Journal of Agricultural Science; Vol. 10, No. 2; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Sugarcane Crop Residue and Bagasse Allelopathic Impact on Oat (*Avena sative* L.), Tall Morningglory (*Ipomoea purpurea* L. Roth), and Redroot Pigweed (*Amaranthus retroflexus* L.) Germination

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Received: November 6, 2017 Accepted: December 2, 2017 Online Published: January 15, 2018

doi:10.5539/jas.v10n2p15 URL: https://doi.org/10.5539/jas.v10n2p15

Abstract

Allelopathy, the chemical interaction between plants, may result in the inhibition of plant growth and development, and includes compounds released from a primary crop that adversely impact crop or weed species. The objective of this research was to observe the allelopathic impact of sugarcane (*Saccharum* sp.) post-harvest crop residue and mill bagasse leachate on seed germination of three other plant species. Oat (*Avena sative* L.) var. 'Corral', tall morningglory (*Ipomoea purpurea* L. Roth), and redroot pigweed (*Amaranthus retroflexus* L.) seeds were treated with 5 leachate concentrations (0, 12.5, 25, 50, and 100 g/L) from either sugarcane crop residue or sugarcane bagasse. Each experiment was repeated twice (Experiment 1 & 2) with each plant species, leachate concentrations, and leachate source (sugarcane crop residue and mill bagasse). The impact of leachates from sugarcane variety 'HoCP 96-540' crop residue and sugarcane bagasse differed by the species evaluated (oat, morningglory, and redroot pigweed), the leachate source (crop residue vs. bagasse), and leachate concentration (0 to 100 g/L). Oat germination was not affected leachate source or concentration. Germination for both weed species, tall morningglory and redroot pigweed, were adversely affected by leachate source and concentration. In both cases, the sugarcane crop residue leachate had a greater deleterious impact on germination than did the bagasse leachate. The response to the leachates was more consistent and severe for tall morningglory germination than redroot pigweed germination. Averaged across experiments, the 12.5 g/L crop residue concentration decreased the tall morningglory germination to 17% compared to 34% germination for the bagasse leachate, and the 100 g/L residue concentration reduce germination to 6% compared to 19% for bagasse 100 g/L bagasse concentration. The 100 g/L concentration of crop residue reduced redroot pigweed germination by 13% (Experiment 1) and 27% (Experiment 2), while the bagasse leachate reduced germination by 5% (Experiment 1) and 15% (Experiment 2). Future research should investigate the allelopathic compounds present in the sugarcane crop residue and bagasse, determine if the same allelopathic compounds are present and in the same concentration among other sugarcane varieties, and further examine which weed and crop species may be vulnerable to the allelopathic compounds present in sugarcane crop residue and bagasse.

Keywords: allelopathy, pestiphytology, morningglory, redroot pigweed, seed germination, sugarcane

1. Introduction

1.1 Allelopathy

Many plant species, both crop and weed plants, are now known to produce compounds that when released into the environment can impact the growth and development of other plants (Rice, 1984). Allelopathy is the term used to describe this biochemical interaction between plants, whether inhibiting or stimulating plant growth and development (Molisch, 1937; Rice, 1984). There is a growing interest by the general public for naturally produced crops and, therefore, a positive incentive to explore the use of natural plant chemicals to either promote crop growth and production, or inhibit weed growth and development (Bowmick & Doll, 1982; Rice, 1984; Russo et al., 1997a, 1997b; Webber et al., 2015a, 2015b, 2017a, 2017b, 2017c). Information gleaned from allelopathic compounds has been used to produce natural herbicides and develop synthesized herbicides which are closely related the allelopathic compounds (Duke & Dayan, 2013; Cheema & Khaliq, 2000; Gerwick & Sparks, 2014).

