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RESEARCH PAPER

Incorporated Sorghum Residues Reduce Emergence and Seedling Growth of Some Crops

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Abstract

H. Tibugari, C. Chiduza, A.B. Mashingaidze, and S. Mabasa. 2021. Incorporated Sorghum Residues Reduce Emergence and Seedling Growth of Some Crops. Int. J. Agric. Nat. Resour. 97-107. Allelochemicals from sorghum [*Sorghum bicolor* (L.) Moench] residues may inhibit the emergence and growth of other crops. We examined the effects of residues from two sorghum landraces, IS9456, a high sorgoleone producer, and IS22320, a zero sorgoleone producer. Residues were applied at 7.2 g, 14.4 g and 21.6 g kg^{-1} of soil. Emergence and the growth of maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and soybean [*Glycine max* (L.) Merr.] were tested in three glasshouse pot experiments at the University of Zimbabwe in 2017. The 2×3 factorial experiments were laid as a randomized complete block design with six replications. Residues from IS22320 significantly ($P<0.05$) reduced the emergence of maize by 22.2% compared to residues from IS9456. Sorghum variety as a source of residue did not significantly ($P>0.05$) reduce the emergence, height, chlorophyll content or dry weight of soybean. Increasing the residue rate significantly ($P<0.05$) reduced the percent emergence, height, chlorophyll content and dry weight of soybean. There was a significant sorghum variety × residue application rate interaction on the percent emergence ($P<0.001$) and chlorophyll content ($P<0.05$) of wheat. Increasing the IS9456 residue application rate from 7.2 to 14.4 g kg^{-1} soil increased the chlorophyll content of wheat. The timing of maize and wheat planting after sorghum residue incorporation may be critical.

Keywords: Allelochemicals, crop rotations, maize, soil-incorporated stover, soybean, wheat.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) allelopathy can be used in integrated weed management (Głab *et al.*, 2017; Jabran, 2017; Rashid *et al.*, 2017), a strategy that is mostly adopted in smallholder farming systems in Africa's semiarid areas to promote food security (Abdullahi *et al.*, 2017; Salim *et al.*, 2017; FAO, 2019a; FAO & WFP, 2019; Mundia *et al.*, 2019). Due to changes in the climate that may be characterized by dry conditions (FAO, 2019a), frequent droughts (Davis, 2011; Ziervogel *et al.*, 2014; Bloomfield *et al.*, 2019) and seasonal erratic

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rains (FAO, 2019b), there is a good chance that sorghum will be a key cereal crop in the future (Tibugari *et al.*, 2019). In Zimbabwe, sorghum is primarily cultivated in drought-prone areas in agro-ecological Regions IV and V, which are classified as unsuitable for intensive cropping (Tibugari *et al.*, 2020a). Maize (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.) are also important crops that are grown for food and industrial uses (Cox *et al.*, 2019), and in some instances, sorghum is included in rotations that involve these crops. Maize, sorghum, soybean, and winter wheat rotations are popular in some parts of the world (Hunter *et al.*, 2019; Schlegel *et al.*, 2019). Sorghum cover crops may be grown between cash crops such as soybean and wheat (NRCS-USDA, 2011). As such, when rotated with sorghum, these crops may be exposed to allelochemicals that are leached by sorghum residues (Silva, 2019).

After the harvesting period, most farmers incorporate the crop residues into the soil to provide organic matter (Karlen *et al.*, 2019; Tibugari *et al.*, 2020b). These crop residues, such as those from sorghum, may contain herbicidal properties (Uddin & Pyon, 2010; Khaliq *et al.*, 2011; Lahmod & Alsaadawi, 2014) that can be used to control weeds (Khaliq *et al.*, 2011). When these residues are incorporated into the soil (Liebman & Dyck, 1993) and start decomposing, they release allelopathic compounds (Kandhro *et al.*, 2016; Głąb *et al.*, 2017) that can affect both weeds and crops (Khaliq *et al.*, 2011; Weston *et al.*, 2013). Sorghum residues release three major allelopathic compounds (sorgoleone, dhurrin, and phenolic acids) (Weston, 1996; Inderjit & Duke, 2003). Sorgoleone, which is highly lipophilic (Dayan *et al.*, 2010; Trezzi *et al.*, 2016; Pan *et al.*, 2018), is produced by living sorghum roots (Dayan *et al.*, 2010) and its levels may be lower in dry sorghum residues whose allelopathic activity is activated by water (Inderjit & Duke, 2003).

