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Short title: Testing Alternative Herbicides

Comparing Alternative Non-Selective Herbicides in Oregon and New Mexico

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Abstract

Municipalities are considering alternatives to traditional herbicides for suppressing weeds and vegetation in areas frequented by the public. Two field experiments were conducted to test the efficacy of alternative non-selective herbicides: one in Corvallis, Oregon, on a mixed lawn of perennial ryegrass, annual bluegrass, and broadleaf weeds, and another experiment in Las Cruces, New Mexico, on a predominantly bermudagrass lawn with broadleaf weeds. The experimental objective was to quantify and compare the effects of repeated applications of ten non-selective herbicides to terminate a lawn with mixed vegetation. Applications were made every two weeks for four applications starting on 15 April 2022 in Corvallis and 26 May 2022 in Las Cruces. Data collected included the percent green cover over time calculated using an area under the percent green cover progress curve (AUPGCPC), the percent green cover at the conclusion of the experiment, and the change in monocot and dicot density over the course of the experiment. All treatments resulted in a lower AUPGCPC compared to water only except for mint oil + sodium lauryl sulfate + potassium sorbate. The only treatments with an average percent green cover less than 50% was a combination of ammoniated soap of fatty acids + maleic hydrazide (47% green cover) in Corvallis and pelargonic acid (38%) in Las Cruces, suggesting that more applications would be needed to terminate the lawn under similar circumstances. At the conclusion of the experiment, the water only plots averaged 90% and 93% green cover in Corvallis and Las Cruces, respectively. The change of monocot and dicot densities over the course of the experiment indicated that some of the products tested may be more sensitive to dicots, or in some cases monocots, suggesting a potential for future selective herbicide research in certain locations and climates.

Nomenclature: Acetic acid; ammoniated soap of fatty acids + maleic hydrazide; ammonium nonanoate; caprylic acid + capric acid; cinnamon oil + clove oil; clove oil; d-limonene; mint oil + sodium lauryl sulfate + potassium sorbate; pelargonic acid; sodium chloride;
annual bluegrass, *Poa annua* L. POAAN; annual sowthistle, *Sonchus oleraceus* L. SONOL; bermudagrass, *Cynodon dactylon* L. Pers. CYNDA; dandelion, *Taraxacum officinale* F.H. Wigg. TAROF; perennial ryegrass, *Lolium perenne* L. LOLPE; white clover, *Trifolium repens* L. TRFRE.

Keywords: Turfgrass

Introduction

Weed control is one of the most burdensome and costly aspects of land management throughout the United States. Non-native and invasive weeds on both private and public lands are an important issue, resulting in damages and control costs of billions of dollars annually (Pimentel et al. 2005; Fuller and Mangold 2017). Herbicides are commonly used to suppress weeds; however, weed management in urban landscapes can be challenging, especially in areas where public exposure to pesticides is concerning. Municipal areas and school properties are of particular concern because young people are often more vulnerable to pesticides (Landrigen et al. 2004) and exposure to pesticides may affect children's behavioral and neurological development (Liu and Schelar 2012). Exposure to pesticides among students and staff at schools has been documented (Alarcon et al. 2005), indicating that more work can be done to reduce these risks. Today, most states have pesticide regulations specific to school areas (Hurley et al. 2014).

Examples of pesticide restrictions in the urban environment include a pesticide ban, except for a human health emergency, in daycare through eighth-grade schools and on their grounds in Connecticut (State of Connecticut 2005), and similar rules are in place in New York (New York State Department of Environmental Conservation 2010). Other locations with pesticide restrictions include South Portland, Maine, where only pesticides listed as "allowed" on the USDA National List (USDA 2023) for organic crop production or "minimum risk pesticides" as defined by the EPA (EPA 2023) may be used on municipal property (South Portland 2024). A School IPM law has been in place in Oregon since 2012, defining and limiting use of 'low-impact' pesticides, and allowing the use of these only if nonchemical pest control measures are ineffective. This law has additional, school-specific requirements for notification, posting, and record-keeping of pesticide applications (Oregon Public Law 2022). Additionally, while certain state policies, like those in New Mexico, do not have any statewide requirements or public laws regarding restricted spray zones or pesticide use around school property (New Mexico Department of Agriculture 2023), there are local school district policies that give priority to non-chemical methods of pest control (New Mexico State Legislature 2021). For example, Santa Fe, New Mexico, permits synthetic chemical use on public and municipal lands only as a last resort after other weed control methods have been attempted and were shown to be ineffective (City of Santa Fe 2023).

