg ⁽¹⁾	H+Al	V
0-20 cm	CaCl ₂	%	Mg/dm ³	-----mmolc/dm ³ -----				%
1	5.5	1.5	8.2	0.26	2.2	0.8	2.4	57.6
2	6.1	1.6	6.7	0.45	3.7	1.3	1.1	54.5

⁽¹⁾ Mellich. O.M: Organic matter and V: Base saturation.

The experiment was done in 2021 and 2022 in completely randomized design with two Main plots and two Sub-plots. The main plots were cultivation of grain sorghum (DOW 1G100) and maize (SHS 7990 PRO3) for straw. The subplots (1.5 m x 5 m) were: weed control using aqueous sorghum extract and control. The treatments were replicated 5-times.

The experimental area was divided into two Main plots, in one plot sorghum was cultivated and in second plot corn (*Zea mays* L.) was cultivated under no-till system for straw. After the harvest of sorghum and corn, soybeans were sown in Main Plots and weed control test was done in sub-plots (1.5 x 5.0 m). The weed control treatments were: Application of aqueous sorghum leaf extract on weeds and Control (without weed control measures). Maize and grain sorghum were sown in first week of March every year. At harvest, they were cut with a hand-held bushcutter and deposited straw on the ground. Thereafter, soybeans were planted in corn and sorghum straw in October and November of first and second years, respectively, after a rainfall of at least 100 mm. The seeds were treated with a single fungicide/insecticide pyraclostrobin, Thiophanate-methyl and Fipronil and inoculated with *Bradyrhizobium japonicum* at 12×10^5 cells of the bacteria per seed. At phenological stage R₂, fungicide Fuxapirroxad and Pyraclostrobin were applied.

The aqueous sorghum extracts was prepared from 30-days-old grain sorghum plants grown in field. The leaves were washed with running water, placed in paper bag and dried in forced-air circulation oven at 70 °C for 72 h. These were pulverized using a hammer Mill. Then 3 g powdered mass was mixed with 60 mL ethanol and left for 72 h at 40 °C and then filtered (17). The extract of 75 % concentration was diluted to 25 % with distilled water, i.e. in each 750 ml extract 250 ml water was added. It was then sprayed on plants using a backpack sprayer @ 150 L/ha. Soybeans were planted in corn and sorghum straw. In soybean, post-emergence weed control was done with foliar spray of sorghum extract. The aqueous sorghum extracts were sprayed thrice against the weeds at V₃, R₁, and R₅ phenological stages. The soybean plants were assessed 15 days after the last spray, while the weeds were assessed at the R₉ phenological stage of soybean.

For the evaluations, a custom-built wooden square (50 cm x 50 cm) was used. The square was dropped three times at varying positions in each of five sub plots (1.5 m x 5 m) and data was averaged.

Growth Variables and Species Abundance

The weeds studies were done when the soybean plants were at R₉ stage. The height, biomass, high frequency, and economic detriment height of dominant weed were recorded. The plant height was measured using a tape from the ground up to the apex. The aboveground dry mass of dominant weed was determined by drying it in oven at 70 °C for 72 h. In both years, the dominant weed specie was *Ipomoea nil* (L.) Roth. Weed species were identified, the quantity of each species in plots was recorded, and their respective families were documented.

Soybean Plants Parameters

To assess the relative chlorophyll index, a portable chlorophyll meter (SPAD) was used on fully expanded leaves 15 days after the final application of aqueous sorghum extract on weeds. The useful plot was harvested manually. The number of pods per plant, grain

mass per plant, number of grains per plant, and yield were recorded in reproductive phase (R₉) and adjusted to 13 % moisture content.

Microbial Studies

For microbiological analyses, soil samples were collected near the roots at depth of 0.00-0.20 m and following studies were done:

