PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.1741

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Soybean growth and production under straw of maize, *Urochloa brizantha*, *Conyza* spp. and *Digitaria insularis*

Katyussa Karolyne G. Pinheiro[1], Leandro P. Albrecht[2], Alfredo Junior P. Albrecht[2], Andreia Cristina P. R. da Costa[1], Bruna Lana C. Soares[1], Daniela O. Silva[1], André Felipe M. Silva[3*] & Jonathan Dieter[2]

[1]Department of Agronomic Science, State University of Maringá, Umuarama - 87502-970, Paraná, Brazil
[2]Department of Agronomic Science, Federal University of Paraná, Palotina - 85950-000, Paraná, Brazil
[3]Crop Science Pesquisa e Consultoria Agronômica Ltda., Maripá - 85955-000, Paraná, Brazil

*Email: afmoreirasilva@alumni.usp.br

OPEN ACCESS

ARTICLE HISTORY
Received: 21 February 2022
Accepted: 31 August 2022
Available online
Version 1.0 : 02 November 2022

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS etc.
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Pinheiro K K G, Albrecht L P, Albrecht A J P, Costa A C P R, Soares B L C, Silva D O, Silva A F M, Dieter J. Soybean growth and production under straw of maize, *Urochloa brizantha*, *Conyza* spp. and *Digitaria insularis*. Plant Science Today (Early Access). https://doi.org/10.14719/pst.1741

Abstract

Weeds can cause serious damage during soybean development, due to allelopathy, competition for water, light and nutrients. It is necessary to investigate the influence of straw, of weeds *Conyza* spp. and *Digitaria insularis*, in soybean growth, production and composition and grains. If there is influence of allelopathic compounds at the crop. The aim of this study was to evaluate the influence of straw of maize and *Urochloa brizantha* (A.Rich.) R.D.Webster crops and *Conyza* spp., *D. insularis*, on growth, production and composition of grains produced by soybean. Treatments consisted of the control (absence of straw), maize straw, *Urochloa brizantha* straw, *Conyza* spp. straw (500, 1000, 1500 or 2000 kg ha^{-1}) and *D. insularis* straw (500, 1000, 1500 or 2000 kg ha^{-1}). The chlorophyll index, height of plants and insertion of the first pod, stem diameter at the collar and at 5 cm from the collar, root dry mass, number of pods and grains, weight of total grains, weight of 100 grains, protein and nitrogen (N), catalase and peroxidase contents in grains were evaluated. There was no difference between treatments for plant height, first pod height and chlorophyll index, as well as for total pods and 100 grain weight and protein content, N content and peroxidase and carboxylase enzymatic activity of the grains produced. For stem diameter, a higher value was found for the treatment with maize straw compared to the control (no straw). For dry root matter, treatments without straw and with *Conyza* spp. straw up to 1500 kg ha^{-1}, differed from the treatment with maize straw. Even in some respects they provided beneficial effects compared to the absence of straw, which indicates the importance of crop residues. No allelopathic effects of weeds were observed on the growth and development of soybean. *Conyza* spp., *D. insularis,* maize or *U. brizantha* straws do not negatively affect soybean growth, production and grain composition.

Keywords

Agronomic performance, allelopathy, competition, *Glycine max* (L.) Merrill, interference

Introduction

Glycine max (L.) Merrill (soybean) in the 2020-2021 growing season occupied approximately 38.5 million ha, the largest area ever planted in Brazil, with a yield of 3529 kg ha^{-1}. In Brazil, it occupies a prominent position and is the most important culture in grain production and export (1). Soybean is considered one of the main sources of vegetable oils and proteins for human and animal food. It is a vital product in the Brazilian economy, especially for

the supply of oil for domestic consumption, animal feed as the main protein source, and biofuel production. Thus, there are many studies aimed at the cultivation of soybeans, with the aim of obtaining information that enable an increase in yield and/or a reduction in production costs (2-4), but regarding weed allelopathy and interaction in soybean crop, mainly in sandy soils, there is little information available.

During soybean cultivation, weeds develop, interfering with production. These are the plants defined as species that grow where they are not expected or develop spontaneously in agricultural areas or areas of human interest. The control of these plants is of paramount importance so that it is possible to obtain greater yield in any agricultural sector (5). Weeds can cause serious damage during crop development, in addition to causing an increase in the cost of control and/or yield losses (6, 7) due to allelopathy, competition for water, light, nutrients and other interferences (5) making crop management difficult.

