



## Assessment of Effectiveness of Vinegar and Hydrogen Peroxide Based Herbicide Formulation Against Common Weeds in Thailand

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### Abstract

Acetic acid has been proposed by farmers and popular press as an environmentally friendly bioherbicide. Nonetheless, most relevant peer-reviewed studies were conducted in North America where weeds and environment may differ from other regions. Our greenhouse experiment in Thailand showed that vinegar (5% acetic acid) had weak herbicidal effects on crabgrass while 5% acetic acid + 5% salt + 0.2% dish soap killed crabgrass completely. In field trials, this formulation completely killed crabgrass, sleepy grass, Bermuda grass, torpedo grass and swamp morning glory after repeated applications. For organically compliant formulations, soapberry extract can be used in substitute for dish soap. To avoid soil salinization, salt content in the formulation can be reduced. 10% hydrogen peroxide + 0.2% dish soap eliminated most tested weed while 10% hydrogen peroxide + 0.2% soapberry extract suppressed sleepy grass but not other grassy weeds. These results provide the basis for developing bioherbicides for Thailand and other countries beyond North America.

**Keywords:** organic, South East Asia, weed management

### Introduction

The entire world uses approximately four million tons of pesticides per year; nearly half of which is herbicide (FAO, 2020; Sharma et al., 2019). Growing public concerns about health and environmental impacts of herbicide residues together with rising demand of organic food products call for bioherbicide alternatives. Reports in popular press and weed control research literatures indicate potential uses of acetic acid as contact herbicide (Table 1). Previous studies showed that household vinegar with 5% acetic acid can be used effectively against broadleaf weeds such as *Morrenia odorata* (stranglervine), *Solanum nigrum* (black nightshade) and *Abutilon theophrasti* (velvetleaf), especially in their early growth stage (Abouziena, Omar, Sharma, & Singh, 2009; Webber III, White Jr, Shrefler, & Spaunhorst, 2018). Higher acetic acid concentration was often required for controlling grassy or late-stage weeds. Indeed, several bioherbicides in the market such as Burn-out® and Alldown® have concentrated acetic acid as a key ingredient.

Key factors influencing the efficacy of herbicides, including vinegar based herbicides, are types and growth stages of weeds as well as weather conditions particularly relative humidity and temperature (Abouziena et al., 2009; Evans, Bellinder & Goffinet, 2009; Brainard et al., 2013). These factors strongly depend on geographical locations and microclimates of the sites where herbicides are applied. Unfortunately, nearly all published research in acetic acid based herbicides were conducted in North America (Table 1). Asian developing countries such as China, India and Thailand have been among the top pesticides consumers, most of which are herbicides (Pariona, 2017). While some farmers and popular press in these countries have long claimed effectiveness of vinegar as herbicide against local weeds, no rigorous experimental evidence so far has supported such claims.



In Thailand, household vinegar + table salt + dish soap formulation was often mentioned by farmers and popular press as a safe and effective homemade herbicide. Salt may damage weed tissue via dehydration while dish soap functions as a surfactant that helps acetic acid absorb better to weed tissue. However, no research literature qualitatively measured the efficacy and explore limitation of this formulation. Additionally, there is a concern about side effects from formulation ingredients. Over-application of salt could cause soil salinisation while regular dish soap often contains synthetic chemicals that are not organically compliant.

Here, we attempt to answer the following questions. First, comparing among various vinegar or hydrogen peroxide based formulations, which one are effective against one of the most common weeds in Thailand: Crabgrass (*Digitaria sp.*)? Second, to what extent these formulations are effective against other common weeds in Thailand in the field? Third, can we replace salt and/or dish soap with other ingredients that are organically compliant and potentially have less side effects on soil? We found that vinegar + salt + dish soap herbicide formulation can effectively control various broadleaf and grassy weeds even in their late growth stage. We showed that soapberry extract can be used in substitute for dish soap in order to be compliant with organic agriculture principles. Vinegar + soapberry extract formulation without salt still has herbicidal activity albeit less than that of vinegar + salt + soapberry formulation. Additionally, we found that hydrogen peroxide, an organic compliant disinfectant, together with dish soap or soapberry extract can also be used as herbicide without salt. Our greenhouse and field experiments were conducted on common weeds in Thailand thereby adding to missing data on efficacy of vinegar based herbicide under tropical climate outside North America.

