Weed Suppressive Potential of Sudangrass is Driven by Interactions of Root Exudates and Decomposing Shoot Residue

Sam E. Wortman,* Jared J. Schmidt, and John L. Lindquist

Abstract

Sudangrass [*Sorghum bicolor* (L.) Moench var. *sudanense*] is an increasingly popular forage and cover crop, but farmers have questions about how to manage sudangrass residues for maximum weed suppression. The objective of this greenhouse study was to quantify the relative contribution of sudangrass root exudates (e.g., sorgoleone) and decomposing shoot residue to green foxtail [*Setaria viridis* (L.) P. Beauv.] suppression across a range of soil mixtures. Green foxtail emergence was reduced by up to 76% by shoot residues and by up to 55% by root exudates. Synergism between decomposing shoot residues and root exudates was observed as the combination of treatments delayed time to >50% green foxtail emergence by 4 to 12 days. Results suggest that the weed suppressive potential of sudangrass is driven by independent and synergistic effects of decomposing shoot residue and root exudates in the soil. Thus, farmers removing sudangrass shoot residue by grazing or haying could experience reduced weed suppressive benefits from this crop.

SUDANGRASS is often planted as a summer cover crop or forage crop and can be useful for increasing soil organic matter and suppressing weeds when planted at high densities (Forney and Foy, 1985; Weston, 1996). Many studies have demonstrated the capacity for sorghum [*Sorghum bicolor* (L.) Moench] and sudangrass to suppress germination, emergence, and growth of weeds and other plant species (Hoffman et al., 1996; Nimbal et al., 1996b; Roth et al., 2000; Weston et al., 1989). The mechanism of suppression may be related to a combination of factors, including interplant competition during sudangrass growth (Weston, 1996), physical interference of mulched residues with weed seed germination and growth (Teasdale and Mohler, 1993), delayed nutrient availability to weeds as sudangrass residues are decomposed (Liebman and Davis, 2000), negative soil microbial feedback effects (Klironomos, 2002), or chemical allelopathy (Einhellig and Souza, 1992).

S.E. Wortman, Assistant Professor, Dep. of Crop Sciences, Univ. of Illinois at Urbana-Champaign, 1201 S. Dorner Dr., Urbana, IL 61801; J.J. Schmidt and J.L. Lindquist, Graduate Student and Professor, Dep. of Agronomy and Horticulture, Univ. of Nebraska-Lincoln, 279 Plant Science Hall, Lincoln, NE 68583. Received 30 Oct. 2013. *Corresponding author (swortman@illinois.edu).

Published in Crop Management
DOI 10.2134/CM-2013-0037-RS

Among the possible mechanisms for weed suppression in sudangrass, chemical allelopathy has received the most attention from farmers and researchers (Dayan et al., 2010). Forney and Foy (1985) first demonstrated that root leachate from Sudex (a sorghum × sudangrass hybrid) inhibited the growth of grass and broadleaf seedlings and Forney et al. (1985) found that Sudex used as a green manure before alfalfa (*Medicago sativa* L.) suppressed several broadleaf species. In addition, Netzly and Butler (1986) found that sorghum roots exuded a biologically active substance, now known as sorgoleone (2-hydroxy-5-methoxy-3-[(8'Z, 11'Z)-8',11',14'-pentadecatriene]-*p*-benzoquinone). Since these initial discoveries, many studies have explored the biochemical properties of sorgoleone and its potential role in sustainable weed management (Dayan et al., 2010). Sorgoleone accounts for 76 to 99% of root exudates in sorghum, but the concentration is quite variable among varieties (Nimbal et al., 1996b). As a result, many of the demonstrated weed suppressive effects of sorghum attributed to sorgoleone may not be replicated in all varieties of *S. bicolor* (i.e., sudangrass; var. *sudanense*).