Allelopathy is the influence of a biomolecule on the morphophysiological development of other plants. Often more than one function is achieved by plant allelopathy, such as reduced nutrient uptake, reduced or inhibited photosynthesis, altered plant respiration, altered membrane permeability (8, 9). It was verified that the influence of *Abutilon theophrasti* Medik. on soybean and cotton yields under different densities and interference exposure, whereas for soybeans and *Zea mays* L. (maize), *Cyperus difformis* L. residues affected root and shoot growth (10).

Factors such as clay fraction, organic matter, water availability, soil pH and microbiological activity directly interfere with the release of allelopathic compounds in the soil, with the expression of different forms of the same compound (11). It was observed that sandy soils have a low content of organic matter, therefore the inactivation and degradation of these compounds is slower due to the low number of microorganisms than in organic matter-rich clayey soils (12).

As an important weed in soybean cultivation, it can be mentioned the sourgrass (*Digitaria insularis* (L.) Mez ex Ekman), of the family Poaceae, native to subtropical and tropical regions of America. It forms clumps, reproduction is through seeds, has a slow growth until 45 days after emergence and soon after, there is a rapid increase in roots, due to the formation of rhizomes, so control is indicated up to 35 days after emergence (13, 14). The coexistence of 8 *D. insularis* plants m^{-2} with the soybean crop is already enough to reduce yield by 80% (6). The extract of *D. insularis* plants had a negative effect on germination and early development of the soybean crop in germination test (15), which indicates a possible allelopathic effect of this weed on soybean.

Another relevant weed in soybean cultivation is *Conyza* spp. belongs to the family Asteraceae, the main species are hairy fleabane (*Conyza bonariensis* (L.) Cronquist), horseweed (*Conyza canadensis* (L.) Cronquist) and Sumatran fleabane (*Conyza sumatrensis* (Retz.) E. Walker). It has an annual life cycle and herbaceous size, with high seed production, found in different agricultural environments, such as grain crops. A genus with widely adaptable species, with high genetic diversity and complex morphological identification in the differentiation between species. The dispersion of fleabane occurs exclusively through seeds present in the achene fruit (16). On the impact of this species on soybean, it was indicated that 2.7 *Conyza* plants m^{-2} can already reduce soybean yield by 50%. Some studies also indicate allelopathic effects of *Conyza* spp. on other plant species (17-19).

Therefore, it is necessary to investigate the influence of straw, of weeds *Conyza* spp. and *D. insularis*, in soybean growth, production and composition and grains. If there is influence of allelopathic compounds at the crop. The aim of this study was to evaluate the influence of straw of maize and *Urochloa brizantha* (A.Rich.) R.D.Webster crops and *Conyza* spp., *D. insularis*, on growth, production and composition of grains produced by soybean.

Materials and Methods

Experimental design

The experiment was carried out in Umuarama, state of Paraná (PR), Brazil (23°79'15''S 53°25'61''W, 400 m altitude), the region climate is mesothermal subtropical humid - Cfa (*C*: mild temperate; *f*: fully humid; *a*: hot summer), according to the Koppen-Geiger classification (20). A completely randomized design was used, with 11 treatments and 5 replications, each experimental unit consisting of a 16 dm^3 pot and each pot containing 2 plants. The treatments consisted of the control (no straw), 15340 kg ha^{-1} maize straw; 8871 kg ha^{-1} *U. brizantha* cv. MG-5 straw; for both, average values of straw production were used. For *Conyza* spp. and *D. insularis*, 500; 1000; 1500 and 2000 kg ha^{-1} were used, which corresponds to 12.3; 24.5; 36.8 and 49 plants of *Conyza* spp. per m^2 (40 cm tall) or 1.4; 2.8; 4.3 and 5.7 plants of *D. insularis* per m^2 (perennial plant clumps) respectively. Plant material, after collection, was dried in a forced -air oven at 40 °C to a constant weight, for subsequent covering of the pots.

To fill the pots, soil with a sandy texture, cation exchange capacity of 6.35 $cmol_c\,dm^{-3}$, pH (in H_2O) of 4.7 was used. Fertilization was carried out with 2270 kg ha^{-1} dolomitic limestone, 293 kg ha^{-1} single superphosphate. Six seeds were sown per pot, soybean cultivar BRS 1010 IPRO, early cycle, maturity group 6.1, indeterminate growth. Plant emergence occurred on December 24, 2017, with subsequent thinning to only 2 plants per pot.

Pots were kept in the open air and were kept free of weeds throughout the experiment. Pots were irrigated to soil field capacity. Fig. 1 illustrates the rainfall data during the experimental period (December 2017 to April 2018). When the soybean plants reached the V_3 stage (second fully developed trifoliate leaf) (21), straw from each treatment and top dressing (200 kg ha^{-1} KCl) were added.