- (i). **Microbial Biomass Carbon:** The microbial biomass carbon (MBC) was determined using the irradiation-extraction method (18), which involves the use of electromagnetic energy to induce energy and temperature transfer, resulting in cell disruption and release of intracellular compounds. The soil extractor used was K₂SO₄ 0,5 mol L⁻¹, and the carbon content in the extracts was quantified by wet oxidation procedure with 0.066 mol L⁻¹ potassium dichromate, followed by titration with 0.033 mol L⁻¹ ammonium ferrous sulfate (39). The conversion factor (K_c) used was 0.33.
- (ii). **Soil Basal Respiration (C-CO₂ Released):** To quantify the released C-CO₂, 100 g soil was placed in glass jars with screw caps, where soil moisture was adjusted to 70 % of field capacity. In center of each jar, a vial 0 mL of 0.1 mol L⁻¹ NaOH was placed. The jars were sealed hermetically and kept in a climatic chamber at 27°C for a specified period according to a calibration curve. The titration of free NaOH was done with 0.1 mol L⁻¹ HCl by subtracting amount of CO₂ that combined with NaOH. The results were expressed in mg C-CO₂ kg⁻¹ soil.day⁻¹ (2).
- (iii). **Metabolic Quotient (qCO₂):** The metabolic quotient (qCO₂) was calculated according to (2), as the ratio of released C-CO₂ to MBC.

Statistical Analysis

Data for two years was analysed using Analysis of variance (ANOVA) and Newman-Keuls mean test at 5 % significance level. The multivariate analysis involved the construction of correlation networks using the *qgraph package*, canonical variables using the *candisc package*, and multiple regression employing the *forward stepwise* model (32). These analyses were performed using the RBIO software (5) and Statsoft (33).

RESULTS AND DISCUSSION

The phytosociological survey of weeds (Table 2) showed that 35 weed species were identified in the experimental area, 63 % were broadleaved species and 37 % were narrowleaved species. Despite the greater number of broadleaf species, the narrow-leaf plants occupied 80 % experimental area, i.e. there was less diversity but more abundance.

Approximately 74 % weeds identified in the two harvests occurred in the first crop year and 54 % in the second crop year. According to (10), weed diversity is lower in the no-till system compared to the conventional system. The straw's physical effect reduced light and temperature in the soil's surface layers and inhibited the seed germination. Thus, the lower species diversity in the second year is explained by the physical effect of straw, which is cumulative over the years due to the increased thickness of straw. The use of alternative control methods is important to control the native invasive plants, as they were more aggressive. According to (9), controlling native invasive species is more difficult due to the development of soil microbial communities and the release of substances that suppress the development of non-native species.

Table 2. Phytosociological survey of broad-leaved and narrow-leaved weeds in soybean planting in the No-Till system with corn straw (CS) and sorghum straw (SS) evaluated in 2-years of cultivation (2021 and 2022).

Weed species	Weeds		Years		Straw	
	Broad-leaved	Narrow-leaved	2021	2022	Corn	Sorghum
<i>Amaranthus spinosus</i> (L.)	X		X	X		X
<i>Ambrosia artemisiifolia</i> (L.)	X		X			X
<i>Bidens Pilosa</i> (L.)	X		X	X	X	
<i>Brachiaria brizantha</i> (CV.)		X	X		X	
<i>Brachiaria ruziziensis</i> (CV.)		X	X		X	X
<i>Cenchrus echinatus</i> (L.)		X	X	X		X
<i>Chamaesyce hirta</i> (L.)	X		X	X	X	X
<i>Chloris gayana</i> (Kunth.)		X		X		X
<i>Commelina benghalensis</i> (L.)	X		X		X	
<i>Cynodon dactylon</i> (L.) Pers		X	X	X		X
<i>Cyperus rotundus</i> (L.)		X		X		X
<i>Desmodium tortuosum</i> (SW.) DC	X		X		X	X
<i>Digitaria ciliaris</i> (Retz.) Koeler		X		X	X	
<i>Digitaria insularis</i> (F.)		X	X			X
<i>Echinochloa colonum</i> (L.)		X	X	X	X	X
<i>Eleusine indica</i> (L.) Gaertn		X	X		X	X
<i>Emilia fosbergii</i> (D.)	X		X		X	
<i>Emilia sonchifolia</i> (L.)	X			X	X	X
<i>Emilia sonchifolia</i> (L.) DC.	X			X		X
<i>Euphorbia heterophylla</i> (C.)	X		X	X	X	X
<i>Galinsoga parviflora</i> (A.)	X		X			X
<i>Glycine max</i> (L.)	X		X		X	X
<i>Ipomoea nil</i> (L.) Roth	X			X	X	
<i>Miscanthus giganteus</i> (C.)	X		X		X	X
<i>Oxalis sp.</i> (L.)	X		X	X		X
<i>Paspalum dilatatum</i> (P.)		X	X			X
<i>Rhynchelytrum repens</i> (Willd.)		X	X	X	X	X
<i>Richardia brasiliensis</i> (L.) Gomes	X		X	X	X	
<i>Senna obtusifolia</i> (L.) I. E. Barneby	X		X			X
<i>Spermacoce verticillata</i> (L.) G.Mey.	X			X	X	X
<i>Spigelia anthelmia</i> (L.)	X			X		X
<i>Stellaria alsine</i> (G.)	X		X		X	X
<i>Turnera subulata</i> (W.) Schult	X		X			X
<i>Zea mays</i> (L.)		X	X		X	
<i>Zinnia elegans</i> (J.)	X			X	X	