While restrictions on school properties may reduce exposure to certain pesticides, a perceived decrease in athletic field quality in Connecticut has been reported following a pesticide ban (Bartholomew et al. 2015). At the same time, even though player safety can be degraded when the presence of weeds reduces the under-foot safety of the playing surface (Brosnan et al. 2014), a survey in Connecticut found that respondents agreed with a ban on pesticides on elementary and middle schools (67%) and on high school athletic fields (66%) (Campbell and Wallace 2020). A different survey found that there was strong support for bans on pesticides at the state level and municipal areas as well as home lawns (Wallace et al. 2016).

In lawns, weed management can be largely overcome by maintaining a dense stand of turfgrass through common cultural practices like mowing, irrigation, and fertilization (Braithwaite et al. 2020; Turgeon and Kaminski 2020). When large weed infestations do occur, a selective broadleaf herbicide is often applied along with properly timed overseeding with desired turfgrasses to fill in voids in the landscape. If renovating a lawn becomes necessary, a non-selective herbicide will often be applied prior to re-establishment of turfgrass (Braun et al. 2021). In the absence of herbicides, timely mechanical removal of all vegetation is possible, although labor intensive, which is typically followed by the application of sod or sowing at recommended times which can increase the likelihood of obtaining a manageable landscape (Brosnan et al. 2020). In areas where pesticide restrictions occur and when mechanical removal is not feasible, alternative herbicides may be an option, although only limited data are available regarding their efficacy (Reiter and Windbiel-Rojas 2020; Young 2004). Examples of alternative herbicide products include acids such as acetic acid (vinegar) or pelargonic acid, fatty acids such as ammonium nonanoate, and plant derived oils such as clove or mint oil. Only limited research has evaluated these types of products for successful lawn termination.

The majority of the few turfgrass experiments focusing on alternative non-selective herbicides to date occurred in California. It is unclear why limited research is currently available; however, in some areas of California, there is a desire by the public to find alternatives to non-selective herbicides like glyphosate, which is listed as a carcinogen in the California Proposition 65 list (California.gov 2024; Reiter and Windbiel-Rojas 2020). One such study compared the efficacy and costs of acetic acid, plant essentials, pine oil, and glyphosate applications necessary to suppress vegetation along roadsides (Young 2004). This study concluded that the natural products tested were not comparable from an economical nor an efficacious standpoint compared to the use of glyphosate in the same setting (Young 2004). Another field experiment in California also compared alternatives like plant essential oils, chelated iron, and fatty acid soaps to glyphosate in a lawn setting using one application in Dinuba, CA on a mixed stand of bermudagrass and broadleaf weeds and two applications in Sacramento, CA on predominantly bermudagrass (Reiter and Windbiel-Rojas 2020). This research demonstrated that non-selective alternatives to glyphosate products yielded a quick response; however, in both settings, the vegetation recovered after one or two applications, likely because of the contact burn-down activity of the products, which only damaged the leaves.

For pesticides to be used in the urban environment, safety is a high concern, and alternative products need to be effective and limited in application number to reduce exposure time and frequency as well as the cost of applications. For this reason, it is necessary to address the knowledge gap regarding the number of applications necessary for alternative non-selective herbicides to effectively suppress vegetation. Considering this need, two field experiments were conducted, one in Corvallis, Oregon, and one in Las Cruces, New Mexico, with the aim of comparing several alternative non-selective herbicides for their ability to terminate a lawn of mixed monocot and dicot plants.