### Methods and Materials

All herbicide formulations in this work were made from the following purchased ingredients: 5% acetic acid (Aor Sor Ror vinegar, PFO FOOD Co.,Ltd.), 50% hydrogen peroxide (Pornpoj Chemical Engineering Product Ltd. part), dish soap (Sunlight Unilever Co., Ltd.), molasses (Nakorn Chemical Co.,Ltd.), glycerol (Amresco LLC) dried Sapindus rarak (soapberry) and salt (local market in Phitsanulok, Thailand). Tap water was used as a solvent for all formulations. Formulations with soapberry were made by mixing dried soapberry with tap water at 1:1 or 1:10 ratio by weight. The mixture was crushed and boiled for 10 minutes. After cooling down, the liquid part can be used as a substitute for dish detergent in formulation.

Greenhouse experiments (Table 2) were conducted at Naresuan University in Phitsanulok, Thailand for initial screening of herbicide formulations. The Crabgrass (*Digitaria sp.*) from natural habitat were collected, replanted in 5" x 11" plastic plant bags with 1 kg of soil and left to rest for four days before treatment began. The greenhouse was under natural daylight with 70–80% humidity and 37–39 C temperature. All grass plants were 10–20 cm tall with 3–6 leaves. For each treatment, two pots of grass plants were sprayed until uniformly wet with herbicide formulation once a day at noon. The percentage of total leaf area that turned brown were recorded daily.

The first field experiment (Table 3) was conducted at three wasteland sites near Naresuan University in Phitsanulok, Thailand during October– December 2019. Phitsanulok province's latitude and longitude are 16° 48'57" North 100° 15'49" East, respectively, and has an elevation of 51 meters. The province experiences tropical savannah climate with most rainfall during June – October. Dominant weeds at trial sites by area covered were: sleeping grass (*Mimosa pudica*) 25.02%, swamp morning glory (*Ipomoea aquatica*)



22.23%, bermuda grass (*Cynodon dactylon*) 22.23%, torpedo grass (*Panicum repens.*) 19.4%, crabgrass (*Digitaria ciliaris*) 2.78%, other 8.33%.

All weeds at the trial sites were at least 3 week old and 15–30 cm tall. The experimental design was a randomized complete block. Plots were 0.5 by 0.5 m, and all treatments were replicated three times. Formulated herbicides were delivered with a hand held garden sprayer during 11 am – 1 pm at 1500 L / ha. Spray applications were repeated every 2, 4 and 7 days or until weeds were completely die-off. The temperature during the time of experiment was 37–39 C with 70–80% humidity. Visual observations on weed mortality were recorded daily and estimated as percent of weeds that turned brown in the plot areas. Average weed control efficacies were compared using pairwise t-test function in R software.

The second field experiments (Table 4) were conducted at the other three wasteland sites (site A, B and C) near Naresuan University in January 2020. The dominant weed at trial site A was sleeping grass covering 97% by area; trial site B and C were 99% covered by various grassy weeds including torpedo grass. Plot size, spraying dose and time, temperature and humidity were the same as the first field experiment. Spray applications were repeated every 2 days. Visual observations on weed mortality were recorded daily.