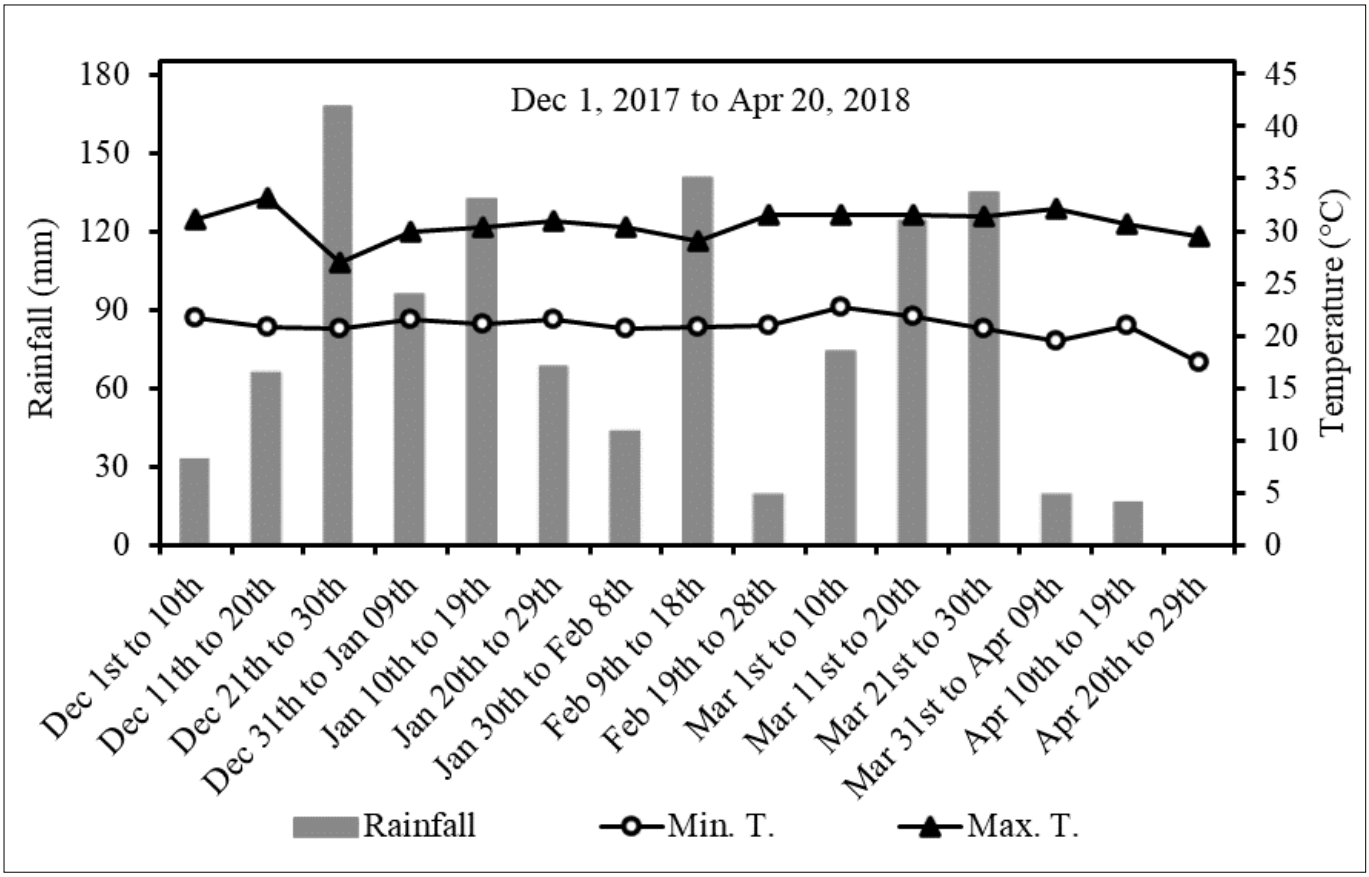

Fig. 1. Rainfall and air temperature during the experiment. Umuarama, PR, Brazil, 2017-2018 season.

Evaluations

For the chlorophyll index, a portable chlorophyll meter (CFL1030) was used, which provides the Falker chlorophyll index (FCI) (22). The central leaflet of the penultimate fully expanded trifoliate of each plant per pot was measured when the plants were at the R_1 (start of flowering) to R_2 stage (full flowering) (21).