Materials and Methods

The layout of the experiment was a randomized complete block design and included ten alternative non-selective herbicides with water as a control treatment (Table 1). Products in this experiment were selected because at the time of the experiment all products met current and proposed municipal legislation in New Mexico and eight products met the current and proposed legislation for applications on public schools in Oregon. Well established mown turfgrass areas in Corvallis (established in 2017) and Las Cruces (at least five years in age) were chosen for the study. The Corvallis experiment (44.33°N, 123.12°W) took place on a Malabon silty clay loam, classified as part of the Pachic Ultic Argixerolls Subgroup of USDA taxonomy. This site is in the cool-season zone and consisted primarily of perennial ryegrass (*Lolium perenne* L. LOLPE) and annual bluegrass (*Poa annua* L. POAAN). The dominant dicot plants were white clover (*Trifolium repens* L. TRFRE), and common dandelion (*Taraxacum officinale* F.H. Wigg.

TAROF). The Las Cruces experiment (32.20°N, 106.74°W) took place on a Belen clay loam, classified as part of the thermic Vertic Torrifluvents subgroup of the USDA taxonomy. This site is in the warm-season zone and consisted primarily of bermudagrass (*Cynodon dactylon* L. Pers. CYNDA). The dominant dicot plants were common dandelion, white clover, and sowthistle (*Sonchus oleraceus* L. SONOL). Both sites were mown at least once a week at 7.6 cm height and clippings were removed. In OR, irrigation was not necessary because rainfall was sufficient during the experiment averaging 24.5 mm per week (Figure 1). Irrigation was applied once a week in NM to maintain healthy turf and weed stands.

At both locations, treatments (Table 1) were applied with a handheld boom attached to a CO_2-pressurized (210 kPa) backpack sprayer delivering a carrier volume of 815 L ha^{-1}. In Corvallis, applications began on 15 April 2022 and were applied every two weeks through 27 May 2022 for a total of four applications. In Las Cruces, applications began on 26 May 2022 and were applied every two weeks through July 21, 2022, for a total of five applications. To compare the effects of treatments across both sites, the Las Cruces data presented in this manuscript includes data for the first four applications (the fifth application on 21 July 2022 is not included in these analyses). The experiment was replicated over four blocks in Corvallis and three blocks in Las Cruces. Initial application timings were reflective of target turfgrass breaking winter dormancy in Las Cruces (average of 79% green cover on 25 May 2022) and turfgrass was actively growing in Corvallis (95% green cover on 15 April 2022). Weed growth and development were satisfactory for herbicide applications in both locations and in both temperature zones. High and low temperatures, as well as precipitation over the course of the experiment, were recorded at both sites (Figure 1).

Dependent variables in this experiment included area under percent green cover progress curves (AUPGCPC), percent green cover on the final rating date, and change in monocot and dicot densities over the course of the experiment. These variables were derived from images collected using a battery-powered photo light box that was placed in the same location throughout the experiment. In Corvallis, two images were collected twice a week using a Sony DSC-H9 (Sony, Tokyo, Japan) camera and the light box covered an area of 0.31 m^2 for each image. In Las Cruces, one image was collected twice a week using a Canon SX 700HS (Canon, Tokyo, Japan) camera, and the lightbox covered 1.00 m^2.