## Results

### Greenhouse evaluation of acetic acid and hydrogen peroxide based herbicides

Crabgrass (*Digitaria sp.*) was chosen for the initial herbicide formulation test due to its prevalent in Thailand. This grassy weed has also been used in several previous herbicide studies (Table 1). Daily spraying 5% acetic acid + 5% salt + 0.2% dish soap formulation for four days completely killed crabgrass in both duplicate pots we tested (Table 2). Without salt, 5% acetic acid + 0.2% dish soap formulation still completely killed crabgrass in four days of repeated spraying, albeit requiring a longer time to cause leaf browning. 5% acetic acid without salt and dish soap caused browning but did not kill crabgrass within four days. Salt solution alone, even at 10% concentration, had no observable effect on crabgrass. Taken together, the combination of acetic acid, salt and dish soap yielded better crabgrass control efficacy than acetic acid or salt alone.

Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) is commonly used as a disinfectant. Due to its highly oxidative properties, hydrogen peroxide can damage or kill living cells or tissues upon contact. While hydrogen peroxide is derived from chemical synthesis, it can quickly disintegrate into oxygen and water, leaving no harmful residue that may have side-effect on human health or soil properties. Some popular literature mentioned the potential use of hydrogen peroxide as organically compliant contact herbicide. However, to the best of our knowledge, no scholarly literature has confirmed such claim. We showed that repeated application of 10% hydrogen peroxide + 0.2% dish soap also killed crabgrass completely within four days. Without dish soap, 10% hydrogen peroxide damaged but did not completely kill crabgrass.

We decided to pursue both 5% acetic acid + 5% salt + 0.2% dish soap formulation and 10% hydrogen peroxide + 0.2% dish soap formulation further in field experiment. 5% acetic acid + 5% salt + 0.2% dish soap was the most effective formulations we had at this stage; 10% hydrogen peroxide + 0.2% dish soap formulation was the second most effective but had an advantage in that, for this formulation, we have less to concern about side-effects on soil from acidity (of acetic acid) and salinity (from salt).



### Field evaluation of acetic acid and hydrogen peroxide based herbicides

The 5% acetic acid + 5% salt + 0.2% dish soap formulation and 10% hydrogen peroxide + 0.2% dish soap formulation were tested against common broadleaf and grassy weeds in the field. The field experiment sites were covered by sleeping grass, swamp morning glory, bermuda grass, torpedo grass, crabgrass and other grassy weeds. Overall, broadleaf and grassy weeds each covered approximately 50% of the experiment site areas. The first spray application of the 5% acetic acid + 5% salt + 0.2% dish soap formulation killed up to 78–80% of weed in the area on average (Table 3), significantly higher than 10% hydrogen peroxide + 0.2% dish soap formulation which killed about 30–47% of weed on average. Nonetheless, after four repeated applications, both formulations completely eliminated all weeds in the tested area.

Regular dish soap contains synthetic chemicals that may be not be organically compliant. Thus, we attempted to omit or substitute this ingredient with other organic alternatives. Soapberry (*Sapindus rarak* DC) is known to have saponins, amphipathic glycosides that have been useful for the development of cosmetics and drugs (Wisetkomolmat, Suppakittpaisarn, & Sommano, 2019). We hypothesized that soapberry extract could be used as a surfactant in substitute for dish soap in our formulations. In the field experiment at the same sites above, we showed that the first spray application of the 5% acetic acid + 5% salt formulation without any surfactant killed up to only 10% of weed in the area. This level of efficacy was significantly lower than that of 5% acetic acid + 5% salt + 0.2% dish soap formulation. With soapberry extract as a surfactant, average weed control efficacy of the first application went up to 55–67%. After repeated applications, 5% acetic acid + 5% salt + 0.2% soapberry formulation can eliminate 90% of weeds in the applied area. Note that the average weed control efficacy of 5% acetic acid + 5% salt + 0.2% soapberry formulation was lower but not statistically different from that of 5% acetic acid + 5% salt + 0.2% dish soap formulation (Table 3).