When the plants reached the R_8 stage (full maturation) (21), the following variables were analyzed: plant height, first pod height, stem diameter in the collar, stem diameter at 5 cm from the collar, root dry mass, number of pods, number of grains, total grain weight, 100-grain weight, protein content, nitrogen (N) content, grain catalase and grain peroxidase. For plant height and the first pod height, 2 plants were measured in each pot, with a ruler from the ground level to the maximum point of growth, with presentation of the average value per plant. The stem diameter was measured with a digital caliper in the 2 plants of each pot, with the presentation of the average value per plant.

For number of pods and number of grains, values of the 2 plants per pot were measured and added up. For grain weight per pot, grains harvested from the 2 plants were measured, dried in an oven at 105 °C to constant weight, moisture was corrected to 13% and the corrected production was quantified. For 100-grain weight, 2 subsamples were measured, moisture corrected to 13%. For the root dry mass, soil in the pots was washed under running water, roots were separated, dried in an air circulating oven to constant weight and then weighed on a scale accurate to 2 decimal places.

The % of nitrogen on a wet basis and the % of proteins on a wet basis were determined using the Instituto Adolfo Lutz methodology (23). 3 gms of grains were dried in an air circulating oven to constant weight at 65 °C for 24 hr, ground in a blender, sieved and 0.2 g of each sample was weighed to quantify the 2 variables.

In the quantification of catalase and peroxidase, 1 g of grains harvested from each repetition were homogenized and randomly selected. These grains were cold macerated, together with phosphate buffer and polyvinylpyrrolidone and centrifuged at 3000 RPM for 10 min and extracted the supernatant. Catalase was evaluated according to the standard method described (24) and peroxidase was evaluated (25).

Statistical analysis

The Shapiro-Wilk normality test ($P < 0.05$) was applied to check the normality of the data and, when necessary, data were transformed (26). The means for number of pods, weight of grains, number of grains, catalase and peroxidase were transformed using the equation $\sqrt{(x+1)}$. Data obtained were subjected to analysis of variance by F-test ($P<0.05$) and the means were compared by Tukey's (27) test ($P<0.05$). Data were analyzed in Sisvar 5.6 (28).

Results

There was no difference between treatments for plant height, first pod height and chlorophyll index (Table 1), as well as for total pods and 100-grain weight (Table 2), and protein content, N content and peroxidase and carboxylase enzymatic activity of the grains produced (Table 3).

Table 1. Straw effect on some selected growth parameters of soybean.

Straw treatments	CI	PH	FP	SD	SDC	RDM
	FCI			cm		g
Without straw	33.4	45.9	12.8	0.69 ^{c}	0.56 ^{b}	06.6 ^{c}
15,340 kg ha^{-1} maize	35.1	60.1	9.4	0.99 ^{a}	0.81 ^{a}	14.4 ^{a}
8,871 kg ha^{-1} *U. brizantha*	34.6	54.0	10.0	0.95 ^{ab}	0.72 ^{ab}	11.1 ^{abc}
500 kg ha^{-1} *Conyza* spp.	35.1	46.9	11.7	0.79 ^{abc}	0.55 ^{b}	07.0 ^{c}
1,000 kg ha^{-1} *Conyza* spp.	32.6	50.6	12.8	0.71 ^{ab}	0.56 ^{b}	07.6 ^{bc}
1,500 kg ha^{-1} *Conyza* spp.	33.9	46.9	11.7	0.76 ^{bc}	0.60 ^{ab}	06.9 ^{c}
2,000 kg ha^{-1} *Conyza* spp.	34.1	50.9	11.3	0.81 ^{abc}	0.67 ^{ab}	08.7 ^{abc}
500 kg ha^{-1} *D. insularis*	34.2	44.7	10.5	0.75 ^{bc}	0.58 ^{b}	09.7 ^{abc}
1,000 kg ha^{-1} *D. insularis*	34.7	45.5	9.9	0.80 ^{abc}	0.67 ^{ab}	08.8 ^{abc}
1,500 kg ha^{-1} *D. insularis*	33.6	52.5	13.4	0.87 ^{abc}	0.65 ^{ab}	13.3 ^{a}
2,000 kg ha^{-1} *D. insularis*	34.1	48.7	9.5	0.84 ^{abc}	0.71 ^{ab}	11.4 ^{abc}
CV (%)	9.3	15.6	17.0	12.9	15.2	28.0
F	ns	ns	ns	*	*	*

CI: chlorophyll index, **PH**: plant height, **FP**: insertion height of the first pod, **SD**: stem diameter in the collar, **SDC**: stem diameter at 5 cm from the collar, **RDM**: root dry matter, **FCI**: Falker chlorophyll index.

*Means followed by the same superscript letter in the column do not differ by Tukey's (27) test (P<0.05). ^{ns}Non-significant, means do not differ each other by F-test (P>0.05).