Percent green cover data were collected for each rating date by analyzing lightbox images using Sigma Scan Pro version 5.0 software (Grafiti LLC, Palo Alto, CA). These data were used to build area under percent green cover progress curves calculated using the trapezoidal method (Shaner and Finney 1977). Monocot and dicot percentages were assessed using stratified sampling (Laycock and Canaway 1980; Richardson et al. 2001) by overlaying a digital grid onto images collected on each plot using Sigma Scan Pro. When the grid lines crossed in the image, the plant was identified as either monocot, dicot, or no plant. In Corvallis, the change in monocot and dicot densities was calculated using images from the beginning of the study (15 Apr 2022) to the last rating date (10 Jun 2022) for a total period of 56 days after initial treatment (DAIT). Images from Corvallis were overlaid with a 121-point digital grid per image (242 data points per 0.62 m^2). In Las Cruces, the change in monocot and dicot densities was calculated using images from the beginning of the study (25 May 2022) to two weeks after the fourth herbicide application (21 Jul 2022) for a total period of 57 DAIT. Images from Las Cruces were overlain with a 225-point digital grid per image (225 data points per 1.00 m^2). These data were used to calculate the change in monocot and dicot densities over the course of the trial in both locations by subtracting the initial percentage from the final percentage and dividing by the final percentage [(Final – Initial) / Final]. All dependent variables in the experiment in both locations satisfactorily met the assumptions of ANOVA and were analyzed in R (R Core Team, 2022). When significant differences were observed, pairwise comparisons were assessed using Tukey's HSD at a 0.05 level of significance.

Results and Discussion

Area Under Percent Green Cover Progress Curve:

This research demonstrated that all treatments, with the exception of the mint oil + sodium lauryl sulfate + potassium sorbate combination, reduced the AUPGCPC compared to water, indicating non-selective herbicide effects. Treatments with the lowest AUPGCPC, or the greatest nonselective herbicide effect, included the acetic acid treatment in Corvallis and D-limonene and pelargonic acid in Las Cruces (Table 2). In Corvallis, acetic acid was more effective than 5 of the 10 alternative herbicide treatments, and in Las Cruces, D-limonene and pelargonic acid were more effective than 4 of the 10 treatments. In the experiment by Reiter and Windbiel-Rojas (2020), d-limonene and acetic acid had a lower NDVI on all rating dates after initial application up to 21 days, and it was also observed that a lower NDVI resulted from 22% ammoniated soap of fatty acids applied in a 10% v/v solution, supporting findings in this research. A study in Norway focusing on desiccation of white clover seed crops observed a decrease in green color when treatments of acetic acid, sodium chloride, or pelargonic acid were applied one- or two-times pre-harvest (Havstad et al., 2022) also supporting observations in this experiment.

While clove oil as well as cinnamon oil + clove oil were more effective than water, all other treatments were more effective at reducing the AUPGCPC than these two treatments in Corvallis. In Las Cruces, clove oil and cinnamon oil + clove oil performed similarly to the combination of mint oil + sodium lauryl sulfate + potassium sorbate, which did not decrease the AUPGCPC compared to water. These results indicate that these treatments are not likely the best product choice if vegetation suppression efficacy is the most important criterion for landscape managers. Previous research exploring the herbicidal effects of a variety of essential oils found that among twenty-five oils tested, cinnamon, clove, summer savory, and red thyme caused visible injury to dandelion leaf disks (Tworkoski 2002). When applied to johnsongrass (*Sorghum halepense* L.), common lambsquarters (*Chenopodium album* L.), or common ragweed (*Ambrosia artemisiifolia* L.) 25 to 30 cm in height, a 1% concentration of cinnamon or clove oil injured these plants, and a 5 and 10% concentration killed most plants 7 days after treatment (Tworkoski 2002). Boyd and Brennan (2006) observed control of nettle (*Urtica urens* L.) at a 10% concentration and common purslane (*Portulaca oleracea* L.) at a 20% concentration of clove oil. In this present study, clove oil was diluted to a concentration of 0.33% (as per the product label rate directions) and when a combination of cinnamon oil and clove oil was applied (as per product label directions), the final concentration was 2.3% for each oil. These low rates would suggest that the oil concentrations were insufficient to expect results similar to those observed by Tworkoski (2002). Reiter and Windfbiel-Rojas (2020) observed a decrease in normalized difference vegetation index (NDVI) when the combination of 47% caprylic acid and 32% capric acid were applied in a 9% v/v solution to ‘TifSport’ hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*). The same study did not observe a decrease in NDVI when the combination of 8% citric acid and 2% clove oil was applied in a 25% v/v solution.