The ANOVA for number of grains per plant, yield, chlorophyll index, weeds density, dominant weed height and root length in soybean plants are shown in Table 3. The number of pods per plant and grain yield per plant did not show significant differences between treatments (data not shown). The number of grains per plant, yield, dominant weed height and root length showed significant interactions indicating that the behavior of one

treatment depends on the levels of other treatment. The chlorophyll index showed significant differences only in treatments with use of different straw in soil, while weed density showed significant differences in the treatments.

Table 3. Summary of ANOVA in soybeans for number of grains per plant (NGP), yield (YSOY), chlorophyll index (SPAD), dominant weed height (HDW) and root length (RLW) and weeds density (DENS) in soybean planted in soil with corn or sorghum straw and weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Source of Variation	Mean Squares						
	GL	NGP	YSOY (bags/ha)	SPAD	HDW (cm)	RLW (cm)	DENS (pt/m ²)
Straw (S)	1	400 ^{ns}	1204 ^{ns}	182*	11 ^{ns}	32*	2508*
Error 1	8	289	12	23	183	1.3	106
Extract (E)	1	1637*	20 ^{ns}	0.4 ^{ns}	435*	15*	386*
SxE	1	1722*	155*	0.23 ^{ns}	8405*	66*	12.8 ^{ns}
Error 2	8	82	20	12	234	2.5	63.7
Total	19						
CV ₁ %		13.8	4.8	10.6	16.8	11.6	10.8
CV ₂ %		7.4	6.3	7.9	19.0	16.3	8.3

* Significant at 5 % probability; NS: not significant by F test

The summary of the ANOVA for dominant weed biomass, microbial biomass carbon, soil basal respiration and metabolic quotient in soybean plants is shown in Table 4. The dominant weed biomass, microbial biomass carbon and metabolic quotient showed significant interactions indicating that the behavior of one treatment depends on the levels of other treatment. The soil basal respiration showed significant differences for the treatment with the use of different straw in the soil and post-emergence control with sorghum extract.

Table 4. Summary of ANOVA for dominant weed biomass (DWB), microbial biomass carbon (MBC), soil basal respiration (SBR), metabolic quotient (qCO_2) in soybean planted in soil with corn or sorghum straw and weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Source of Variation	Mean Squares				
	DF	DWB (g)	MBC (mgC.kg ⁻¹ soil)	SBR (mgC-CO ₂ kg ⁻¹ de soil day ⁻¹)	qCO_2 (mgC-CO ₂ . mg ⁻¹ Cmic.day ⁻¹)
Straw (S)	1	1035*	10134*	438*	0.04*
Error 1	8	10	916	24	0.00
Extract (E)	1	1531*	25499*	299*	0.14*
SxE	1	2193*	13859*	2.2 ^{ns}	0.19*
Error 2	8	7.9	936	13	0.01
Total	19				
CV ₁ (%)	-	23.0	19.3	9.3	21.5
CV ₂ (%)	-	20.0	19.5	6.9	24, .8

* Significant at 5 % probability; NS: not significant by F test

The mean test for chlorophyll content, weed density and soil basal respiration is shown in table 5. The SPAD index differed significantly depending on the type of straw used. Soybean plants grown on sorghum straw had 12 % lower SPAD index than those

grown on corn straw. Weed density was 21 % higher in area with corn straw than in area with sorghum straw. The post-emergent application of sorghum leaf extract did not reduce the weed density. This was because density is directly related to the quantity of germinated seeds and the seeds germination was inhibited by soil mulch.

The number of weed species was lower in area with corn straw and without post-emergent control with sorghum extract. These results showed that the allelopathic action of sorghum was more efficient in plant density than in preventing species diversity. These results indicated that sorghum straw has important allelopathic effects on weed germination, making it possible to reduce the number of species germinated in the same area. Phenolic acids are the most important allelochemicals in sorghum plants that reduce growth, concentration of photosynthetic pigments and block respiration and photosynthesis (14). According to (14,35,37), sorgoleone present in sorghum plant exudates inhibits seed germination and early growth of many plant species.