Table 2. Straw effect on total pods, total grains, grain weight, and 100-grain weight of soybean.

Straw treatments	TP	TG	GW	100-GW
			g	
Without straw	56.2	132.6 ^{b}	20.4 ^{b}	15.9
15,340 kg ha^{-1} maize	148.0	361.6 ^{a}	57.0 ^{a}	15.8
8,871 kg ha^{-1} *U. brizantha*	128.0	314.4 ^{ab}	48.3 ^{ab}	15.6
500 kg ha^{-1} *Conyza* spp.	93.2	233.4 ^{ab}	34.1 ^{ab}	14.8
1,000 kg ha^{-1} *Conyza* spp.	76.0	185.0 ^{ab}	27.3 ^{ab}	14.7
1,500 kg ha^{-1} *Conyza* spp.	74.0	178.2 ^{ab}	26.3 ^{ab}	14.8
2,000 kg ha^{-1} *Conyza* spp.	89.2	217.6 ^{ab}	33.5 ^{ab}	15.1
500 kg ha^{-1} *D. insularis*	75.0	182.0 ^{ab}	29.0 ^{ab}	16.2
1,000 kg ha^{-1} *D. insularis*	65.8	157.8 ^{ab}	25.2 ^{ab}	16.1
1,500 kg ha^{-1} *D. insularis*	107.4	268.2 ^{ab}	39.9 ^{ab}	14.8
2,000 kg ha^{-1} *D. insularis*	103.6	239.0 ^{ab}	37.9 ^{ab}	15.9
CV (%)	23.5	22.8	21.9	7.9
F	ns	*	*	ns

TP: total pods, **TG**: total grains, **GW**: grain weight, **100-GW**: 100-grain weight.

*Means followed by the same superscript letter in the column do not differ by Tukey's (27) test (P<0.05). ^{ns}Non-significant, means do not differ each other by F-test (P>0.05).

Table 3. Straw effect on proteins and N content, enzymatic activity of peroxidase and catalase of grains of soybean.

Straw treatments	Proteins	N	Peroxidase	Catalase
	%			
Without straw	34.3	5.5	0.001529	0.001529
15,340 kg ha^{-1} maize	33.5	5.4	0.001279	0.001279
8,871 kg ha^{-1} *U. brizantha*	32.3	5.2	0.001111	0.001111
500 kg ha^{-1} *Conyza* spp.	33.3	5.3	0.001295	0.001295
1,000 kg ha^{-1} *Conyza* spp.	33.8	5.4	0.001216	0.001216
1,500 kg ha^{-1} *Conyza* spp.	35.3	5.6	0.001856	0.001856
2,000 kg ha^{-1} *Conyza* spp.	35.7	5.7	0.001268	0.001268
500 kg ha^{-1} *D. insularis*	36.4	5.8	0.001523	0.001523
1,000 kg ha^{-1} *D. insularis*	36.0	5.8	0.001896	0.001896
1,500 kg ha^{-1} *D. insularis*	35.2	5.6	0.001312	0.001312
2,000 kg ha^{-1} *D. insularis*	36.3	5.8	0.001793	0.001793
CV (%)	7.2	7.2	0.1	0.1
F	ns	ns	ns	ns

TP: total pods, **TG**: total grains, **GW**: grain weight, **100-GW**: 100-grain weight. ^{ns}Non-significant, means do not differ each other by F-test (P>0.05).

Conyza spp., *D. insularis*, maize or *U. brizantha* straws do not affect these soybean parameters.

For stem diameter, a higher value (0.99 cm) was found for the treatment with maize straw compared to the control (no straw) (0.69 cm). However, the stem diameter values observed for maize straw did not differ from those observed for *U. brizantha* straw and for *Conyza* spp. and *D. insularis* in the highest amounts of straw (Table 1).

For dry root matter, treatments without straw (6.6 g) and with *Conyza* spp. straw up to 1500 kg ha^{-1} (6.9 to 7.6 g), differed from the treatment with maize straw (14.4 g) (Table 1). This is possibly because this weed has thicker and heavier stems, where the amount of 2000 kg ha^{-1} was not enough to completely cover the soil. Although, these treatments resulted in a lower number of roots than the others, only the treatment without straw resulted in a lower number and weight of grains per pot compared to the use of maize straw (Table 2).

The results did not show any allelopathic effect of weeds on the growth and development of soybean plants. Weeds even sometimes had a beneficial effect on soybeans, compared to the absence of straw, which reiterates the importance of plant residues in the system, even if from weeds. Obviously, the use of weeds as cover in off-season periods is not recommended, given the risk of seed

dissemination in the production system, but the importance of soil cover, for example with cover crops is highlighted.