### Development of low salt, organically compliant herbicide formulations

Despite being organically compliant, the use of 5% acetic acid + 5% salt + 0.2% soapberry could still lead to problems about soil salinization. Thus, we attempted to reduce or replace salt in the formulation with other solutes that may have similar herbicidal effects but can readily be degraded in soil. The next field experiment was conducted on a wasteland covered by either sleeping grass or torpedo grass and other grassy weeds (Table 4). We showed that 5% acetic acid + 0.2% soapberry and 5% acetic acid + 1% salt + 0.2% soapberry formulation killed up to 60% of Sleeping grass in the sprayed area after the first application and up to 80% after two repeated applications. The 5% acetic acid + 5% salt + 0.2% soapberry formulation killed more sleeping grass at a lower dose: 80% control at the first application and up to 95% control after two repeated applications. Torpedo grass and other grassy weeds were less sensitive to these formulations than sleeping grass. Still, the formulation with 5% salt tended to out-perform the formulation with 1% or 0% salt.

We reasoned that salt in the formulations enhanced herbicidal effects of acetic acid by dehydrating weed tissues. We hypothesized that organic solutes such as molasses or glycerol, adjusted concentrations to the same osmolarity as 5% salt, could have a similar herbicidal effect. Since organic solutes can be metabolized by soil microorganisms into carbon dioxide or assimilated into organic structure of microbial cells, these organic solutes are less likely to have long term impacts on soil than salt. Unfortunately, we found that 5% acetic acid + 32.5% molasses + 0.2% soapberry formulation and 5% acetic acid + 12.5 glycerol + 0.2% soapberry formulation were generally less effective than even 5% acetic acid + 0.2% soapberry (i.e. no salt) formulation.



The 10% hydrogen peroxide + 0.2% soapberry killed up to 90% of sleeping grass after five repeated applications. The first application had no observable effects on sleeping grass. The overall efficacy of this formulation against grassy weeds was low: 0–20% weed control after five repeated applications.

**Table 1** Previous studies of acetic acid based bioherbicide. The Scopus database was systematically searched from its inception to January 2020 for the presence of search terms “weed” or “herbicide” in title, abstract or keywords and the presence of search terms “vinegar” or “acetic” in abstract. Search hits were manually curated to discover 13 articles shown here. Weed genera used in the current are underlined

Author, Year, Country	Genus of targeted weeds
Fausey (2003) USA	(Bryophyte) <i>Bryum</i> , <i>Machantia</i>
Young (2004) USA	(Broad) <i>Anagallis</i> , <i>Centaurea</i> , <i>Croton</i> , <i>Erodium</i> , <i>Plantago</i> , <i>Rumex</i> , <i>Vicia</i> (Grassy) <i>Avena</i> , <i>Bromus</i> , <i>Hordeum</i> , <i>Taeniatherum</i> , <i>Vulpia</i>
Moran & Greenberg (2008) USA	(Broad) <i>Amaranthus</i> , <i>Helianthus</i> , <i>Portulaca</i>
Abouziena et al. (2009) USA	(Broad) <i>Abutilon</i> , <i>Amaranthus</i> , <i>Brassica</i> , <i>Morrenia</i> , <i>Senna</i> , <i>Solanum</i> (Grassy) <i>Cyperus</i> , <i>Dactyloctenium</i> , <i>Eleusine</i> , <i>Lolium</i> , <i>Setaria</i> , <i>Sorghum</i>
Brainard et al. (2009) USA	(Broad) <i>Amaranthus</i> , <i>Brassica</i> , <i>Chenopodium</i> (Grassy) <i>Digitaria</i> , <i>Setaria</i>
Evans & Bellinder (2009) USA	(Broad) <i>Amaranthus</i> , <i>Capsella</i> , <i>Chenopodium</i> , <i>Galinsoga</i> , <i>Polygonum</i> , <i>Portulaca</i> , <i>Stellaria</i> (Grassy) <i>Digitaria</i>
Evans et al. (2009) USA	(Broad) <i>Abutilon</i> , <i>Amaranthus</i>
Ivany (2010) Canada	(Broad) <i>Chenopodium</i> , <i>Polygonum</i> , <i>Spergula</i>
Rowley, Ransom, Reeve, & Black (2011) USA	(Broad) <i>Chenopodium</i>
Glenn et al. (2015) USA	(Grassy) <i>Digitaria</i>
Webber III et al. (2018) USA	(Broad) <i>Laciniata</i> , <i>Mollugo</i> , <i>Oenothera</i> (Grassy) <i>Digitaria</i>
Patton, Braun, and Weisenberger (2018) USA	(Broad) <i>Glechoma</i>
Domenghini (2019) USA	(Broad) <i>Amaranthus</i> , <i>Cerastium</i> , <i>Chenopodium</i> , <i>Convolvulus</i> , <i>Conyza</i> , <i>Daucus</i> , <i>Ipomoea</i> , <i>Oxalis</i> , <i>Plantago</i> , <i>Ranunculus</i> , <i>Solanum</i> , <i>Sorghum</i> , <i>Taraxacum</i> , <i>Trifolium</i> , <i>Veronica</i> (Grassy) <i>Festuca</i> (Sedge) <i>Cyperus</i>





