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Impact of Acetic Acid Concentration, Application Volume, and Adjuvants on Weed Control Efficacy

Charles L. Webber III[1], Paul M. White Jr.[1], James W. Shrefler[2] & Douglas J. Spaunhorst[1]

[1] Sugarcane Research Unit, USDA, Agriculture Research Service, Houma, LA, USA

[2] Cooperative Extension Service, Division of Agriculture Sciences and Natural Resources, Oklahoma State University, Durant, OK, USA

Correspondence: Charles L. Webber III, Research Agronomist, Sugarcane Research Unit, USDA, Agriculture Research Service, Houma, LA 70360, USA. E-mail: chuck.webber@ars.usda.gov

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Abstract

Acetic acid (CH_3COOH) is produced naturally through anaerobic fermentation (vinegar) or synthesized through various industrial chemical methods. The primary components of vinegar are water and acetic acid. Acetic acid can destroy cell membranes, which then can result in plant tissue desiccation and plant death. Therefore, vinegar has the potential as a natural contact herbicide for the control of weeds in organically produced crops. Additional information is needed to determine the influence of acetic acid concentration, application volume, and adjuvants on weed control. Typically, household vinegar contains 5% acetic acid and greater acetic acid concentrations are available commercially. Field research was conducted in southeast Oklahoma (Lane, OK) to determine the effect of acetic acid concentrations, application volumes, and adjuvants on weed control efficacy. The factorial experimental design included three acetic acid concentrations (0, 5 and 20%), two sprayer application volumes (187 and 935 L/ha), three adjuvants (none, orange oil, and canola oil), and one weedy-check. The experiment was repeated twice. Visual weed cover and control ratings were collected 4 days after treatment. The experiment had very high weed densities with multiple grass and broadleaf weed species. The weedy check average weed cover percentages were 98% total weeds, 53% grass, 44% broadleaf weeds, 52% large crabgrass (*Digitaria sanguinalis* L.), 25% carpetweed (*Mollugo verticillata* L.), and 14% cutleaf evening primrose (*Oenothera laciniata* Hill). Total weed control ranged from 0% control (no acetic acid) to 74% control (20% acetic acid, 935 L/ha, & canola oil). Acetic acid was more effective in controlling broadleaf weeds than in controlling grasses. Optimum total grass and crabgrass weed control occurred with 20% acetic acid applied at 935 L/ha, resulting in weed control that ranged from 44% to 63%. Broadleaf weed control was 84% or greater for plots receiving either 10% acetic acid applied at 935 L/ha or 20% acetic acid applied at 187 or 935 L/ha. In addition, 5% acetic acid applied at 187 L/ha provided good cutleaf evening primrose control (77% to 90%). When averaged across application volumes (187 and 935 L/ha) and adjuvants (none, orange oil, and canola oil), weed control increased for all species as acetic acid concentrations increased from 5% to 20%. When averaged across acetic acid concentrations and adjuvants, weed control increased as application volumes increased from 187 to 935 L/ha. Individual comparisons among adjuvants within acetic acid concentrations and application volumes showed little or no advantage to adding either orange oil or canola oil to vinegar spray solutions.

Keywords: acetic acid, natural herbicides, organic herbicides, vinegar; weeds

1. Introduction

Reports in the popular press and weed control research literature indicate the potential of vinegar (acetic acid, CH_3COOH) as a natural herbicide for organic weed control (Evans & Bellinder, 2009; Evans et al., 2009; Evans et al., 2011; Johnson et al., 2003; Radhakrishnan et al., 2002, 2003; Webber et al., 2012). Vinegar is a solution containing acetic acid, an organic acid produced though the natural fermentation of plant materials containing sugars. Household vinegar typically contains 5% acetic acid. Acetic acid does not persist in the environment; rather, it readily breaks down producing water as a by-product. Although acetic acid occurs naturally, care must be taken when handling vinegar, especially when the acetic acid concentration increases above the typical 5%. Vinegars with acetic acid concentrations of 11% or greater are available commercially, these products can burn the skin and cause serious to severe eye injury, including blindness (Webber et al., 2012). Protective clothing that includes eye protection and gloves should be used. It has been suggested that acetic acid injures and kills plants by first destroying the cell membranes, which then causes the rapid desiccation of the plant tissues (Owens, 2002). There is no evidence that the acetic acid is absorbed into the plant and translocated to other plant parts to inflict damage; therefore, it is considered to be a contact herbicide rather than a systemic herbicide such as glyphosate. As a contact herbicide, acetic acid should be more effective on seedlings and annuals than on more mature plants and perennials. Plants that readily regrow from the roots, even when the foliage is destroyed, will be more difficult to kill with vinegar or other contact herbicides. Multiple applications and application timing in respect to the weed's size, maturity or life cycle may increase control.