Discussion

Our results highlight the importance of soil cover, for example with cover crops. Straw, from any plant species, protects the soil against the impact of rain drops, resulting in less soil run-off and preventing the breakdown of particles. It also improves the use of available natural resources: water, nutrients and light, increases soil fertility with nutrient recycling, increases soil organic content, improves physical, chemical and biological properties, reduces soil erosion and compaction. It also plays a key role in the control of nematodes and weeds (29-31).

We assume that if plants of *Conyza* spp., *D. insularis*, maize and *U. brizantha* release allelopathic compounds, they may be in the root exudation of these plants, since in the present study, only plant straws were used, without the presence of roots thereof. Since, in other studies, the release of allelopathic compounds into the medium can occur through waste decomposition, leaching, volatilization and root exudation (32, 33).

In the present study, the amount of weed straw may not have been enough to release allelopathic compounds on soybean. While (19) it was reported a negative effect of aqueous extracts of *Conyza sumatrensis* (from roots and shoots) on seed germination of *Bidens pilosa*, with an increase due to the increased concentration of extracts, as well as a stronger effect for the root extracts. Similar to observed for *D. insularis* extracts on canola germination (34).

Another factor that may have influenced the absence of allelopathic compounds, in the present study, is the time of year. In this respect, on concentrations of sesquiterpenes, there were variations according to the seasons, proving that environmental conditions influence the presence of these compounds and according to the authors, these results are due to environmental variations in temperature and light (35). The release of allelopathic compounds may be related to the availability of water, soil pH, organic matter and microbiological activity, interfering with the expression of these compounds in soil (8). Sandy soils have lower organic matter content compared to clayey soils, making the inactivation and degradation of allelopathic compounds slower (9).

There were no differences in protein and N content in grains in our study. These contents are governed by genetic factors, but they are also influenced by the environment throughout the seed filling period (36, 37), however in the present study the environment did not influence these contents. As for the activity of catalase and peroxidase, no significant results were found. The presence of these enzymes is associated with the antioxidant complex of plants, they use these enzymes for detoxification (38, 39). As there was no high activity of these enzymes with the aim of detoxification, then it is inferred that exogenous oxidizing factors from the straw covers were not observed affecting the seeds produced.

Weeds, in coexistence with soybean, cause serious damage during crop development, making plant management difficult, due to allelopathy, competition for water, light, nutrients and other interferences. But in the present study, weed straw did not affect soybeans negatively. With the exception of the risks of weeds during the off-season, in some respects the weed straw was even beneficial. This reinforces the importance of cover crops during the off-season in grain cultivation.

Conclusion

Conyza spp., *D. insularis*, maize or *U. brizantha* straws do not negatively affect soybean growth, production and grain composition. It was not possible to verify whether the root system of these plants produce allelopathic substances capable of negatively influencing soybean performance, indicating the possibility of further research in this field of study in different soil and climate conditions.

Acknowledgements

The authors are grateful for the support of the State University of Maringá (UEM) and the Federal University of Paraná (UFPR).

Authors contributions

KKGP conceptualized the study, performed the field work, laboratory and analysis, and wrote the manuscript. LPA conceptualized the study, supervised the project, performed the analysis, and wrote and edited the manuscript. AJPA conceptualized the study, supervised the project, and wrote and edited the manuscript. ACPRC performed the methodology, and edited the manuscript. BLCS performed the field work and laboratory, and edited the manuscript. DOS performed the field work and laboratory, and edited the manuscript. AFMS performed the analysis and wrote the manuscript. JD performed the laboratory study and edited the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

References

1. Companhia Nacional do Abastecimento (CONAB). Acompanhamento da safra brasileira de grãos, safra 2020/21, décimo primeiro levantamento. Brasília (Brazil): CONAB; 2021.
2. Umburanas RC, Kawakami J, Ainsworth EA, Favarin JL, Anderle LZ, Dourado-Neto, D et al. Changes in soybean cultivars released over the past 50 years in southern Brazil. Sci Rep. 2022;12:508. https://doi.org/10.1038/s41598-021-04043-8