**Table 2** Herbicide testing results on crabgrass (*Digitaria* sp.) in a greenhouse. All formulations use freshwater as solvent. Salt (NaCl) concentration was measured in weight/ volume; acetic acid ( $\text{CH}_3\text{COOH}$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) concentration was measured in volume/volume. Crabgrass control efficacy was graded as the following: N = no effect, Y = crabgrass in 1 out of 2 pots turning brown > 80%, X = crabgrass in both pots turning brown > 80%

Formulation	Crabgrass control efficacy			
	Day 1	Day 2	Day 3	Day 4
Control (no treatment)	N	N	N	N
10% NaCl	N	N	N	N
5% $\text{H}_2\text{O}_2$	N	N	N	N
10% $\text{H}_2\text{O}_2$	N	N	Y	Y
5% $\text{CH}_3\text{COOH}$	N	N	Y	Y
5% $\text{H}_2\text{O}_2$ + 0.2% dish soap	N	N	Y	Y
10% $\text{H}_2\text{O}_2$ + 0.2% dish soap	N	N	Y	X
5% $\text{CH}_3\text{COOH}$ + 0.2% dish soap	N	N	N	X
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% dish soap	N	Y	Y	X

**Table 3** Impacts of herbicide formulations (acetic acid + salt + dish soap, hydrogen peroxide + dish soap, acetic acid + salt and acetic acid + soapberry extract) and frequencies of herbicide treatment (every 2, 4 or 7 days, starting on Day 1) on weed control averaged across triplicate field experiment. Weed control efficacies were measured on Day 0, 2, 5, 10, 15 and 20 before the treatment of that day, if there is any. Values within a column followed by different letters are significantly different at  $P = 0.05$ . N/A = no data available. (1:1) and (1:10) indicate the ratio between dried soapberry and water before crushing

Treatment	Weed control (%)					
	Day 0	Day 2	Day 5	Day 10	Day 15	Day 20
Control (no treatment)	0 a	0 d	0 d	0 e	0 c	0 c
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% dish soap, every 2 days	0 a	80 a	97 a	100 a	100 a	100 a
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% dish soap, every 4 days	0 a	80 a	80 ab	97 ab	100 a	100 a
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% dish soap, every 7 days	0 a	78 a	78 abc	95 ab	98 a	100 a
10% $\text{H}_2\text{O}_2$ + 0.2% dish soap, every 2 days	0 a	30 cd	77 abc	97 ab	100 a	100 a
10% $\text{H}_2\text{O}_2$ + 0.2% dish soap, every 4 days	0 a	47 bc	47 bc	77 bc	97 a	100 a
10% $\text{H}_2\text{O}_2$ + 0.2% dish soap, every 7 days	0 a	43 bc	43 c	53 d	63 b	90 b
5% $\text{CH}_3\text{COOH}$ + 5% NaCl, every 2 days	0 a	10 d	47 bc	68 cd	N/A	N/A
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% soapberry (1:1), every 2 days	0 a	55 abc	68 abc	79 abc	N/A	N/A
5% $\text{CH}_3\text{COOH}$ + 5% NaCl + 0.2% soapberry (1:10), every 2 days	0 a	67 ab	80 ab	90 abc	N/A	N/A