Cultivar differences in the production of allelochemicals by sorghum have been reported (Alsaadawi *et al.*, 2015; Tibugari *et al.*, 2019; Tibugari *et al.*, 2020b, 2020c). In a study that quantified sorgoleone in 353 sorghum accessions from Southern Africa, the results showed that the South African accession IS9456 and the Botswanan accession IS22320 produced the highest levels of sorgoleone (584.69 µg mg^{-1} of root fresh weight) and no sorgoleone (0.0 µg mg^{-1} of root fresh weight), respectively (Tibugari *et al.*, 2019). These results revealed that these accessions may also produce water-soluble allelopathic compounds that have not yet been quantified. Water-soluble allelochemicals are likely to be released when sorghum residues start to decompose (Inderjit & Duke, 2003). The overall objective of this study was to determine the potential allelopathic effects of sorghum residues obtained from two sorghum landraces (a high sorgoleone producer and a nonsorgoleone producer) applied at three application rates on the emergence and early growth of maize, wheat and soybeans.

Materials and Methods

Description, treatments and experimental design

This experiment was conducted in a greenhouse in the Department of Crop Science at the University of Zimbabwe (17.7850° S, 31.0546° E) in 2017. Sorghum stalks, leaves and roots were harvested from the two varieties after physiological maturity and grain harvest at 135 days after emergence. The varieties were IS9456, a high sorgoleone producer, and IS22320, a zero sorgoleone producer. Sorghum was planted on February 24, 2017 in medium-grained sandy clay loam soil at Panmure Experiment Station in Shamva, Zimbabwe (31°47'E and 17°35'S) under supplementary irrigation. The soil type at the station is classified as chromic luvisols (Zimbabwean classification) or rhodexeralf alfisols (USDA classification) (Nyamapfene, 1991). A seeding rate of 7 kg ha^{-1} was used with an inter-row distance of 75 cm and planting stations 30 cm apart. A basal fertilizer, Compound D (7% N, 14% P_2O_5, 7% K_2O), was applied at a rate of 150 kg ha^{-1} at planting. The crop was top dressed with ammonium nitrate (34.5% N) at a rate of 150 kg ha^{-1} at four weeks after crop emergence. Weeds were controlled through hand hoeing during the second and fifth weeks after crop emergence. The crop was harvested at the hard dough stage. To collect the roots, a soaking overhead irrigation of 35 mm was applied. After 12 hours, all of the erect stalks were dug up using a hoe. The roots were collected from a radius of 30 cm and a depth of 40 cm. The roots were washed gently with tap water to remove the soil. The fresh stalks, leaves and roots were chopped with a knife into 2 to 3 cm pieces (Khaliq *et al.*, 2013) and mixed together by hand to allow for uniform distribution of the stalk, leaf and root portions.

In this study, three pot experiments were set up to evaluate the effects of the two sorghum varieties and three sorghum residue application rates (7.2 g, 14.4 g and 21.6 g kg^{-1} of soil) on the emergence and growth of maize, soybean and wheat seedlings. The pot experiments were laid out as a 2×3 factorial arranged in a randomized complete block design that was replicated 6 times. Sandy soil (79.3% sand, 15.8% silt and 4.9% clay), which was slightly acidic (pH 5.2) and collected from a 2-year fallowed farmer's field in Mudzi district (31°11' E and 17°49' S), was used in these experiments. The soil was classified as cambic arenosols (Zimbabwean classification) or psamments entisols (USDA classification) (Nyamapfene, 1991). The soil was sterilized by autoclaving at 120 °C for 24 hours. Planting pots measuring 13 cm diameter across the top, 15 cm vertical height, and 10 cm diameter across the bottom were used. Each pot was filled with 1.2 kg of soil. Sorghum residues of 7.2 g, 14.4 g or 21.6 g kg^{-1} soil from IS9456 and IS22320 were incorporated into the top 5 cm of the soil a day before planting. In addition, 1.5 grams of Compound D (7% N, 14% P_2O_5, 7% K_2O) was applied to the maize and wheat, while 1.5 grams of Compound L (4% N, 17% P_2O_5, 11% K_2O) was applied to the soybeans. A control in which no residues were applied was maintained for comparison. A day before planting, the pots were watered to 100% field capacity. To ensure the emergence of adequate numbers of even-age seedlings as described by Uddin & Robinson (2017), a total of 10 seeds (Tanveer *et al.*, 2014) of maize (variety SC727® Seed-Co), soybean (Serenade® Seed-Co), and wheat (Sahai® Seed-Co) were planted in each pot. The pots were watered daily with 10 ml of water to sustain the plants and to concurrently leach out any water-soluble allelochemicals from the residues into the soil (Hoffman *et al.*, 1996). Three days after emergence, the seedlings were thinned to one per pot. The average temperature in the greenhouse was 25 ± 2 °C.