3. Santos TG, Battisti R, Casaroli D, Alves Junior J, Evangelista AWP. Assessment of agricultural efficiency and yield gap for soybean in the Brazilian Central Cerrado biome. Bragantia. 2021;80:e1821. https://doi.org/10.1590/1678-4499.20200352
4. Todeschini MH, Milioli AS, Rosa AC, Dallacorte LV, Panho MC, Marchese JA, Benin G. Soybean genetic progress in South Brazil: physiological, phenological and agronomic traits. Euphytica. 2019;215:124. https://doi.org/10.1007/s10681-019-2439-9
5. Silva AFM, Giraldeli AL, Silva GS, Araújo LS, Albrecht AJP, Albrecht LP, Victoria Filho R. Introdução à ciência das plantas daninhas. In: Barroso AAM, Murata AT, Editors. Matologia: estudos sobre plantas daninhas. Jaboticabal (Brazil), Fábrica da Palavra; 2021.
6. Gazziero DLP, Adegas FS, Silva AF, Concenço G. Estimating yield losses in soybean due to sourgrass interference. Planta Daninha. 2019;37:e019190835. https://doi.org/10.1590/S0100-83582019370100047
7. Daramola OS. Timing of weed management and yield penalty due to delayed weed management in soybean. Planta Daninha. 2020;38:e020236046. https://doi.org/10.1590/S0100-83582020380100072
8. Farooq M, Bajwa AA, Cheema SA, Cheema ZA. Application of allelopathy in crop production. Int J Agric Biol. 2013;15:1367-78.
9. Scavo A, Restuccia A, Mauromicale G. Allelopathy: principles and basic aspects for agroecosystem control. Sustain Agric Res. 2018;28:47-101. https://doi.org/10.1007/978-3-319-90309-5_2
10. Bortolini MF, Fortes AMT. Allelopathic effects on the germination of soybean seeds (*Glycine max* L. Merrill). Semina: Cienc Agrar. 2005;26:5-10. http://dx.doi.org/10.5433/1679-0359.2005v26n1p5
11. Trezzi MM, Vidal RA, Balbinot Junior AA, Bittencourt HV, Silva Filho APS. Allelopathy: driving mechanisms governing its activity in agriculture. J Plant Interact. 2016;11:53-60. https://doi.org/10.1080/17429145.2016.1159342
12. Almeida GD, Zucoloto M, Zetun MC, Coelho I, Sobreir FM. 2008. Oxidative stress in vegetable cells mediated by allelochemicals. Rev Fac Nac Agron Medellín. 2008;61:4237-47.
13. Machado AFL, Ferreira LR, Ferreira FA, Fialho CMT, Tuffi-Santos LD, Machado MS. Growth analysis of *Digitaria insularis*. Planta Daninha. 2006;24:641-7. https://doi.org/10.1590/S0100-83582006000400004
14. Gemelli A, Oliveira Junior RS, Constantin J, Braz GBP, Jumes TMC, Gheno EA, et al. Estratégias para o controle de capim-amargoso (*Digitaria insularis*) resistente ao glyphosate na cultura milho safrinha. Rev Bras Herb. 2013;12:162-70. https://doi.org/10.7824/rbh.v12i2.201
15. Gonçalves A, Tonet A, Stofell A. Potencial alelopático das plantas daninhas sobre o desenvolvimento de plântulas de soja (*Glycine max* L.). Rev Eletron Fac Cienc Exatas Terra - Prod/Constr Tecnol. 2015;4:52-59.
16. Bajwa AA, Sadia S, Ali HH, Jabran K, Peerzada AM, Chauhan BS. Biology and management of two important *Conyza* weeds: a global review. Environ Sci Pollut Res. 2016;23:24694-710. https://doi.org/10.1007/s11356-016-7794-7
17. Trezzi MM, Vidal RA, Patel F, Miotto Junior E, Debastiani F, Balbinot Junior AA, Mosquen R. Impact of *Conyza bonariensis* density and establishment period on soyabean grain yield, yield components and economic threshold. Weed Res. 2015;55:34-41. https://doi.org/10.1111/wre.12125
18. Hu G, Zhang ZH. Aqueous tissue extracts of *Conyza canadensis* inhibit the germination and shoot growth of three native herbs with no autotoxic effects. Planta Daninha. 2013;31:805-11. https://doi.org/10.1590/S0100-83582013000400006
19. Ferreira PJ, Zonetti PC, Albrecht AJP, Rosset IG, Silva AFM, Albrecht LP, Vieira AH, Paulert R. *Conyza sumatrensis* allelopathy effect on *Bidens pilosa* (Asteraceae) seed germination. Bot Sci. 2020;98:348-54. https://doi.org/10.17129/botsci.2445
20. Aparecido LEO, Rolim GS, Richetti J, Souza PS, Johann JA. Köppen, Thornthwaite and Camargo climate classifications for climatic zoning in the State of Paraná, Brazil. Cienc Agrotecnol. 2016;40:405-17. https://doi.org/10.1590/1413-70542016404003916