Percent Green Cover on Final Rating Date:

In Corvallis, a combination of ammoniated soap of fatty acids + maleic hydrazide resulted in the lowest percent green cover on the final rating date (47%) and was similar to the acetic acid (51%), sodium chloride (53%), pelargonic acid (54%), and a combination of caprylic + capric acid (58%) treatments (Table 2). In Las Cruces, the pelargonic acid treatment averaged 45% green cover on the final rating date and was similar to all other treatments except the combination of mint oil + sodium lauryl sulfate + potassium sorbate and water. Even though these results are not encouraging for landscape managers desiring to apply a single alternative non-selective application for effective weed control, they do demonstrate that there was substantial suppression of the plant species present during the study. However, after four treatments over 56 days in Corvallis and four treatments over 57 days in Las Cruces, it is unlikely that these products are viable options for terminating vegetation in well-established sites such as for lawn renovations or for overgrown landscape beds or in hardscapes since the vegetation quickly recovered following termination of the study (data not shown). Further research is required to determine if complete termination of vegetation could be achieved if applications continue over long periods, or several successive seasons, until the plant's vegetative nutrient reserves have been exhausted.

Change in monocot and dicot density over time.

Suppression of either monocots or dicots was explored using the same lightbox images in both Corvallis and Las Cruces. In Corvallis, the clove oil treatment increased monocot cover compared to water only (Table 3). The combination of ammoniated soap of fatty acids and maleic hydrazide was the only treatment that reduced monocot population to an extent that was greater than the water control (Table 3). In Las Cruces, no differences in the change of monocot density were observed compared to water only. These differences between the observations in Corvallis and Las Cruces may be a function of the environment and more vigorous growth and survivability of stressors such as herbicide injury of bermudagrass, which has a stoloniferous and rhizomatous growth habit compared to bunch-type grasses like perennial ryegrass and annual bluegrass at Corvallis.

Except for the combination of mint oil, sodium lauryl sulfate, and potassium sorbate, all herbicides reduced the density of dicots in both Corvallis and Las Cruces. This observation, along with the AUPGCPC and monocot density data, suggests that some treatments may provide opportunities for future research into how to use alternative non-selective products as selective dicot weed controls in a landscape setting. For instance, clove oil was applied at 1% (as per product label directions) and resulted in a decrease in dicot density in Corvallis by 32% and in Las Cruces by 87% while resulting in a numerical increase in monocot density in both locations. In research by Boyd and Brennan (2006), clove oil applied at 10 and 20% v/v controlled nettle and common purslane but had no effect on rye (*Secale cereale* L.). The dynamics of the ecology of the lawn are complex and will depend on the dominant monocot species and the season when the applications are applied, although these results support future research in the use of alternative non-selective herbicides as selective contact dicot control products in a lawn setting.

The motivation behind pesticide restrictions and complete bans on pesticides are often unclear; however, public health and safety are likely primary factors, especially on school grounds. The more efficacious a treatment is regarding suppression of vegetation, the less frequent applications will need to be made, thus reducing exposure of pesticides to applicators and potentially others. These results indicate that more than four applications would be necessary to suppress vegetation under similar conditions in both locations and in both types of turfgrass. Such an approach could increase public exposure to herbicides compared to standard non-selective chemistries and might limit the practicality of their use. If alternative herbicides are not adopted, lawn renovation can still be achieved by mechanical removal using machines like sod cutters or fraise mowers. For landscape beds, mulching remains an option with applications of alternative herbicides perhaps being more successful when vegetation is smaller and especially younger (Kudsk and Streibig 2003). For hardscapes, vegetation size will likely play a factor in suppression and other weed management techniques, such as heat or steam, may be options in these settings (Kolberg and Wiles 2017; Peerzada and Chauhan 2018). Cost is also likely a concern. At the time of publication, cost for all treatments (except for the combination of mint oil, sodium lauryl sulfate, and potassium sorbate which had no effect on green cover reduction) would be at least nine times greater per hectare than one application of glyphosate.