According to (7), basal respiration is the constant rate of respiration in the soil that results from the mineralization of organic matter and is estimated based on the evolution of carbon dioxide or the uptake of oxygen. Nevertheless, the results in Table 5 showed that basal soil respiration was lower under sorghum straw ($48.3 \text{ mgC-CO}_2 \text{ kg}^{-1} \text{ soil day}^{-1}$) compared to soil with maize straw ($57.6 \text{ mgC-CO}_2 \text{ kg}^{-1} \text{ soil day}^{-1}$), the use of sorghum leaf extract also reduced basal respiration. This result can be attributed to the different sites of the sorgoleone molecule that are degraded by the microorganisms, where the benzoquinone site is degraded more slowly and consequently reduces the basal respiration of the soil, unlike the methoxy site, which is degraded more rapidly, as reported in studies on the mineralization of sorgoleone in soils in the United States and Denmark (15).

Table 5. Newman-Keuls mean test for variables without significant interaction between straw and extract application: chlorophyll content (SPAD), weed density (DENS) and soil basal respiration (SBR) in soybean planted soil with corn or sorghum straw and weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Type of straw soil	Mean test for Straw Type		
	SPAD	DENS (m ²)	SBR (mgC-CO ₂ kg ⁻¹ de soil day ⁻¹)
Corn straw	48.6a	106.4a	57.6a
Sorghum straw	42.6b	84.0b	48.3b
Extract	Mean test for use of sorghum extract		
	SPAD	DENS	RBS
WSE	45.4a	99.6a	49.1b
ASE	45.7a	90.8b	56.8a

Means followed by the same letter in the column do not differ from each other at 5 % probability using the Newman-Keuls test.

The Test of mean of significant interactions for variables number of grains per soybean plant (NGP), soybean yield (YSOY), dominant weed height (HDW) and root length (RLW) in soybean crop (Table 6). In treatments using sorghum extract for post-emergence weed control and/or using sorghum straw in the soil, higher number of grains per soybean

plant and higher grain yield were obtained in relation to treatment with corn straw and without use of sorghum extract. These results indicated that sorghum has important herbicidal potential. Sorgoleone from sorghum plants interferes with photosynthesis, slows plant development and interferes with weed growth (26 30).

Table 6. Newman-Keuls mean test of significant interactions for the number of grains per soybean plant (NGP), soybean yield (YSOY), dominant weed height (HDW) and root length of (RLW) in soybean planted in soil with corn or sorghum straw and with weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Interaction	NGP		YSOY		HDW		RLW	
	ASE	WSE	ASE	WSE	ASE	WSE	ASE	WSE
Corn straw	100.0bB	136.6aA	68.1aB	75.7aA	75.8bA	87.3aA	9.9aA	11.8aA
Sorghum straw	127.5aA	126.9aA	73.2aA	69.2bA	115.3aA	44.8bB	11.0aA	5.6bB

The same lowercase letters in the columns and uppercase letters in the rows indicate no significant difference at 5 % probability by Newman-Keuls test. The variables have following units: YSOY (bags/ha), HDW (cm) and RLW (cm).

In this study, the dominant weed, characterized by the highest height, plant mass and frequency of economic detriment, consistently manifested in the broadleaf specie: *Ipomoea nil* (L.) Roth. The assessment of this specie revealed the herbicidal efficacy of sorgoleone. Dominant weeds on sorghum straw and subjected to post-emergent control using sorghum extract reduced plant height (41 %) and root length (43 %), than their counterparts on maize straw without post-emergent control. Prior studies have suggested that sorgoleone exerts detrimental effects on root system development, hindering the absorption of soil solution by inhibiting the nitrification process and H₂O₂ production in the roots. This leads to reduced stomatal opening and adversely impacts photosynthesis and overall growth (4,11,25).

The mean test for variables with significant interactions, dominant weed biomass (DWB), microbial biomass carbon (MBC), soil basal respiration (SBR), metabolic quotient (qCO_2) in soybean plantations are shown in table 7. There was significant reduction (60 %) in biomass of dominant weed, when grown on sorghum straw and subjected to post-emergent control using the extract, in contrast to plants on corn straw without such control. This outcome strongly signifies the allelopathic influence of sorgoleone on inhibiting weed growth. Biomass serves as a reliable metrice for assessing plant growth, and its meticulous examination plays a pivotal role in discerning the plant vigour (24). Furthermore, as highlighted by (39) the application of sorghum extract represents a pivotal practice in weed management, when employed synergistically with other ecologically sound control measures, thereby contributing to the maintenance of elevated wheat productivity.