While most research has focused on the allelopathic potential of sorghum and sudangrass root exudates, shoot residues also have demonstrated weed suppressive potential. Sorghum shoot residue releases cyanogenic glucosides and several phenolic acids (e.g., *p*-hydroxybenzoic, *p*-hydroxybenzaldehyde, syringic, *p*-coumaric, and ferulic) during soil decomposition, which have been shown to reduce plant growth and inhibit germination and growth of several weed species (Einhellig and Rasmussen, 1989; Putnam et al., 1983; Weston et al., 1989). Biochemicals in sorghum (e.g., sorgoleone, glucosides, and phenolic acids) can be effective when purposefully used to suppress weeds in agronomic systems (Einhellig and Rasmussen, 1989), but the weed-suppressive potential of certain sorghum varieties against select weeds may be dependent on contributions from different plant parts (Hoffman et al., 1996; Yarnia et al., 2009). Moreover, synergism between phytochemicals in root exudates and decomposing shoot residue may lead to greater weed suppression than when each is used alone (Hoffman et al., 1996). Previous studies suggest that the allelopathic potential of sorghum depends on variety, target weed species, and plant part incorporated into the soil. Thus, the objective of this study was to determine the relative contribution of sudangrass (cv. Piper) shoot residues and root exudates in the suppression of green foxtail (an economically important weed species in agronomic cropping systems; Lindquist et al., 1999) across a range of soil mixtures. The "Piper" cultivar was selected for study because it is a commonly available cover crop cultivar and has been shown to produce 1 mg of high purity (98.6%) sorgoleone per gram of root fresh weight (Nimbal et al., 1996a).

EXPERIMENTAL DESIGN

To accomplish study objectives, two staggered runs of a greenhouse experiment were conducted between 12 Jan. 2012 and 22 Mar. 2012. Run one began on 12 January and run two began on 19 January. Each experiment was set up as a completely randomized factorial design with three factors and four replications. The first factor was soil mixture and treatments included (i) low organic matter (OM) (1:1:1 mixture of field soil:sand:vermiculite; 1.4% OM), (ii) medium OM (3:1:1 mixture of field soil:sand:vermiculite; 2.0% OM), and (iii) a soilless high OM control (Miracle Grow Potting Mix, The Scotts Company LLC; 47.8% OM). Organic matter was measured as percent oxidizable carbon using the Walkley–Black method (AgSource Laboratories, Lincoln, Nebraska). The second factor was soil condition and treatments included (i) non-conditioned soil ([-] root exudates) and (ii) sudangrass root-conditioned soil ([+] root exudates). A root-conditioned soil was one in which sudangrass was grown, but all visible root and shoot residues were removed from the soil leaving only fine roots and exudates, whereas a non-conditioned soil remained fallow until time of planting weed seed. The third factor was shoot residue and treatments included (i) sudangrass shoots ([+] shoots) and (ii) no sudangrass shoots ([-] shoots). To include shoot residues, leaf and stem tissue were cut into 2.5-cm segments and mixed in the top 5 cm of the potting mix. Two concentrations of inert aspen wood mulch chips (approximately 2.5 cm in length) were included as residue treatments in a preliminary trial to quantify physical interference with green foxtail emergence, but results were not different from a bare soil control (data not shown). Therefore, we expect that any observed deleterious effects of sudangrass residue on green foxtail are the result of chemical or possibly microbial effects, and not the physical effects of the residue.

To begin each experimental run, sudangrass was grown in 2.4 L conic frustum pots (16.5 cm diameter × 11.4 cm depth × 12.7 cm height) filled with one of the three soil mixture treatments. Twenty pots were filled with each of the three soil mixtures (60 total experimental units per run) and eight sudangrass seeds were planted to a depth of 1.5 cm in half of the pots. While the non-conditioned soil treatment was not planted to sudangrass, these pots were managed similar to sudangrass root-conditioned pots to avoid potentially confounding effects of soil fertility or microbial activity within soil mixture treatments. Greenhouse temperature was maintained between 22 and 26°C during the day and 16 and 21°C during the night. Light–dark cycles were set to 12–12 with supplemental artificial light. One week after planting, sudangrass was thinned to four plants per experimental unit. All experimental units were watered daily to achieve field capacity and fertilized two times per week (Jack's Professional 20–20–20; JR Peters, Inc.) to ensure adequate soil moisture and fertility.