Allelopathy can also adversely impact the same crop that is producing the allelopathic compounds (autotoxicity) when an annual crop is replanted in the same field or where a perennial crop is present multiple years (Putnam, 1985; Schreiner & Reed, 1907). Examples of autotoxicity for annual crops include barley (*Hordeum vulgare* L.) (Ben-Hammouda et al., 2002), corn (*Zea mays* L.) (Almezori et al., 1999; Anderson & Cruse, 1995), rice (*Oryza sativa* L.) (Chen et al., 2008; Chou & Chiou, 1979; Dilday et al., 1994), winter wheat (*Triticum aestivum* L.) (Wu et al., 2001, 2007), and sorghum (*Sorghum bicolor* L. Moench) (Ben-Hammouda et al., 1995). Sorghum produces sorgoleone, an allelopathic compound that exhibits similar herbicidal activity as the commercial herbicide atrazine (Nimbal et al., 1996). Examples of perennial crops exhibiting autotoxicity include alfalfa (*Medicago sativa* L.) (Chung & Miller, 1995; Hedge & Miller, 1990), asparagus (*Asparagus officinalis* L.) (Motoki et al., 2002), and sugarcane (*Saccharum* sp.) (Viator et al., 2006).

1.2 Sugarcane and Allelopathy

Allelopathic compounds have been detected in leachates from sugarcane leaves in several studies (De Carvalho et al., 1996; Singh et al., 2003; Viator et al., 2006). For example, Viator et al. (2006) identified benzoic acid from post-harvest sugarcane crop residue, variety 'LCP 85-384'. Benzoic acid and its derivatives have been shown to be allelopathic to cotton (*Gossypium hirsutum* L.) (Lodhi et al., 1987), wheat (Lodhi et al., 1987) and ryegrass (*Lolium* spp.) (Wu et al., 2002) and dicamba, a commercial herbicide, is a benzoic acid compound. In addition, the allelopathic compounds of ferulic, vanillic and syringic acids have been isolated from sugarcane crop residue leachates (Sampietro et al., 2005; Sampietro & Vattuone, 2006b). Phenolic compounds, used in commercial herbicides (*i.e.* bromoxynil and isonil), have been isolated from sugarcane leaves (Sampieto & Vattuone, 2006a).

Sugarcane crop residue leachates reduced germination and radical growth of the field crops oat (*Avena nuda* L.), (Viator et al., 2006), rye (*Secale cereale* L.) (Viator et al., 2006), sorghum (*Sorghum bicolor* L. Moench) (Sampietro & Vattuone, 2006b), and wheat (*Triticum aestivum* L.) (Sampietro & Vattuone, 2006b); the vegetable crops tomato (*Solanum lycopersicum* L.) (Webber et al., 2017b), Chinese kale (*Brassica oleracea* L. var. *alboglabra* Bailey) (Webber et al., 2017b), cucumber (*Cucumis sativus* L.) (Webber et al., 2017b), and radish (*Raphanus sativus* L.) (Sampietro & Vattuone, 2006b); and the weeds arrowleaf sida (*Sida rhombifolia* L.) (Sampietro et al., 2007), pigweed (*Amaranthus quitensis* L.) (Sampietro & Vattuone, 2006b), redroot pigweed (*Amaranthus retroflexus* L.) (Webber et al., 2017c), spiny pigweed (*Amaranthus spinosus* L.) (Webber et al., 2017c), wild mustard (*Brassica campestris* L.) (Sampietro & Vattuone, 2006b), tall morningglory (*Ipomoea purpurea* L. Roth) (Viator et al., 2006), and red morningglory (*Ipomoea coccinea* L.) (Webber et al., 2017c).

Webber et al. (2017c) was the first to document that sugarcane root leachate were allelopathic. In a bioassay experiment, the highest root concentration tested (100 g/L) decreased red morningglory and redroot pigweed germination by 20% and 19%, respectively, while spiny amaranth germination was unaffected (Webber et al., 2017c). In addition to the sugarcane leaves and roots, Rodrigues et al. (2001) documented that the breakdown of sugarcane bagasse lignocellulosic material produced toxic compounds that inhibit cellular growth. Others have indicated that the leaching or the microbial breakdown of the bagasse may have an allelopathic (toxic) impact on squash plants (Facelli & Pickett, 1991; Rice, 1984; Rodrigues et al., 2001; Webber et al., 2017a) and tomato (Webber et al., 2017b). Research was initiated to determine the allelopathic impact of sugarcane crop residue and sugarcane bagasse leachates on the germination of three plant species (oat, morningglory, and redroot pigweed).