In addition, the biomass of the dominant weed on sorghum straw was 95 % lower with post-emergence control than without post-emergence control. This result demonstrated the herbicidal effects of the sorghum leaf extract used in spraying and is based on the weeds density, because the density of weeds growing on sorghum straw is lower, the dominant plants grow more in absence of post-emergent control, thus justifying two levels of control in this study, at soil level (straw) and post-emergence (extract). This assertion is supported

by the results in Table 7, which showed that the dominant weed has negative effects on plant density, meaning that the greater the number of plants in a given area, the less likely is that any one plant will become dominant.

Table 7. Newman-Keuls mean test for significant interactions for the variables dominant weed biomass (DWB), microbial biomass carbon (MBC) and metabolic quotient (qCO₂) in soybean planted in soil with corn or sorghum straw and with weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Interaction	BPD		MBC		qCO ₂	
	ASE	WSE	ASE	WSE	ASE	WSE
Corn straw	5.2bA	8.6aA	188.5aA	169.8aA	0.37aA	0.34bA
Sorghum straw	40.5aA	2.1bB	196.2aA	72.1bB	0.27aB	0.64aA

The same lowercase letters in the columns and uppercase letters in the rows indicate no significant difference at 5 % probability by the Newman-Keuls test. The variables have the following units: BPD (g), MBC (mgC.kg⁻¹ soil), qCO₂ (mgC-CO₂. mg⁻¹Cmic.day⁻¹).

The carbon of microbial biomass was 62 % lower in the soil under sorghum straw with weeds exposed to sorghum extract than in the soil under maize straw without the use of extract due to the action of sorgoleone (Table 6). Similar results were found by other authors (40), who studied the effects of sorgoleone *in-vitro*, reported that the allelochemicals had great potential to inhibit some taxa of microorganisms, in field and greenhouse conditions, sorgoleone inhibited 76 % microorganisms studied, with the genus *Bacillus* being the most affected. Another study (36) also showed growth inhibition of soil microbiota, particularly the species *Nitrossomonas europea* L.

The metabolic quotient was higher in soil under sorghum straw and with the use of extract in relation to all other treatments. In addition, when the soil was covered with sorghum straw and weeds were controlled on this soil with sorghum leaf extract, the metabolic quotient was 42 % higher than control treatment with corn straw and without use of sorghum extract. Studies have shown that competition between plant roots and microorganisms (19) and the production of antimicrobial compounds like sorgoleone by roots (3), can increase microbial activity and CO₂ evolution, leading to low carbon use efficiency by soil microorganisms. This, in turn, results in increased metabolic quotient (6).

The results of the regression analysis (Table 8) indicated that 82 % variation in weed was accounted by the analyzed variables. The data revealed that taller and more dominant weeds have negative impacts on weed density. This is because larger plants are more competitive for resources and thus limit the growth of other species. More developed plants are better equipped to compete for resources and limit growth of other species, and decreases plant density (24).

Table 8. Multiple regression analysis to evaluate the influence of the variables analyzed on weed density in soybean planted in soil with corn or sorghum straw and with weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

Weed density (plants/m ²)	R²= 0.82		F (7. 12) =8.07		P <0.00005	
	Beta	S.E. of Beta	B	S.E. of Beta	t (12)	p-level
Intercept			38.846	39.223	0.990	0.342
NS	0.063	0.179	0.828	2.369	0.349	0.733
HDW	-0.663	0.257	-0.341	0.132	-2.580	0.024*
RLW	0.844	0.205	4.592	1.115	4.119	0.001*
BPD	-0.555	0.223	-0.518	0.208	-2.483	0.029*
MBC	0.721	0.407	0.186	0.105	1.772	0.102
SBR	-0.022	0.182	-0.044	0.369	-0.121	0.906
qCO ₂	0.445	0.390	39.846	34.884	1.142	0.276

Variables: Number of species (NS), Height of dominant weed (HDW), Root length of dominant weed (RLW), Dominant weed biomass (DWB), Microbial biomass carbon (MBC), Soil basal respiration (SBR) and Metabolic quotient (qCO₂).