**Table 4** Weed control efficacies of reduced salt, organically compliant herbicide formulations. All treatments started on Day 1. Efficacies were measured on Day 0, 2, 5 and 8. Field experiment site A was dominated by sleeping grass (*Mimosa pudica*); site B and C were dominated by torpedo grass (*Panicum repens*) and other grassy weeds

Treatment (all treatments were applied every 2 days)	Site	Weed control (%)			
		Day 0	Day 2	Day 5	Day 8
Control (no treatment)	A	0	0	0	0
	B	0	0	0	0
	C	0	0	0	0
5% CH <sub>3</sub> COOH + 0.2% soapberry (1:10)	A	0	60	80	80
	B	0	0	80	90
	C	0	0	20	20
5% CH <sub>3</sub> COOH + 1% NaCl + 0.2% soapberry (1:10)	A	0	60	80	80
	B	0	0	40	60
	C	0	0	40	50
5% CH <sub>3</sub> COOH + 5% NaCl + 0.2% soapberry (1:10)	A	0	80	95	95
	B	0	10	50	90
	C	0	0	40	50
5% CH <sub>3</sub> COOH + 32.5 % molasses + 0.2% soapberry (1:10)	A	0	0	0	20
	B	0	0	10	40
	C	0	0	0	10
5% CH <sub>3</sub> COOH + 12.5% glycerol + 0.2% soapberry (1:10)	A	0	0	50	60
	B	0	0	50	50
	C	0	0	50	60
10% H <sub>2</sub> O <sub>2</sub> + 0.2% soapberry (1:10)	A	0	0	70	90
	B	0	0	0	0
	C	0	0	10	20

## Discussion

### Acetic acid based herbicide can control common weeds in Thailand

In this work, we presented one of the first studies evaluating acetic acid based herbicide against common weeds outside North America. We showed in our greenhouse experiment that 5% acetic acid had weak herbicidal activity against crabgrass. Similarly, previous work demonstrated that 33.2% crabgrass control efficacy of 5% acetic acid at 935 L/ha application volume (Webber III et al., 2018). The same work showed that increasing acetic acid concentration to 20% or adding clove oil or canola oil as adjuvant did not significantly improve herbicidal activity. Some other previous work mentioned adding crop oil, yucca extract or potassium salt fatty acid as an adjuvant to acetic acid based herbicide but did not show how such adjuvants affecting weed control efficacy (Evans & Bellinder 2009; Evans et al., 2009; Abouziena, Omar, Sharma & Singh, 2009; Moran &



Greenberg 2008). In our case, we demonstrated that 5% acetic acid + 0.2% dish soap adjuvant can completely kill crabgrass after four repeated applications. Moreover, addition of 5% salt to this formulation further sped up crabgrass wilting. Taken together, this work highlights the significance of adjuvant/ additive in practical use of acetic acid based herbicide.

Our field experiment further demonstrated a broader application range of acetic acid base herbicide against common weeds in Thailand. Specifically, we showed that 2– 4 repeated applications of 5% acetic acid + 5% salt + 0.2 % dish soap can eliminate nearly 100% of mixed weeds in plots covered with sleeping grass, swamp morning glory, Bermuda grass, torpedo grass and crabgrass. Treatment applied at 2, 4 and 7 days interval gave statistically similar weed control outcome (Table 3). Thus, this herbicide formulation may simply need a few days to take full effect and it may not be necessary to apply the herbicide as frequently as one treatment every 2 or 4 days. By substituting dish soap with soapberry extract, we can obviate the need for synthetic chemical ingredients. The 5% acetic acid + 5% salt + 0.2 % soapberry formulation is organically compliant and can kill up to at least 90% of mixed weed after repeated applications.