Thirty-six days after planting sudangrass (17 Feb. 2012 for run one and 24 Feb. 2012 for run two), plants were removed from original pots to implement experimental treatments. The shoot tissue (leaves and stems) was cut into 2.5-cm segments and 10 g of fresh biomass from each pot was weighed and set aside. Soil from individual experimental units was sieved by hand to remove and discard all visible roots (if sudangrass had been grown in that pot). After removing roots, soil was mixed by hand to simulate tillage and a random subsample of this mixture was then placed into a smaller square pot measuring 8.9 cm wide × 11.4 cm deep. Ten grams of sudangrass fresh shoot residue (equivalent of approximately 2 Mg ha^{-1}) was then placed on the surface of the soil mix and incorporated into the top 5 cm of the experimental units designated to receive shoot residues. This mixing procedure was followed regardless of treatment; for example, pots designated for the non-conditioned soil + no shoots treatment combination were still mixed and repotted in a smaller pot without shoot residues. In each of the newly potted experimental units, 30 green foxtail seeds were planted to a depth of approximately 0.5 cm. Similar to management of the sudangrass, green foxtail seedlings were watered daily and fertilized two times per week (Jack's Professional 20–20–20; JR Peters, Inc.) to ensure adequate soil moisture and fertility.

DATA COLLECTION AND ANALYSIS

Green foxtail emergence was counted and summed daily until 28 (run one) or 27 days (run two) after planting weed seeds. From this data, cumulative emergence and days to reach >50% cumulative emergence was calculated for each experimental unit. Values for cumulative emergence and days to >50% emergence were compared among treatments using analysis of variance in the GLIMMIX procedure of SAS 9.2 (SAS Institute, 2008). Fixed effects in the model included soil mixture, soil conditioning treatment, shoot residue treatment, and all possible interactions of these effects. Experimental runs were analyzed separately due to interactions between run and fixed effects. Least square (LS) means and standard errors were calculated for all significant fixed effects at an α level of 0.05.

SUDANGRASS ROOT EXUDATES AND SHOOT RESIDUES REDUCED FINAL FOXTAIL EMERGENCE

Cumulative emergence of green foxtail was influenced by root-conditioned soil and sudangrass shoot residues, though the effects varied among soil mixtures (Table 1). Sudangrass root-conditioned soil reduced cumulative emergence of green foxtail four weeks after planting (regardless of soil mixture) by 55.1 and 51.9% in runs one and two, respectively (data not shown). The effectiveness of sudangrass root exudates across soil mixtures was somewhat unexpected as we hypothesized that the weed-suppressive potential would decrease as soil organic matter increased. Sorgoleone is a highly hydrophobic compound (Dayan et al., 2010), but these results suggest that strong soil sorption in higher OM soils should not limit the capacity for *Sorghum* spp. to inhibit emergence of grass weeds like green foxtail.

Decomposition of sudangrass shoot residues also reduced cumulative emergence of green foxtail in the low (run two) and medium (runs one and two) OM soil mixtures (Fig. 1). In run one, incorporation of sudangrass shoots reduced green foxtail emergence by 33.3% in the low OM mixture (though the difference was only approaching significance, *P* value <0.10) and by 57.0% in the medium OM mixture. Results from run two were more pronounced (possibly due to minor changes in greenhouse microclimate between runs [e.g., number of cloudy days]) as decomposing shoot residues reduced green foxtail cumulative emergence by 61.5 and 75.5% in the low and medium OM mixtures, respectively. Despite changes in the magnitude of suppression between runs, the relative differences among treatments remained. Reduced efficacy of decomposing shoot residues in the low OM mixture (compared to the medium OM mixture) may be due to increased leaching of water soluble phenolic acids out of the weed emergence surface profile (Kobayashi, 2004). Overall, the observed reductions in cumulative emergence are consistent with Hoffman et al. (1996) who observed a 48% reduction in green foxtail germination in the presence of sorghum and Yarnia et al. (2009) who reported a 60% reduction in redroot pigweed (*Amaranthus retroflexus*) germination in response to extracts from sorghum.

Table 1. *F*-values from analysis of variance for effects and all possible interactions of sudangrass root conditioning, shoot residues, and soil mixture on cumulative emergence of green foxtail for runs one and two. Significance of *F*-values is designated as * = *P* < 0.05, ** = *P* < 0.01, and * = *P* < 0.001.**

Source	df†	Cumulative emergence Run 1	Cumulative emergence Run 2
Conditioning	1	34.6***	28.8***
Shoot residues	1	4.8*	31.1***
Soil mixture	2	5.1**	0.01
Conditioning × shoot residues	1	1.4	0.1
Conditioning × soil mixture	2	0.5	1.1
Shoot residues × soil mixture	2	4.7*	5.7**
Conditioning × shoot residues × soil mixture	2	0.2	0.3

† Abbreviation: df, degrees of freedom.