Data analysis

Data on percent crop emergence were measured 7 days after planting (DAP) by dividing the number of seedlings that emerged by the number of seeds that were planted and multiplying by 100. The leaf chlorophyll content was determined nondestructively on Day 4 after crop emergence using a hand-held SPAD-502 Plus chlorophyll meter (Konica Minolta, Inc.). The height of the plants was measured at the termination of the experiment at 21 DAP. Furthermore, at 21 DAP, the plants were cut at ground level, oven dried for 48 hours at 70 °C and weighed to obtain their dry weight. The data were tested for normality using the Shapiro–Wilk test and subjected to analysis of variance using GenStat Release 14.1 (2011). Differences between means were compared using SED tests when the analyses indicated significant main or interaction effects at the $P<0.05$ level.

Results

Maize

The results (Table 1) show the effect of the source of the residue, residue application rate and their interaction on the percent emergence, height, chlorophyll content and dry weight of *Z. mays.* There was no significant ($P>0.05$) sorghum variety

× residue rate interaction on percent emergence, height, chlorophyll content or plant dry weight of the maize. There was a significantly higher maize emergence when residues from IS9456, the high sorgoleone producer, were incorporated than when residues from IS22320, the low sorgoleone producer, were incorporated in the soil. Maize dry weight was significantly higher when residues from IS22320 were incorporated than when residues from IS9456 were incorporated, in contrast to the emergence data. Averaged across the sorghum varieties, the maize plant dry weight, chlorophyll content and percent emergence significantly decreased ($P<0.001$) as the sorghum residue application rate increased from 7.2 g to 21.6 g kg^{-1} soil. Increasing the residue rate significantly ($P<0.001$) reduced the percent emergence, height and dry weight of the maize seedlings. Increasing the residue rate did not significantly ($P>0.05$) reduce the leaf chlorophyll content of the maize seedlings.

Soybean

The results (Table 2) show the effect of the source of residue, residue application rate and their interaction on the percent emergence, height, chlorophyll content and dry weight of soybean. There was no significant ($P>0.05$) sorghum variety × residue rate interaction on percent emergence, height, leaf chlorophyll content or dry weight of soybean. The main effects of sorghum accession on percent emergence, height, leaf chlorophyll content and dry weight of soybeans were also not significant ($P>0.05$). The main effect of the residue application rate was significant for the percent emergence ($P<0.05$), height ($P<0.001$), chlorophyll ($P<0.05$) and dry weight ($P<0.001$). Increasing the residue rate significantly ($P<0.05$) reduced the percent emergence, height, leaf chlorophyll content and dry weight of soybean seedlings.

Wheat

There was a significant ($P<0.001$) sorghum variety × residue application rate interaction effect on the percent emergence of wheat (Figure 1).

Increasing the rate of application of residues from IS22320 from 7.2 to 14.4 g kg^{-1} soil caused no significant reduction in the percent emergence of wheat. In contrast, wheat emergence significantly decreased as the rate of application of residues from IS9456 increased from 7.2 to 14.4 g kg^{-1} soil.

The results (Table 3) show the effect of the source of the residue, residue application rate

Table 1. Effect of sorghum variety and residue application rates on percent emergence, height, chlorophyll and dry weight of *Z. mays*

	% emergence	Height (cm)	Chlorophyll (nmol cm^{-2})	DW (g plant^{-1})
Source of residues (*Sorghum variety*)				
IS9456	85.0a	31.81a	33.90a	5.74b
IS22320	77.8b	27.28b	29.97b	6.78a
p value	$P<0.05$	$P<0.001$	$P<0.05$	$P<0.05$
±s.e.d.	2.91	1.150	1.624	0.370
Residue application rate (g kg^{-1} of soil)				
7.2	91.7a	32.83a	31.03	7.90a
14.4	81.7b	30.08a	31.86	6.25b
21.6	70.8c	25.71b	32.92	4.62c
p value	$P<0.001$	$P<0.001$	$P>0.05$	$P<0.001$
±s.e.d.	3.56	1.408	1.988	0.453
Source × residue application rate interaction				
p value	$P>0.05$	$P>0.05$	$P>0.05$	$P>0.05$
±s.e.d.	5.04	1.991	2.812	0.641