#### **Salt enhances herbicidal activity of acetic acid**

To the best of our knowledge, no previous scholar literature explored the effect of adding salt to acetic acid based herbicide formulation. We showed in greenhouse experiment that 10% salt by itself had no observable herbicidal effect on Crabgrass. However, the combination of 5% acetic acid + 5% salt + 0.2% dish soap had higher herbicidal efficacy than 5% acetic acid or 5% acetic acid + 0.2% dish soap (Table 2). This result is in agreement with the follow-up field experiment showing that decreasing salt content of 5% acetic acid + 5% salt + 0.2% soapberry formulation down to 1% or 0% reduced herbicidal activity (Table 4). Taken together, these results implied potential use of salt to enhance the efficacy of 5% acetic acid. Nonetheless, the concern about soil salinization still needs to be addressed. We showed that using molasses or glycerol with same osmolarity as 5% salt did not give the same herbicidal activity enhancing effects. Future studies should explore how salt improves acetic acid based herbicide efficacy and find other working substitutes that have less long term impact on soil.

#### **Possible uses of hydrogen peroxide in weed control**

Our greenhouse and field experiment showed that 10% hydrogen peroxide, together with dish soap or soapberry extract as an adjuvant, had herbicidal activity against various local weeds in Thailand. We showed that repeated application of 10% hydrogen peroxide + 0.2% dish soap can eliminate nearly 100% of mixed broadleaf and grassy weed (Table 3). Nonetheless, an organic compliant 10% hydrogen peroxide + 0.2% soapberry extract appeared to be less effective particularly against grassy weeds (Table 4). As an organic compliant bioherbicide, 5% acetic acid + 0.2% soapberry is more effective than 10%  $H_2O_2$  + 0.2% soapberry. Still, the fact that hydrogen peroxide decomposes into water and oxygen makes it attractive as herbicide that has minimal side effects on the environment. Future studies should explore optimal dose and possible adjuvants of hydrogen peroxide based herbicide as well as a range of weeds that are sensitive to this class of herbicide formulation.





### Strengths and weaknesses

This study presents the first quantitative efficacy measurement of acetic acid and hydrogen peroxide based bioherbicide formulations against several common weeds in Thailand. Our analysis included effects of ingredient concentrations and treatment frequencies on weed control. Nonetheless, our field experiments were conducted on mixed weed populations. Thus, it is hard to assess the efficacy of bioherbicide formulations against individual weed species. Future studies should explore how species and growth stages of these weeds affect their sensitivity to bioherbicides. Additionally, comprehensive studies into mechanisms of actions for each component in bioherbicide would provide an insight for optimizing future formulations as well as finding other more potent ingredients.

### Conclusion and Suggestions

Both acetic acid based and hydrogen peroxide based herbicide can be used for controlling common weeds in Thailand, including sleeping grass, Bermuda grass, torpedo grass, crabgrass and swamp morning glory. The combination of 5% acetic acid + 5% salt + 0.2% dish soap yield the best herbicidal effects. Dish soap could be substituted with soapberry extract and salt content could be reduced, albeit at the cost of lower weed control efficacy. Repeated applications of 10% hydrogen peroxide + 0.2% dish soap can eliminate most tested weed while 10% hydrogen peroxide + 0.2% soapberry extract can control sleepy grass but not grassy weeds.