COMBINED EFFECTS OF SUDANGRASS ROOT EXUDATES AND SHOOTS DELAYED FOXTAIL EMERGENCE

Emergence of green foxtail was not delayed in the root-conditioned soil or when shoot residues were incorporated in the soil, but the combination of the two treatments delayed time to >50% emergence by four days in run one and four and 12 days in run two for the low and medium OM mixtures, respectively (relative to non-conditioned soil with no shoot residues; [Table 2; Fig. 2]). These results suggest a synergistic effect of phytochemicals in sudangrass root exudates and decomposing shoot

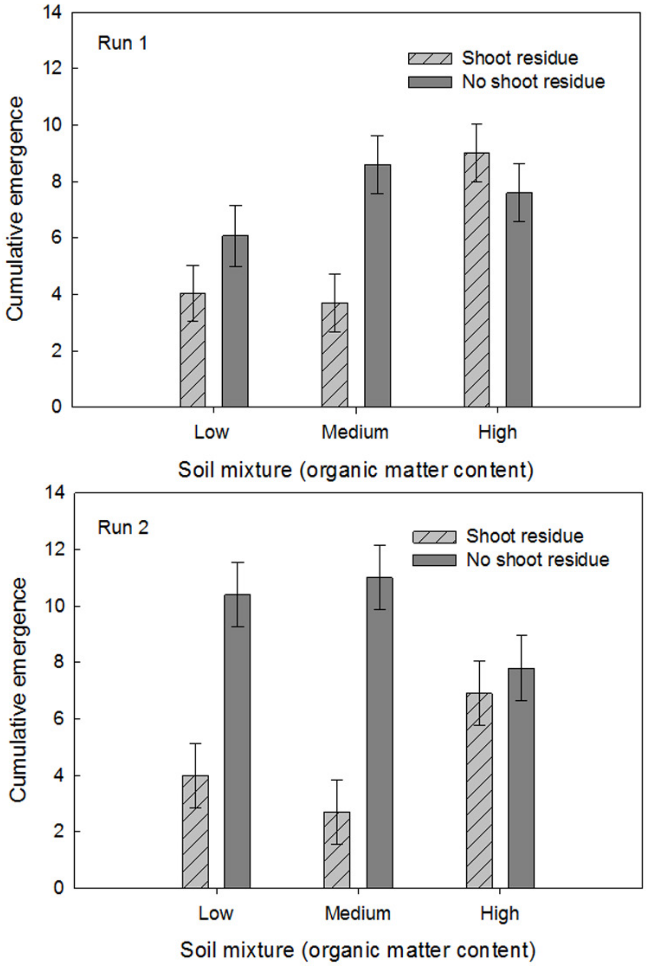

Figure 1. Effects of sudangrass shoot residues and soil mixture on cumulative emergence of green foxtail (out of 30 planted seeds) over the course of 28 and 27 days in runs one and two, respectively. Bars represent ± one standard error of the least square (LS) means.