In greenhouse research, vinegar applied with acetic acid concentrations of 5.0, 10.5, 15.3, and 20.2% killed five weed species—common lambsquarter (*Chenopodium album* L.), giant foxtail (*Setaria faberii*), velvetleaf (*Abutilon theophrasti*), smooth pigweed (*Amaranthus hybridus* L.), and Canada thistle (*Cirsium arvense* L. Scop.). Weed control efficacy increased with acetic acid concentration and decreased with plant maturity. Radhakrishnan et al. (2002) applied the vinegar with a hand sprayer to "obtain a uniform wetting of all foliage"; therefore, the application volume is unclear.

Field research was then conducted to evaluate the effectiveness of directed-spray applications of vinegar for weed control in corn and soybeans (Radhakrishnan et al., 2003). Increasing the acetic acid concentration from 10 to 20% increased crop injury, and foliar applications produced greater crop injury than basal applications. The results further indicated that although soybean plants are more sensitive to vinegar applications than corn, soybean injury decreases with increasing maturity. Weed control in these field trials ranged from 90-100%. It was also determined that a vinegar soil drench reduced total biomass of Canada thistle and also reduced its stem number by 90%.

Research in Canada (Johnson et al., 2003) investigated the use of a 10% acetic acid for broadleaf weed control in spring-planted wheat. Vinegar (10% acetic acid) was applied at 200, 400, 800, 1600, and 2400 L/ha either three days before seeding spring wheat or after the wheat reached the 1-2 leaf stage. In the pre-seed treatments, vinegar applications of 1600 L/ha or greater decreased shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.] control by 80%. In-crop, post-emergence vinegar applications at 400 L/ha or greater produced significant initial wheat injury; however, 28 days after treatment, crop injury was barely visible. Vinegar (10% acetic acid) application volumes of 1600 L/ha or greater produced at least 80% control of wild mustard (*Sinapis arvensis* L.) and cow cockle [*Viccaria hispanica* (Mill.) Rauschert]. Although 1600 L/ha or greater produced weed control levels comparable to commercial herbicides, the 400 and 800 L/ha application volumes were sufficient to sustain maximum wheat yields.

Webber and Shrefler (2009a, 2009b) investigated impact of sprayer volumes (469 and 935 L/ha) of vinegar (20% acetic acid) applied over the top of two sweet onion (*Allium cepa* L) varieties. Each of the application produced outstanding weed control, although the initial crop damage was greater for the 935 L/ha compared to the 469 L/ha. The primary weeds in their research were all seedling broadleaf weeds, less than 2.5 cm tall and having at the most 5 seedling leaves.

Adjuvants are chemicals typically combined with herbicides prior to use, either during the formulation process or after packaging. Adjuvants are added to herbicide solutions for a myriad of purposes with the primary goal of assuring effective herbicidal activity when used according to the label directions. Adjuvants may be added to herbicide solutions for the following purposes: as spreader-stickers, emulsifiers, extenders (protect against weathering), or safeners (protect crop plants from herbicide damage); for drift control or pH buffering; as anti-foaming or wetting agents; and to enhance compatibility, suspension, or penetration of the herbicide. The registration labels for commercial herbicides provide instructions concerning the addition of adjuvants to herbicide spray solutions, including the type and amount to be added. Normally, if adjuvants are recommended, the adjuvants are added to a spray solution according to the application rate of the herbicide (*i.e.* amount per area) or by the application volume (*i.e.* 0.25% by volume of spray solution). The addition of adjuvants to a spray solution can have tremendous positive impact on controlling weeds, increasing the herbicidal activity, protecting the non-target plants, and enhancing the safety and application of the herbicide. Conversely, adding an adjuvant may interfere with the herbicide's delivery and effectiveness, may increase the hazard to non-target plants or to those applying the herbicides, or may simply provide no benefit whatsoever.