The canonical variables analysis (Figure 2) represented 97.7 % variation in data was related to assessments in weeds and soil. This result demonstrated that weed density was more strongly influenced by treatments involving corn straw, regardless of whether sorghum leaf extract was applied or not, if the straw used in the no-till system is corn, the weed density will be higher.

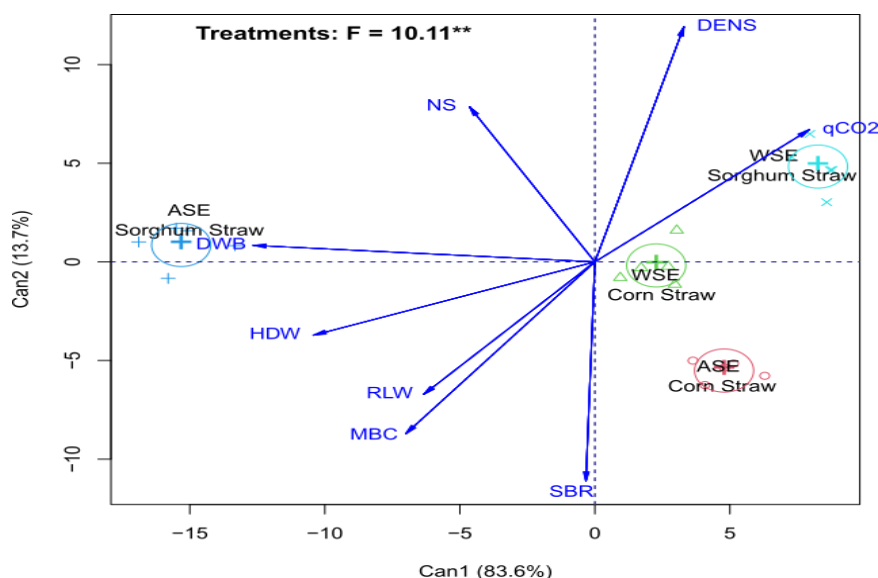


Figure 2. Analysis of canonical variables for ordering variables: Number of species (NS), Dominant weed biomass (DWB), Height of the dominant weed (HDW), Root length of the dominant weed (RLW), Microbial biomass carbon (MBC), Soil basal respiration (SBR), Metabolic quotient (qCO₂) and Weed density (DENS) in soybean planted in soil with corn or sorghum straw and with weeds sprayed with sorghum extract (WSE) or without sorghum extract (ASE).

The metabolic quotient was positively influenced by the cropping system with sorghum straw and the use of sorghum extract for weed control, while the biomass of the dominant weed was very high in treatments with sorghum straw on the soil and without the use of sorghum extract, which exerts an allelopathic action for post-emergence control. These results confirmed those previously explained and strengthened the argument that sorghum straw in the no-till system and use of sorghum leaf extract exerted an allelopathic action to inhibit the emergence and growth of weeds.

This study points to a future horizon of sustainability through the use of renewable resources in line with the 2nd objective of the 2030 agenda, which points to food security and sustainable agricultural practices. Our work on using sorghum straw and sorghum leaf extract as important tools for weed control is in line with the 2030 agenda. The allelochemicals present in sorghum promoted significant changes in soil microbiology, reduced weed density and weed physiology to the point of restricting the growth and development of these undesirable species.

CONCLUSIONS

The allelopathic effects of sorgoleone decreased the weed density in a no-till system with sorghum straw on the soil compared to corn straw. Due to the possible adsorption of root exudate to soil colloids, sorghum straw did not have negative effects on soybean yield; however, sorghum straw in combination with post-emergent control with sorghum leaf extract reduces weed growth. The use of sorghum leaf extract negatively affects the growth of the weed *Ipomoea nil* (L.) by reducing biomass accumulation when combined with sorghum straw, also reduced root system development. Sorghum straw and sorghum leaf extract had important influence on the soil microbiota decreased the microbial biomass carbon and basal respiration and increased the soil metabolic quotient, modulating the quantity, diversity and functionality of the soil microbiota. The use of sorghum extract in association with sorghum straw showed a significant repressive effect on the development of weeds and represents an important alternative for weed control through the use of a renewable resource with low environmental impact.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration with all authors. All authors finally approved and drafted the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest. All authors agree to publish it.

DECLARATION

We declare that all authors of this Ms. have made substantial contributions. We did not exclude any author who substantially contributed to this Ms. We have followed our ethical norms established by our respective institutions.

ETHICAL STATEMENT

In this study, we have not been involved any animal and human studies.

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