2. Material and Methods

2.1 Plant Material Collection

Sugarcane var. 'HoCP 96-540' (Tew et al., 2005) crop residue (straw) was collected at the USDA, ARS, Sugarcane Research Unit, Ardoyne Farm, Schriever, LA, immediately after harvesting the sugarcane in 2015. Since 2008, HoCP 96-540 has been planted to more hectares in Louisiana than any other sugarcane variety (Gravois, 2014). The crop residue averaged 716 g/m^2 (71.6 mt/ha) on an oven dry weight basis, which included leaves, immature nodes and growing tips. Sugarcane mill bagasse was collected from the Raceland Raw Sugar Corporation mill in Raceland, LA, in March of 2016. Sugarcane bagasse is the fibrous material remaining after removing the sucrose, water, and other impurities (filter mud) from the millable sugarcane.

2.2 Sugarcane Leachate Preparations

The sugarcane crop residue and bagasse were dried in a forced air oven at 60 °C to a constant weight. The dried material was then ground using a Thomas-Wiley Laboratory Mill with a 2-mm sieve. The plant materials and deionized water were added to 4000-ml flasks and placed on a Lab-Line Orbit Shaker at 100 rpm for 12 h at room temperature (22 °C). The extracts were vacuum filtered using a three step process; 1) filtered through a Buchner funnel sans filter paper, 2) Buchner funnel with a VWR Qualitative, 417 filter (9.0 cm diameter), and 3) Buchner funnel with a Whatman® #2 filter (9.0 cm diameter). The samples were then diluted as needed with deionized water to produce concentrations of 100 g/L (full strength), 50 g/L (half strength), 25.0 g/L (quarter strength) and 12.5 g/L (eighth strength) extracts of sugarcane roots and sugarcane crop residue (Webber et al., 2005a, 2005b, 2017b). The pH for all dilutions was adjusted to 7.0 using 1M KOH and 5% $C_2H_4O_2$ (acetic acid).

2.3 Leachate Treatments of the Seeds

The oat (*Avena sativa* L.) var. 'Corral' was purchased from Seedway (Hall, NY, USA). The tall morningglory (*Ipomoea purpurea* L. Roth) seed was purchased from Eden Brothers (Asheville, NC, USA), while the redroot pigweed (*Amaranthus retroflexus* L.) seed was purchased from River Refuge Seed Company (Brownsville, OR, USA). The tall morningglory and redroot pigweed seed were surface sterilized for 1 min using a 50% bleach (6% sodium hypochlorite) 50% deionized water solution. The seeds were then rinsed with deionized water and allowed to air dry for 10 min. A preliminary germination test determined that the oat seed was adversely impacted by the surface sterilization, therefore the oat seed was not surface sterilized in this experiment. Twenty seeds of each plant species were placed in separate Petri plates which contained 9.0 cm Whatman® No. 2 filter papers. To each Petri plate was added 10 ml of either sugarcane crop residue or bagasse at each of the concentrations [0 (deionized water), 12.5, 25, 50, and 100 g/L]. The Petri plates were covered and placed in a non-illuminated incubator at 27 °C. After 7 d the Petri plates were removed and seed germination was measured. Seeds were considered germinated when the seed radicle was equal to or greater than the length of the width of the seed of the specific plant species being measured. The experimental design for each of the 3 plant species (oat, morning glory, and redroot pigweed) were RCBD which included 2 sources of leachates (sugarcane crop residue and sugarcane bagasse) and 5 treatment leachate concentrations (0, 12.5, 25, 50, and 100 g/L). Each germination experiment was repeated twice with 5 replications in each experiment. All data were subjected to PROC ANOVA and mean separation using LSD with P = 0.05 (SAS Inc., SAS, Ver. 9.4, Cary, NC).

3. Results and Discussion

3.1 Statistical Analysis

Significant interactions existed among plant species (oat, tall morningglory, and redroot pigweed), extract concentration (0, 12.5, 25, 50, and 100 g/L), and experiments (Table 1); therefore, the plant species will be discussed separately, and, where necessary, the experiments will be discussed individually (Tables 2, 3, and 4).

Table 1. Analysis of variance (ANOVA) for percentage germination of oat, tall morningglory, redroot pigweed for source factors experiments, treatments, and experiment × treatment

Source	Oat	Tall Morningglory	Redroot Pigweed
	Pr > F	Pr > F	Pr > F
Experiment	0.1927^Z	0.0175	< .0001
Treatment	0.6415^Z	< .0001	< .0001
Experiment × Treatment	0.7964^Z	0.079^Z	0.0081

Note. ^{Z}Not Significantly Different at P = 0.05, PROC ANOVA.