Although many naturally occurring materials, such as acetic acid, have herbicidal properties there is controversy as to whether they should be allowed to be used in organic crop production systems (Webber et al., 2012; Dayan et al., 2009). Therefore, care must be taken by the producer to know the regulations covering their organic, natural, or sustainable crop production policies. The varying regulations must be considered when selling, purchasing, recommending, or using vinegars as herbicides.

Although previous studies have yielded important information concerning the use of vinegar as a herbicide, further research is indicated in order to increase the understanding of the relationship between acetic acid concentrations, application volumes, weed species, and weed maturity on herbicidal efficacy of vinegar. There is also a need for scientific information concerning the use of adjuvants with vinegar. Field research was conducted in southeast Oklahoma (Atoka County, Lane, OK) to determine the impact acetic acid concentrations, application volumes, and adjuvants on weed control efficacy.

2. Materials and Methods

2.1 Experimental Site and Design

The field experiments were conducted on a 0.2 ha of land [Bernow fine sandy loam, 0-3% slope (fine-loamy, siliceous, thermic Glossic Paleudalf)] at Lane, OK, USA. One month prior to spraying the weed control treatments, the land was cultivated in order to kill the existing weeds and to provide a uniform seed bed for new weed growth. The research involved 19 weed control treatments with 4 replications; plots were 2 m wide and 3 m long, and repeated in sequential years. The factorial experimental design included vinegar at three acetic acid concentrations (0, 5 and 20%), two sprayer application volumes (187 and 935 L/ha), three adjuvants (none, orange oil, and canola oil), and a weedy-check (Table 1). The 5% acetic acid vinegar (Best Choice, White Distilled Vinegar, 5% Acidity, Distributed by Associated Wholesale Grocers, Inc., Kansas City, KS 66106) and the canola oil (Best Choice, Pure Canola Oil, Distributed by Associated Wholesale Grocers, Inc., Kansas City, KS 66106) were purchased locally, while the 20% acetic acid (20% Vinegar, Nature's Guide, Manufactured by Creole Fermentation, Abbeyville, LA, and Distributed by Marshall Distributing Company, 2224 E. Lancaster Ave., Fort Worth, TX 76103-2299) and the orange oil (Orange Oil, Nature's Guide, 351 Winter Haven Blvd. NE, Manufactured by Florida Chemical Co., Inc., Winter Haven, FL 33881-9432) purchased through a commercial nursery. The canola oil and orange oil were mixed at a 0.25% volume/volume (v/v) for the two application volumes (187 and 935 L/ha). A 0.025% v/v of liquid soap (Ultra Joy, Concentrated Soap, Distributed by Procter & Gamble, Cincinnati, Ohio, 45202) was added to the treatments containing canola oil to reduce the surface tension and allow the canola oil to go into suspension. Triclosan was the active ingredient of the soap and the orange oil contained d-Limonene.

All herbicide treatments were applied using a tractor mounted CO_2 sprayer equipped with four extended range, stainless steel, 0.76 L/min (XR TeeJet, XR8002VS, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.) on 51-cm spacing at a height of 48 cm. The 187 and 935 L/ha sprayer application volumes were achieved by holding all other variables (nozzle size, pressure, and mixture volumes) constant and by adjusting the travel speed to either 4.8 km/h or 1.0 km/h, respectively. The herbicide treatments were applied in mid-July in consecutive years.

2.2 Data Collection

Weed stands were visually rated 4 d after treatment (DAT) for percentage weed control on a 0% to 100% scale, where 0% equals no weed control (no dead plants) and 100% equals complete control (all plants dead). The weed rating data were prepared for analysis using a square root arcsine transformation to normalize the data. Data were subjected to analysis of variance (ANOVA) and mean separation using least significant difference (LSD) with P = 0.05 in SAS (ver. 9.1, SAS, Inc., Cary, N.C.). There were no significant year x treatment or year by factorial interaction; therefore the data will be presented averaged across years.