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### References

- Abouziena, H. F. H., Omar, A. A. M., Sharma, S. D., & Singh, M. (2009). Efficacy Comparison of Some New Natural-Product Herbicides for Weed Control at Two Growth Stages. *Weed Technology*, 23(3), 431–437. <https://doi.org/10.1614/wt-08-185.1>
- Brainard, D. C., Curran, W. S., Bellinder, R. R., Ngouajio, M., VanGessel, M. J., Haar, M. J., ... Masiunas, J. B. (2013). Temperature and Relative Humidity Affect Weed Response to Vinegar and Clove Oil. *Weed Technology*, 27(1), 156–164. <https://doi.org/10.1614/wt-d-12-00073.1>
- Domenghini, J. C. (2019). *Comparison of Acetic Acid to Glyphosate for Weed Suppression in the Garden*. Retrieved from <https://doi.org/10.21273/HORTTECH04453-19>
- Evans, G. J., & Bellinder, R. R. (2009). The Potential Use of Vinegar and a Clove Oil Herbicide for Weed Control in Sweet Corn, Potato, and Onion. *Weed Technology*, 23(1), 120–128. <https://doi.org/10.1614/wt-08-002.1>
- Evans, G. J., Bellinder, R. R., & Goffinet, M. C. (2009). Herbicidal Effects of Vinegar and a Clove Oil Product on Redroot Pigweed ( *Amaranthus retroflexus* ) and Velvetleaf ( *Abutilon theophrasti* ). *Weed Technology*, 23(2), 292–299. <https://doi.org/10.1614/wt-08-158.1>



- FAO. (2020). *Pesticides Use Data Set*. Retrieved from <http://www.fao.org/faostat/en/#data/RP/metadata>
- Fausey, J. C. (2003). Controlling liverwort and moss now and in the future. *HortTechnology*, 13(1), 35–38. <https://doi.org/10.21273/horttech.13.1.0035>
- Glenn, B. D., Brecke, B. J., Unruh, J. B., Ferrell, J. A., Kenworthy, K. E., & MacDonald, G. E. (2015). Evaluation of Alternative Herbicides for Southern Crabgrass (*Digitaria ciliaris*) Control in St. Augustinegrass. *Weed Technology*, 29(3), 536–543. <https://doi.org/10.1614/wt-d-14-00094.1>
- Ivany, J. A. (2010). Acetic acid for weed control in potato (*Solanum tuberosum* L.). *Canadian Journal of Plant Science*, 90(4), 537–542. <https://doi.org/10.4141/CJPS09026>
- Moran, P. J., & Greenberg, S. M. (2008). Winter cover crops and vinegar for early-season weed control in sustainable cotton. *Journal of Sustainable Agriculture*, 32(3), 483–506. <https://doi.org/10.1080/10440040802257835>
- Pariona, A. (2011, April 25). Top pesticide using countries. *World Atlas*. Retrieved from <https://www.worldatlas.com/articles/top-pesticide-consuming-countries-of-the-world.html>
- Patton, A. J., Braun, R. C., & Weisenberger, D. V. (2019). Single Applications of Natural Postemergence Weed Control Options Do Not Provide Effective Ground Ivy Control. *Cftm*, 5(1), 1–7. <https://doi.org/10.2134/cftm2018.12.0101>
- Rowley, M. A., Ransom, C. V., Reeve, J. R., & Black, B. L. (2011). Mulch and organic herbicide combinations for in-row orchard weed suppression. *International Journal of Fruit Science*, 11(4), 316–331. <https://doi.org/10.1080/15538362.2011.630295>
- Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, 1(11), 1–16. <https://doi.org/10.1007/s42452-019-1485-1>
- Webber III, C. L., White Jr, P. M., Shrefler, J. W., & Spaunhorst, D. J. (2018). Impact of Acetic Acid Concentration, Application Volume, and Adjuvants on Weed Control Efficacy. *Journal of Agricultural Science*, 10(8), 1. <https://doi.org/10.5539/jas.v10n8p1>
- Wisetkomolmat, J., Suppakittpaisarn, P., & Sommano, S. R. (2019). Detergent Plants of Northern Thailand: Potential Sources of Natural Saponins. *Resources*, 8(1), 10. <https://doi.org/10.3390/resources8010010>
- Young, S. L. (2004). Natural Product Herbicides for Control of Annual Vegetation Along Roadsides. *Weed Technology*, 18(3), 580–587. <https://doi.org/10.1614/wt-03-094r3>