3.2 Oat Germination

There were no significant interactions between experiments (1 and 2) and the leachate concentrations for oat germination; therefore, the oat germination results will be discussed by experiment and averaged across experiments (Tables 1 and 2). There were no significant differences among sugarcane residue and bagasse leachates, leachate concentration within experiment 1, 2, or averaged across both experiments (Table 2). These results are in contrast to Viator et al. (2006) who reported that a sugarcane crop residue variety 'LCP 85-384' significantly decreased oat (*Avena nuda* L.) var. 'Rodeo' when comparing the control, (0% concentration) to the 25% and 100% leachate concentrations.

Although, the sugarcane variety 'HoCP 96-540', which was used in our research, is a complex hybrid derived from crossing 'LCP 85-384' and 'LCP 86-454' (Tew et al., 2005), Wu et al. (2002) determined that allelopathic compounds, their concentration, and bioassay impact can vary across crop varieties. In addition, the oat seed used in the two experiments were very different, actually two different species. Viator et al. (2006) used *Avena* *nuda* L. oat species, which is usually referred to as "naked oat" because it produces a hulless oat seed with only fine hairs called trichomes on the seed. The "common oat" (*Avena sativa* L.) seed used in our research in contrast is a widely cultivated specie with seed husks. If wheat varieties of the same species have been shown to respond differently to allelopathic compounds (Sampietro & Vattuone, 2006b), then different oat species could vary in sensitivity to allelopathic compounds, especially when exhibiting such physiological and anatomically differences between oat species.

Table 2. Impact of sugarcane ('HoCP 96-540') crop residue and sugarcane bagasse leachate concentrations on oat (*Avena sative* L.) var. 'Corral' germination percentage

Extract Source & Concentration	Oat Germination Experiment 1	Oat Germination Experiment 2	Oat Germination Averaged Across Experiments
	%	%	%
<u>Crop Residue</u>			
0 g/L	71 a[Z]	78 a	74.5 a
12.5 g/L	55 a	72 a	63.5 a
25 g/L	67 a	73 a	70.0 a
50 g/L	70 a	68 a	69.0 a
100 g/L	65 a	66 a	65.5 a
<u>Bagasse</u>			
0 g/L	71 a	78 a	74.5 a
12.5 g/L	68 a	68 a	68.0 a
25 g/L	58 a	69 a	63.5 a
50 g/L	73 a	74 a	73.5 a
100 g/L	69 a	64 a	66.5 a

Note. [Z]Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

3.3 Tall Morningglory Germination

There were no significant interactions between experiments (1 and 2) and the leachate concentrations for tall morningglory germination; therefore, the tall morningglory germination results will be discussed by experiment and averaged across experiments (Tables 1 and 3).

Sugarcane crop residue and bagasse leachates reduced tall morningglory germination in experiments 1 and 2, and when averaged across experiments as the leachate concentrations increased from 0 g/L to 100 g/L (Table 3). The decline in germination was more immediate and greater in extent for the crop residue than the bagasse leachates. When averaged across experiments, the 12.5 g/L crop residue concentration decreased the tall morningglory germination to 17% compared to 34% germination for the bagasse leachate, and the 100 g/L residue concentration reduce germination to 6% compared to 18.5% for bagasse 100 g/L bagasse concentration (Table 3).

The sugarcane crop residue extracts results are consistent with earlier research by Viator et al. (2006), which showed that increasing sugarcane (var. "LCP 85-384') crop residue leachate concentrations in a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquents) soil decreased tall morningglory germination. Viator et al. (2006) also reported that the same leachate concentrations in a higher clay content soil, Sharkey clay, (very-fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts) the sugarcane crop residue leachates did not decrease tall morningglory germination. Webber et al. (2017c) determined that sugarcane (variety 'HoCP 96-540') crop residue leachates decreased red morningglory (*Ipomoea coccinea* L.) germination by 29% at the 100 g/L concentration.