3. Results and Discussions

3.1 Weed Species Status

Each year the experimental sites had very high weed densities with multiple species of grass and broadleaf weeds, but the weed species were consistent across years. The weeds present at spraying included ***l***arge crabgrass (*Digitaria sanguinalis* L.), goosegrass (*Eleusine indica*), carpetweed (*Mollugo verticillata* L.), cutleaf evening primrose (*Oenothera laciniata* Hill), spiny amaranth (*Amaranthus spinosus*), Eclipta (*Eclipta prostrata* L.), and yellow nutsedge (*Cyperus esculentus*). Large crabgrass, carpetweed, and cutleaf evening primrose were the most dominant weeds covering at least 50%, 24%, and 14% of the weedy-check, respectively. At the time of spraying, large crabgrass plants averaged 1 or 2 leaves; however, the plots did include a few larger crabgrass plants that had regrown from the earlier tillage operations. Carpetweeds averaged 1 inch wide with 4 or 5 leaves, while cutleaf evening primrose seedlings had only 2 or 3 leaves. No other weed species contributed more than 5% to the weed cover. Only the data for the most dominant weeds and the combined ratings for grass, broadleaf, and total weeds were reported in this manuscript.

3.2 Treatment Analysis

Four days after treatment, the average weed cover ratings for the weedy check were as follows: 98% total weeds; 53% grass; 44% broadleaf; 52% large crabgrass; 25% carpetweed; and 14% cutleaf evening primrose (data not shown). Total weed control ranged from 0 or near 0% control when no vinegar was used to 74% control when 20% acetic acid was applied at 187 L/ha with canola oil (Table 1). Vinegar was more effective in controlling broadleaf weeds than in the controlling grasses. Optimum total grass and crabgrass weed control occurred with 20% acetic acid applied at 935 L/ha, resulting in weed control that ranged from 44 to 63%. Broadleaf (total, carpetweed, and cutleaf evening primrose) control was 84% or greater for plots receiving either 10% acetic acid applied at 935 L/ha or 20% acetic acid applied at 187 or 935 L/ha. Also, 5% percent acetic acid applied at 187 L/ha provided good cutleaf evening primrose control (77% to 90%). In this research, cutleaf evening primrose was the most susceptible to acetic acid applications; however, this response may reflect differences in weed size rather than weed species. Individual comparisons among adjuvants within acetic acid concentrations and application volumes showed little or no advantage to adding either orange oil or canola oil to acetic acid spray solutions.

Table 1. Impact acetic acid concentration (0, 5, and 20%), application volume (187 and 935 L/ha), and adjuvants (none, orange oil, and canola oil) on weed control averaged across two years

Acetic Acid Concentration	Application Volume	Adjuvant	Total Weed	Total Grass	Total Broadleaf	Crabgrass	Carpetweed	Cutleaf Primrose
------- % -------	---- L/ha ----		----------	----------	---------- % ----------	----------	----------	----------
0	187	None	0.9 e[z]	4.0 c	1.4 d	5.1 ef	9.2 bc	0.0 d
0	187	Orange Oil	0.1 e	2.5 c	0.0 d	14.6 def	13.7 bc	0.0 d
0	187	Canola Oil	0.0 e	2.5 c	0.0 d	3.0 ef	6.5 bc	14.6 cd
5	187	None	39.0 c	2.5 c	71.5 b	3.0 ef	81.5 a	90.8 ab
5	187	Orange Oil	20.6 d	4.5 c	42.0 c	6.0 def	25.0 b	87.1 ab
5	187	Canola Oil	7.0 de	4.8 c	11.4 d	8.3 def	12.5 bc	77.7 b
20	187	None	43.7 c	2.5 c	91.5 a	4.5 ef	95.2 a	100 a
20	187	Orange Oil	49.8 bc	11.8 bc	93.7 a	11.7 def	95.0 a	100 a
20	187	Canola Oil	41.6 c	4.8 c	88.1 ab	17.0 def	84.6 a	100 a
0	935	None	0.0 e	4.8 c	0.0 d	5.9 def	0.0 c	2.2 c
0	935	Orange Oil	0.0 e	4.8 c	0.0 d	19.7 de	13.6 bc	14.5 cd
0	935	Canola Oil	0.0 e	0.2 c	0.0 d	2.3 ef	0.0 c	6.6 cd
5	935	None	60.5 ab	33.4 ab	91.5 a	33.2 bcd	91.2 a	100 a
5	935	Orange Oil	44.9 c	2.5 c	94.3 a	3.0 ef	95.2 a	100 a
5	935	Canola Oil	45.7 c	4.8 c	93.1 a	17.0 def	95.2 a	100 a
20	935	None	67.7 a	44.2 a	96.0 a	47.3 abc	96.0 a	100 a
20	935	Orange Oil	62.4 ab	52.1 a	98.3 a	54.2 ab	100.0 a	100 a
20	935	Canola Oil	73.9 a	52.3 a	97.2 a	63.6 a	100.0 a	100 a
Weedy Check	0	0	0.0 e	0.0 c	0.0 d	0.0 f	0.0 a	0.0 d