Table 2. Effect of sorghum residue application rate on % emergence and growth of *G. max*

	% emergence	Height (cm)	Chlorophyll (nmol cm^{-2})	DW (g plant^{-1})
Source of the residues (sorghum variety)				
IS9456	9.4	6.36	16.2	2.38
IS22320	13.3	6.92	19.9	1.91
P value	$P>0.05$	$P>0.05$	$P>0.05$	$P>0.05$
±s.e.d.	4.13	1.145	3.65	0.445
Residue application rate (g kg^{-1} of soil)				
7.2	22.5a	14.16a	25.3a	3.66a
14.4	8.3b	3.92b	17.7b	1.95b
21.6	3.3b	1.84b	11.0b	0.82c
P value	$P<0.05$	$P<0.001$	$P<0.05$	$P<0.001$
±s.e.d.	5.06	1.402	4.46	0.545
Sorghum variety × residue application rate interaction				
P value	$P>0.05$	$P>0.05$	$P>0.05$	$P>0.05$
±s.e.d.	7.15	1.982	6.31	0.771

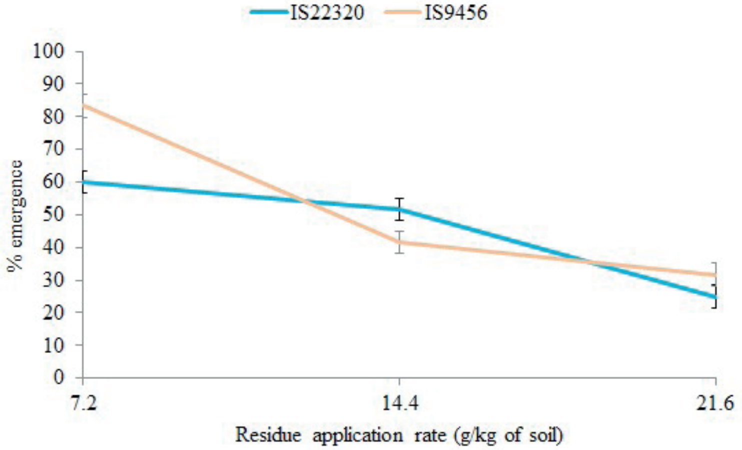

Figure 1. Sorghum variety × residue application rate interaction on the % emergence of wheat

and their interaction on the percent emergence, height, chlorophyll content and dry weight of wheat. The main effects of sorghum accession ($P<0.001$) and residue application rate ($P<0.001$) were significant for height. Sorghum residues from IS9456 significantly ($P<0.001$) reduced the height of wheat seedlings by 5.56 cm compared to residues from IS22320. The height of wheat seedlings significantly ($P<0.001$) decreased as the rate of application of sorghum residue increased.

There was a significant ($P<0.05$) sorghum accession × residue application rate interaction on wheat leaf chlorophyll content (Figure 2). Increasing the IS22320 residue application rate from 7.2 to 14.4 and from 14.4 to 21.6 g kg^{-1} soil did not significantly reduce the leaf chlorophyll content of wheat seedlings ($P>0.05$). In contrast, increasing the IS9456 residue application rate from 7.2 to 14.4 g kg^{-1} soil increased the leaf chlorophyll content of wheat seedlings.

Discussion

Incorporating residues from the sorghum accession IS22320, which did not produce any sorgoleone (0 µg mg^{-1} root fresh weight), and IS9456, which produced the highest sorgoleone (584.69 µg mg^{-1} root fresh weight) (Tibugari *et al.*, 2019), both

Table 3. Effect of sorghum residue application rate on % emergence and growth of *T. aestivum*