Table 3. Impact of sugarcane crop residue and bagasse leachate concentrations on tall morningglory (*Ipomoea purpurea* L. Roth) germination percentage

Extract Source & Concentration	Tall Morningglory Germination Experiment 1		Tall Morningglory Germination Experiment 2		Tall Morningglory Germination Averaged Across Experiments	
	%		%		%	
Crop Residue						
0 g/L	45.00	a[Z]	51.00	a	48.0	a
12.5 g/L	19.00	cd	15.00	cd	17.0	cd
25 g/L	11.00	de	10.00	de	10.5	de
50 g/L	11.00	de	6.00	e	8.5	e
100 g/L	6.00	e	6.00	e	6.0	e
Bagasse						
0 g/L	45.0	a	51.0	a	48.0	a
12.5 g/L	31.00	bc	37.00	b	34.0	b
25 g/L	37.00	ab	49.00	a	43.0	a
50 g/L	21.00	cd	37.00	b	29.0	b
100 g/L	14.00	de	23.00	c	18.5	c

Note. [Z]Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

3.4 Redroot Pigweed Germination

There was a significant interaction between experiments (1 and 2) (Table 1) and the leachate concentrations for redroot pigweed germination; therefore, the redroot pigweed germination results will be discussed by experiment (Table 4). Sugarcane crop residue and bagasse leachates reduced redroot pigweed germination in experiments 1 and 2, but at greater extent for the sugarcane crop residue than the sugarcane bagasse leachates (Table 4). The 100 g/L concentration of crop residue reduced germination by 13% (Experiment 1) and 27% (Experiment 2), while the bagasse leachate reduced germination by 5% (Experiment 1) and 15% (Experiment 2) (Table 4). These results are congruence with research by Webber et al. (2017c) where 100 g/L sugarcane (variety 'HoCP 96-540') crop residue leachates decreased redroot pigweed germination by 17.5% averaged across two experiments. The sugarcane crop residue results are similar to Webber et al. (2015a) who reported a corresponding decrease in redroot pigweed germination as kenaf leaf extracts increased from 0 g/L to 66.7 g/L and Panasiuk et al. (1986) and Yarnia et al. (2009) where sorghum residue and root extracts reduced redroot pigweed germination.

Table 4. Impact of sugarcane crop residue and bagasse leachate concentrations on redroot pigweed (*Amaranthus retroflexus* L.) germination percentage

Extract Source & Concentration	Redroot Pigweed Germination Experiment 1		Redroot Pigweed Germination Experiment 2		Redroot Pigweed Germination Averaged Across Experiments
	%		%		%
Crop Residue					
0 g/L	49	a[Z]	75	a	62.0
12.5 g/L	55	a	72	a	63.5
25 g/L	51	a	60	bc	55.5
50 g/L	50	a	55	cd	52.5
100 g/L	36	bc	48	d	42.0
Bagasse					
0 g/L	49	a	75	a	62.0
12.5 g/L	47	ab	50	cd	48.5
25 g/L	48	ab	68	ab	58.0
50 g/L	33	c	66	ab	49.5
100 g/L	44	abc	60	bc	52.0

Note. [Z]Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

4. Conclusions

The impact of leachates from sugarcane variety 'HoCP 96-540' crop residue and sugarcane bagasse differed by the species evaluated (oat, tall morningglory, and redroot pigweed), the leachate source (crop residue vs. bagasse), and leachate concentration (0 to 100 g/L). The oat (*Avena sativa* L.) germination was not affected by either the source of the leachate or the leachate concentration. This was in contrast to earlier research that resulted in a decrease in germination for a different oat species "naked oat" (*Avena nuda* L.) (Viator et al., 2006). The differences in the impact of the leachates on germination may be a result of using different oat species, seed viability, and/or sugarcane varieties. Future research should use both sugarcane varieties and evaluate germination on both oat species.

Germination for both weed species, tall morningglory and redroot pigweed, was adversely affected by leachate source and concentration. In both cases, the sugarcane crop residue leachates had a more deleterious impact on germination than did the bagasse leachate. This research suggests that the sugarcane crop residue has potential for reducing tall morningglory and redroot pigweed populations and competition due to the crop residue remaining on the field following harvest. The response to the leachates was more consistent and severe on tall morningglory germination than on redroot pigweed germination. The authors suggest the use of 100 g/L sugarcane crop residue leachate concentration as a potential organic weed control method for decreasing tall morningglory germination and competition. Future research should investigate the allelopathic compounds present in the sugarcane crop residue and bagasse, determine if the same allelopathic compounds are present and in the same concentration among other sugarcane varieties, and further examine which weed and crop species may be vulnerable to the allelopathic compounds present sugarcane crop residue and bagasse.

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