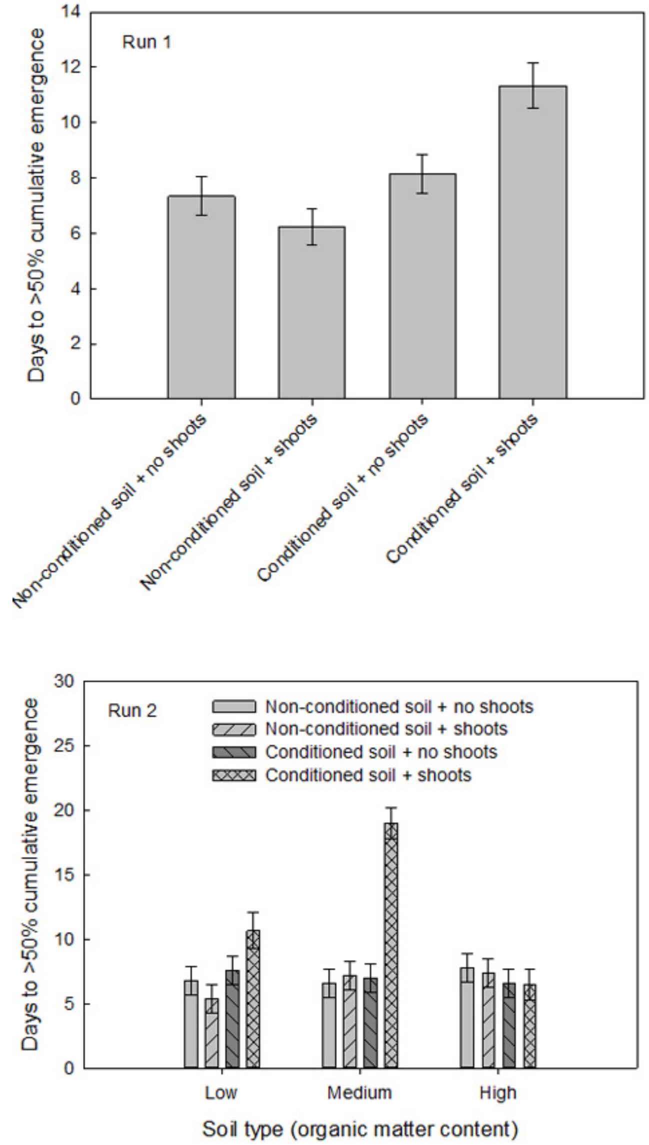

Figure 2. Effects of sudangrass root-conditioned soil, shoot residues (run one), and soil mixture (run two) on days to reach >50% cumulative emergence of green foxtail (a measure of emergence timing) in runs one and two. Bars represent ± one standard error of the least square (LS) means.

Table 2. *F*-values from analysis of variance for effects and all possible interactions of sudangrass root conditioning, shoot residues, and soil mixture on days to >50% emergence of green foxtail for runs one and two. Significance of *F*-values is designated as * = $P < 0.05$, ** = $P < 0.01$, and *** = $P < 0.001$.

		Days to 50% emergence	
Source	df†	Run 1	Run 2
Conditioning	1	16.8***	16.5***
Shoot residues	1	2.1	12.0**
Soil mixture	2	1.8	7.3**
Conditioning × shoot residues	1	8.8**	16.5***
Conditioning × soil mixture	2	2.3	10.1***
Shoot residues × soil mixture	2	0.7	9.6***
Conditioning × shoot residues × soil mixture	2	0.9	6.2**

† Abbreviation: df, degrees of freedom.

residues because alone each was ineffective in delaying emergence of green foxtail. Because germination was not measured, it is unclear whether sudangrass shoot residues and root exudates were negatively affecting green foxtail germination, seedling growth, or both. Sorgoleone is highly hydrophobic, which suggests that this chemical would not be imbibed along with water into the seed and instead is more likely to reduce emergence of newly germinated seedlings traveling through "contaminated" soil (Dayan et al., 2010). Similarly, Weston et al. (1989) found that the allelopathic chemicals released from decomposing sudangrass shoot residue (*p*-hydroxybenzoic acid and *p*-hydroxybenzaldehyde) were most effective in reducing radicle elongation of newly germinated weed seedlings.

CONCLUSIONS AND RECOMMENDATIONS

The magnitude of green foxtail suppression with sudangrass shoots and root exudates in soil-based mixtures of this study is an important finding for farmers and crop consultants. Sudangrass root exudates and shoot residues suppressed green foxtail emergence by as much as 55.1 and 75.5%, respectively, and the combination of both delayed emergence by up to 12 days. Many studies have demonstrated allelopathic effects of sudangrass or sorghum in bioassays void of soil (e.g., Ben-Hammouda et al., 1995; Einhellig and Souza, 1992; Hoffman et al., 1996), but this study demonstrates that sudangrass has potential to provide measurable reductions in grass weed emergence in field soil. Results also suggest that some weed-suppressive benefits of sudangrass will be sacrificed if shoot residues are removed from the field via grazing or haying, for example. To maximize the weed-suppressive capacity of sudangrass, we recommend farmers use sudangrass as a cover crop and incorporate both shoot and root residues into the soil within three weeks of planting cash crops. However, cover crop use paired with reduced tillage has been shown to improve soil quality (Blanco-Canqui et al., 2011), which may be compromised if sudangrass residues are incorporated with tillage. We recommend farmers carefully consider their management objective and these potential tradeoffs before planting and terminating cover crops.