	% emergence	Height (cm)	Chlorophyll (nmol cm^{-2})	DW (g plant^{-1})
Source of the residues (sorghum variety)				
IS9456	52.22a	16.77b	28.88b	1.820
IS22320	45.56b	22.33a	33.14a	1.776
P value	$P<0.05$	$P<0.001$	$P<0.05$	$P>0.05$
±s.e.d.	1.975	1.357	1.186	0.0869
Residue application rate (g kg^{-1} of soil)				
7.2	71.67a	24.71a	30.02	2.176a
14.4	46.67b	20.63b	32.13	1.832b
21.6	28.33c	13.31c	30.89	1.387c
P value	$P<0.001$	$P<0.001$	$P>0.05$	$P<0.001$
±s.e.d.	2.419	1.662	1.453	0.1064
Sorghum variety × residue application rate interaction				
P value	$P<0.001$	$P>0.05$	$P<0.05$	$P>0.05$
±s.e.d.	3.421	2.351	2.054	0.1505

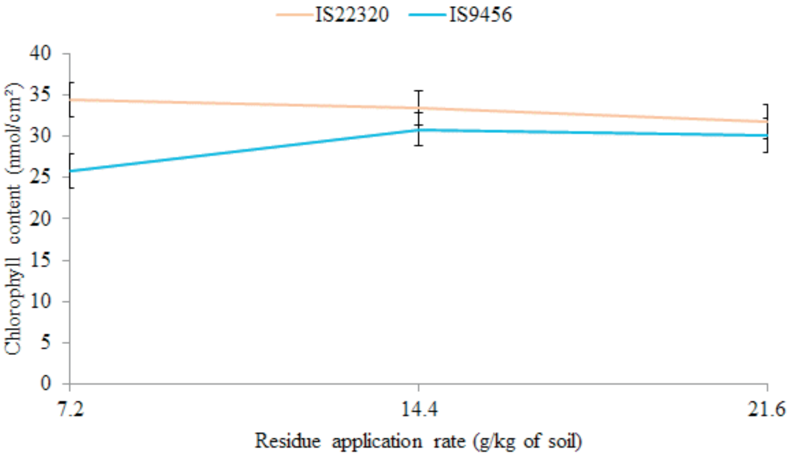

Figure 2. Sorghum variety × residue application rate interaction on the chlorophyll content of wheat

demonstrated possibility of allelopathic activity on crops. This may suggest that sorgoleone is not involved in allelopathic inhibition of crops. Since sorgoleone is exuded by living roots (Dayan *et al.*, 2010), it can be assumed that residues of the sorghum accessions IS9456 and IS22320 exuded water-soluble allelopathic compounds that had inhibitory effects on the three crops. There were differences in the emergence and growth parameters of maize and wheat caused by the sorghum variety as the source of the residues. Averaged across sorghum varieties, there was a decrease in percent emergence, height, and plant dry weight of wheat and maize seedlings and of percent emergence, height, plant dry weight and chlorophyll content of soybean.

The sorghum variety as a source of residue significantly reduced the percent emergence, height, leaf chlorophyll content and dry weight of the maize seedlings. These results imply that IS9456 and IS22320 possibly produced different types and concentrations of inhibitory water soluble allelopathic compounds. In contrast, the sorghum variety as a source of residue did not significantly reduce the percent emergence, height, leaf chlorophyll content or dry weight of soybean seedlings, suggesting that soybeans can possibly tolerate allelopathic stresses from IS22320 and IS9456.

There was no significant effect of sorghum residues from IS22320 on the leaf chlorophyll content of wheat seedlings. In contrast, there was an increase in leaf chlorophyll content when residues from IS9456 were incorporated. It can be deduced from these results that residues from IS22320 do not contain sufficient inhibitory compounds that can affect the chlorophyll content in wheat seedlings. The increase in the leaf chlorophyll content of wheat seedlings due to residues from IS9456 may suggest that this sorghum accession produces higher concentrations of water-soluble allelopathic compounds than IS22320. These results also suggest that the water-soluble phytotoxins (dhurrin and simple phenolic acids) in IS9456 residues possibly stimulate leaf chlorophyll content in wheat seedlings at low doses. A study conducted by Duke *et al.* (2006) agrees with the results of this study that the stimulatory response that was observed for IS9456 might possibly have been caused by physiological attempts to “escape” or compensate for chemical stress. Hormesis has been reported for herbicides (Belz, 2014) as well as for allelopathic plants (Duke, 2011).