21. Fehr WR, Caviness CE, Burmood DT, Pennington JS. Stage of development descriptions for soybeans, *Glycine max* (L.) Merrill. Crop Sci. 1971;11:929-31. https://doi.org/10.2135/cropsci1971.0011183X001100060051x
22. Xavier WD, Castoldi G, Cavalcante TJ, Rodrigues CR, Trindade PR, Luiz IA et al. Portable chlorophyll meter for indirect evaluation of photosynthetic pigments and nitrogen content in sweet Sorghum. Sugar Tech. 2021;23:560-70. https://doi.org/10.1007/s12355-020-00922-y
23. Instituto Adolfo Lutz (IAL). 2008. Métodos físico-químicos para análise de alimentos. 4th ed. São Paulo, SP, Brazil, IAL.
24. Aebi H. Catalase *in vitro*. Methods Enzymol. 1984;105:121-26. https://doi.org/10.1016/S0076-6879(84)05016-3
25. Putter J. Peroxidase. In: Bergmeyer HU, Editors. Methods of enzymatic analysis. Weinheim (Germany): Verlag Chemie; 1974.
26. Warrick AW, Nielsen DR. Spatial variability of soil physical properties in the field. In: Hillel D, Editors. Applications of Soil Physics. Nova York: Academic Press; 1980. https://doi.org/10.1016/B978-0-12-348580-9.50018-3
27. Tukey JW. Comparing individual means in the analysis of variance. Biometrics. 1949;5:99-114. https://doi.org/10.2307/3001913
28. Ferreira DF. Sisvar: a computer statistical analysis system. Cienc Agrotecnol. 2011;35:1039-42. https://doi.org/10.1590/S1413-70542011000600001
29. Piccoli I, Sartori F, Polese R, Berti A. Crop yield after 5 decades of contrasting residue management. Nutr Cycl Agroecosystems. 2020;117:231-41. https://doi.org/10.1007/s10705-020-10067-9
30. Pittman KB, Barney JN, Flessner ML. Cover crop residue components and their effect on summer annual weed suppression in corn and soybean. Weed Sci. 2020;68:301-10. https://doi.org/10.1017/wsc.2020.16
31. Gomes AO, Albrecht LP, Albrecht AJP, Silva AFM, Krenchinski FH, Rodrigues DM et al. Cover crops at soybean agronomic performance in the western region of Paraná state, Brazil. Rev Bras Cienc Agrar. 2022;17:e8916. https://doi.org/10.5039/agraria.v17i1a8916
32. Rice EL. Allelopathy. Nova York: Academic Press; 1984.
33. Seigler DS. Chemistry and mechanisms of allelopathic interactions. Agron J. 1996;88:876-85. https://doi.org/10.2134/agronj1996.00021962003600060006x
34. Campos TS, Sousa AGV, Rego Junior JS, Sousa WS, Benett CGS, Arruda N. Allelopathic effect of *Sorghum bicolor* and *Digitaria insularis* on germination and initial development of Canola. Rev Agric Neotrop. 2020;7:65-72. https://doi.org/10.32404/rean.v7i4.4230
35. Almeida LFR, Portella RDO, Bufalo J, Marques MOM, Facanali R, Frei F. Non-oxygenated sesquiterpenes in the essential oil of *Copaifera langsdorffii* Desf. increase during the day in the dry season. PLoS One. 2016;11:e0149332. https://doi.org/10.1371/journal.pone.0149332
36. Ávila MR, Braccini AL, Scapim CA, Mandarino JMG, Albrecht LP, Vidigal Filho. Isoflavone, protein and oil contents and soybean seed quality. Rev Bras Sem. 2007;29: 111-27. https://doi.org/10.1590/S0101-31222007000300014

37. Assefa Y, Purcell LC, Salmeron M, Naeve S, Casteel SN, Kovács P et al. Assessing variation in US soybean seed composition (protein and oil). Front Plant Sci. 2019;10:298. https://doi.org/10.3389/fpls.2019.00298

38. Hamani AKM, Wang G, Soothar MK, Shen X, Gao Y, Qiu R, Mehmood F. Responses of leaf gas exchange attributes, photosynthetic pigments and antioxidant enzymes in NaCl-stressed cotton (*Gossypium hirsutum* L.) seedlings to exogenous glycine betaine and salicylic acid. BMC Plant Biol. 2020;20:434. https://doi.org/10.1186/s12870-020-02624-9

39. Rajput VD, Singh RK, Verma KK, Sharma L, Quiroz-Figueroa FR, Meena M et al. Recent developments in enzymatic antioxidant defence mechanism in plants with special reference to abiotic stress. Biology. 2021;10:267. https://doi.org/10.3390/biology10040267

§§§