References

Ben-Hammouda, M., R.J. Kremer, H.C. Minor, and M. Sarwar. 1995. A chemical basis for differential allelopathic potential of sorghum hybrids on wheat. J. Chem. Ecol. 21:775–786. doi:10.1007/BF02033460

Blanco-Canqui, H., M.M. Mikha, D.R. Presley, and M.M. Claassen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Sci. Soc. Am. J. 75:1471–1482. doi:10.2136/sssaj2010.0430

Dayan, F.E., A.M. Rimando, Z. Pan, S.R. Baerson, A.L. Gimsing, and S.O. Duke. 2010. Sorgoleone. Phytochemistry 71:1032–1039. doi:10.1016/j.phytochem.2010.03.011

Einhellig, F.A., and I.F. Souza. 1992. Phytotoxicity of sorgoleone found in grain sorghum root exudates. J. Chem. Ecol. 18:1–11. doi:10.1007/BF00997160

Einhellig, F.A., and J.A. Rasmussen. 1989. Prior cropping with grain sorghum inhibits weeds. J. Chem. Ecol. 15:951–960. doi:10.1007/BF01015190

Forney, D.R., and C.L. Foy. 1985. Phytotoxicity of products from rhizospheres of a sorghum-sudangrass hybrid (*Sorghum bicolor* × Sorghum *sudanense*). Weed Sci. 33:597–604.

Forney, D.R., C.L. Foy, and D.D. Wolf. 1985. Weed suppression in no-till alfalfa (*Medicago sativa*) by prior cropping of summer-annual forage grasses. Weed Sci. 33:490–497.

Hoffman, M.L., L.A. Weston, J.C. Snyder, and E.E. Regnier. 1996. Separating the effects of sorghum (*Sorghum bicolor*) and rye (*Secale cereale*) root and shoot residues on weed development. Weed Sci. 44:402–407.

Klironomos, J.N. 2002. Feedback with soil biota contributes to plant rarity and invasiveness in communities. Nature 417:67–70. doi:10.1038/417067a

Kobayashi, K. 2004. Factors affecting phytotoxic activity of allelochemicals in soil. Weed Biol. Manage. 4:1–7. doi:10.1111/j.1445-6664.2003.00112.x

Liebman and Davis. 2000. Integration of soil, crop, and weed management in low-external-input farming systems. Weed Res. 40:27–47. doi:10.1046/j.1365-3180.2000.00164.x

Lindquist, J.L., D.A. Mortensen, P. Westra, W.J. Lambert, T.T. Bauman, J.C. Fausey, J.J. Kells, S.J. Langton, R.G. Harvey, B.H. Bussler, K. Banken, S. Clay, and F. Forcella. 1999. Stability of corn (*Zea mays*)-foxtail (*Setaria* spp.) interference relationships. Weed Sci. 47:195–200.

Netzly, D.H., and L.G. Butler. 1986. Roots of sorghum exude hydrophobic droplets containing biologically active components. Crop Sci. 26:775–778. doi:10.2135/cropsci1986.0011183X002600040031x

Nimbal, C.I., J.F. Pedersen, C.N. Yerkes, L.A. Weston, and S.C. Weller. 1996a. Phytotoxicity and distribution of sorgoleone in grain sorghum germplasm. J. Agric. Food Chem. 44:1343–1347. doi:10.1021/jf950561n

Nimbal, C.I., C.N. Yerkes, L.A. Weston, and S.C. Weller. 1996b. Herbicidal activity and site of action of the natural product sorgoleone. Pestic. Biochem. Physiol. 54:73–83. doi:10.1006/pest.1996.0011

Putnam, A.R., J. Defrank, and J.P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9:1001–1010. doi:10.1007/BF00982207

Roth, C.M., J.P. Shroyer, and G.M. Paulsen. 2000. Allelopathy of sorghum on wheat under several tillage systems. Agron. J. 92:855. doi:10.2134/agronj2000.925855x

SAS Institute. 2008. SAS Version 9.2. SAS Institute, Cary, NC.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673–680. doi:10.2134/agronj1993.00021962008500030029x

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agron. J. 88:860–866. doi:10.2134/agronj1996.00021962003600060004x

Weston, L.A., R. Harmon, and S. Mueller. 1989. Allelopathic potential of sorghum-sudangrass hybrid (sudex). J. Chem. Ecol. 15:1855–1865. doi:10.1007/BF01012272

Yarnia, M., M.B. Khorshidi Benam, and E.F. Memari Tabrizi. 2009. Allelopathic effects of sorghum extracts on *Amaranthus retroflexus* seed germination and growth. J. Food Agric. Environ. 7:770–774.