Increasing the sorghum residue rate generally resulted in a decrease in the emergence and growth of all three crops. It was interesting to note that increasing the sorghum residue rate did not significantly reduce the leaf chlorophyll content of either maize or wheat seedlings, which, together with sorghum, all belong to the Poaceae family. The results may mean that the water soluble allelochemicals produced by residues from IS22320 and IS9456 are selective and possibly do not inhibit chlorophyll synthesis in grasses. This result also suggests that allelochemicals in the residues from IS22320 and IS9456 do not inhibit photosynthesis in maize and wheat. In the current study, increasing the residue rate significantly reduced the soybean seedling leaf chlorophyll content. These results agree with findings by Patterson (1981) that phenolic acids caused growth reduction in soybean due to reduced photosynthesis and chlorophyll content.

Based on this study, the involvement of water-soluble allelopathic compounds in inhibiting emergence and growth of the crops cannot be totally ruled out. Prior to conducting this study, only sorgoleone was quantified in the sorghum accessions (Tibugari *et al.*, 2019), while other potentially allelopathic compounds (dhurrin and phenolic acids) in the mature sorghum were not identified or quantified.

It may be difficult to conclusively attribute the inhibitory effects that were observed in the current study solely to sorghum allelopathy. There is a possibility that the reduced emergence and growth that was observed for maize, soybean and wheat may have been caused by a physical barrier from the sorghum residues since slightly higher than the recommended residue rates were used in the current study. A similar conclusion was reached by Chauhan & Abugho (2013) when they studied the effect of crop residue on the seedling emergence and growth of some weeds. It is also possible that incorporating sorghum residues with a low CN ratio in the soil might have caused immobilization of N such that the higher the rate of application, the less N and other mineral nutrients were available to the crops; hence, the height and plant dry weight decreased as the plant residue application rate increased.

Conclusions

Incorporated residues of IS9456 and IS22320 inhibited the emergence and early growth of maize and wheat irrespective of their sorgoleone contents. This suggests that both accessions produce water-soluble allelopathic compounds that are responsible for these allelopathic effects, as observed in the experiments conducted in this study. Since allelopathic compounds in sorghum residues are released in high quantities during the early stages of residue decomposition, the timing of the planting of maize and wheat after sorghum residue incorporation may be critical. Studies to determine the types and concentrations of water-soluble allelopathic compounds released by sorghum residues need to be conducted. An examination of the potential allelopathic effects of sorghum residues on other crops grown in rotation with sorghum may also be an interesting topic for future studies.

Resumen

H. Tibugari, C. Chiduza, A.B. Mashingaidze, y S. Mabasa. 2021. Los residuos de sorgo incorporados reducen la aparición y el crecimiento de plántulas de algunos cultivos. Int. J. Agric. Nat. Resour. 97-107. Los aleloquímicos de residuos de sorgo [*Sorghum bicolor* (L.) Moench] pueden inhibir la emergencia y el crecimiento de otros cultivos. Examinamos los efectos de los residuos de dos variedades locales de sorgo, IS9456, un alto productor de sorgoleona e IS22320, un productor de cero sorgoleona. Los residuos se aplicaron a 7,2 g, 14,4 gy 21,6 g kg^{-1} de suelo. La aparición y el crecimiento de maíz (*Zea mays* L.), trigo (*Triticum aestivum* L.) y soja [*Glycine max* (L.) Merr.] Se probaron en tres experimentos en macetas de invernadero en la Universidad de Zimbabwe en 2017. El 2×3 Los experimentos factoriales se colocaron como diseño de bloques completos al azar con seis repeticiones. Los residuos de IS22320 redujeron significativamente ($P<0,05$) la emergencia del maíz en un 22,2% en comparación con los residuos de IS9456. La variedad de sorgo como fuente de residuo no redujo significativamente ($P>0.05$) la emergencia, altura, contenido de clorofila y peso seco de la soja. El aumento de la tasa de residuos redujo significativamente ($P<0.05$) el porcentaje de emergencia, la altura, el contenido de clorofila y el peso seco de la soja. Hubo una interacción significativa entre la variedad de sorgo y la tasa de aplicación de residuos en el porcentaje de emergencia ($P<0.001$) y el contenido de clorofila ($P<0.05$) del trigo. El aumento de la tasa de aplicación de residuos de IS9456 de 7,2 a 14,4 g kg^{-1} de suelo aumentó el contenido de clorofila del trigo. El momento de la siembra de maíz y trigo después de la incorporación de residuos de sorgo puede ser crítico.

Palabras clave: Aleloquímicos, maíz, rastrojos incorporados al suelo, rotaciones de cultivos, soja, trigo.

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