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

3.3 Factorial Analysis

When averaged across application volumes (187 or 935 L/ha), adjuvants (none, orange oil, and canola oil), and years, weed control increased for all species as acetic acid concentrations increased from 0 to 20% (Table 2). These results are consistent with earlier research, although the results expand on the weed species, application rates, and acetic acid concentration (Webber & Shrefler, 2009a, 2009b).

Table 2. Weed control ratings in response to acetic acid concentrations averaged across application volumes, adjuvants, and two years

Acetic Acid Concentration	Total Weed	Total Grass	Total Broadleaf	Crabgrass	Carpetweed	Cutleaf Primrose
			%			
0	0 c[z]	3 b	0 c	8 b	7 c	10 c
5	36 b	9 b	67 b	12 b	67 b	93 b
20	57 a	28 a	94 a	33 a	95 a	100 a

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

In the same respect, when averaged across acetic acid concentrations and adjuvants, weed control increased as application volumes increased from 187 or 935 L/ha (Table 3). These results further emphasize that when either the application volume and/or the acetic acid concentration is increased weed control efficacy increases (Webber et al., 2012).

Table 3. Weed control ratings in response to application volume average across acetic acid concentrations, adjuvants, and two years

Application Volume	Total Weed	Total Grass	Total Broadleaf	Crabgrass	Carpet-weed	Cutleaf Primrose
L/ha			%			
187	23 b[z]	5 b	44 b	8 b	47 b	63 b
935	40 a	22 a	63 a	27 a	66 a	72 a

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

There were few significant differences among the adjuvants when their responses were averaged across acetic acid concentrations and application volumes (Table 4). These results indicate that there is not a positive weed control benefit of adding adjuvants to vinegar spray solutions. Obviously, if other "natural" herbicidal materials (*i.e.* clove oil) (Evans et al., 2009) are added to the vinegar spray solutions, there may be an increase in weed control efficacy and a need to add adjuvants that will enhance the compatibility and/or the delivery of a uniform solution to the target plants.

Table 4. Weed control ratings in response to adjuvants averaged across acetic acid concentrations, application volumes, and 2 years.

Adjuvants	Total Weed	Total Grass	Total Broadleaf	Crabgrass	Carpetweed	Cutleaf Primrose
			%			
None	35 a[z]	15 a	59 a	17 a	62 a	69 a
Orange Oil	30 ab	13 a	55 ab	18 a	57 ab	67 a
Canola Oil	28 b	12 a	48 b	19 a	50 b	67 a

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

4. Conclusions

Vinegar was more effective in controlling broadleaf weeds than in controlling grass weeds. Optimum total grass and crabgrass weed control occurred with 20% acetic acid applied at 935 L/ha, resulting in weed control that ranged from 44% to 63%. Broadleaf control was 84% or greater for plots receiving either 10% acetic acid applied at 935 L/ha or 20% acetic acid applied at 187 or 935 L/ha. Also, 5% percent acetic acid applied at 187 L/ha provided good cutleaf evening primrose control (77 to 90%). When averaged across application volumes (187 and 935 L/ha) and adjuvants (none, orange oil, and canola oil), weed control increased for all species as acetic acid concentrations increased from 5% to 20%. When averaged across acetic acid concentrations and adjuvants, weed control increased as application volumes increased from 187 to 935 L/ha. Individual comparisons among adjuvants within acetic acid concentrations and application volumes showed little or no advantage to adding either orange oil or canola oil to vinegar spray solutions.

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