Practical Implications

When it becomes necessary to renovate a lawn, non-selective herbicides are often used to terminate the existing vegetation, with glyphosate as a common choice for this purpose. When legislation or other pressures oblige landscape managers to choose alternatives to glyphosate, little research is available on the efficacy of products sold as non-selective herbicides. In this experiment, none of the treatments successfully terminated an established lawn in either Corvallis, Oregon, or Las Cruces, New Mexico. These findings suggest that the application rates, frequencies, or timings tested in this research will not satisfactorily terminate a lawn under similar circumstances. One interesting finding, however, was that grasses and broadleaves exposed to the herbicides expressed different sensitivities, suggesting that future studies focusing on selective control are warranted. Specifically, the data suggests that some alternative herbicide treatments were more impactful in injuring dicot plants than monocots, especially in New Mexico, where the dominant monocot was bermudagrass. This may indicate the possibility of spot-spraying dicot-specific weeds within a desirable turfgrass landscape with minimal and temporary discoloration of the turfgrass, especially stoloniferous and rhizomatous grass varieties like bermudagrass. Finally, even though none of the treatments successfully terminated the vegetation after four applications, that does not mean that they would be ineffective on less mature plants, with more applications, or in the late summer or early fall; however, future research is needed to help clarify this question.

Disclaimer

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or New Mexico State and Oregon State Universities.

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Table 1. Trade name, formulation, rate, and manufacturer address for treatments included in the experiment in Corvallis, Oregon and Las Cruces, New Mexico.

Trade Name	Formulation	Rate	Manufacturer
Phydura	1% clove oil	33% v/v	Soil Technologies Corp. - Fairfield, IA - www.soiltechcorp.com
Fireworxx	44% caprylic acid, 36% capric acid	6% v/v	OHP, Inc. - Bluffton, SC - ww.ohp.com
BioSafe Weed and Grass Killer	40% Ammonium nonanoate	13% v/v	Biosafe Systems, LLC - East Hartford, CT - www.biosafesystems.com
Avenger	70% d-limonene	25% v/v	Cutting Edge Formulations, Inc. - Buford, GA - www.avengerweedkiller.com
Eco Garden RTU	7.5% sodium chloride	100% v/v	Eco Living Solutions - Laguna Niguel, CA - www.ecogardensolutions.com
Natria Grass and Weed Control with Root Kill	22.11% ammoniated soap of fatty acids, 3% maleic hydrazide	17% v/v	SBM Life Science Corp. - Cary, NC - www.natria.bioadvanced.com
Weed Zap	45% cinnamon oil, 45% clove oil	5% v/v	JH Biotech, Inc. - Ventura, CA - www.jhbiotech.com
Torched	5% mint oil, 5% sodium lauryl sulfate, 5% potassium sorbate	6% v/v	Southland Organics - Bogart, GA - www.southlandorganics.com
Green Gobbler 20% Vinegar Weed Killer	20% acetic acid	100% v/v	EcoClean Solutions, Inc. - Copaigue, NY - www.greengobbler.com
Scythe	57% pelargonic acid	10% v/v	Gowan Company - Yuma, AZ - www.gowanco.com
Water	100% water	100% v/v	

Table 2: Area under percent green cover progress curves and percent green cover on the final rating date in Corvallis, Oregon and Las Cruces, NM. ^{z}AUPGCPC = Area Under Percent Green Cover Progress Curve. ^{y}Numbers followed by the same letter are not significantly different according to Tukey’s HSD at a 5% level of significance.

						Percent green cover			
Herbicide	Rate	Corvallis		Las Cruces		Corvallis		Las Cruces	
	g ai ha^{-1}	- - - - - AUPGCPC^{z} - - - - -				- - - - - - - - % - - - - - - - -			
clove oil	2,669	3439	b^{y}	3747	bc^{y}	86	a^{y}	78	abc^{y}
caprylic acid	20,200	2075	c	3041	cde	58	bcde	78	abc
capric acid	16,527								
ammonium nonanoate	41,844	1732	cde	3104	cde	60	bcd	71	abc
d-limonene	121,652	1843	cd	2046	e	64	bc	56	bc
sodium chloride	64,591	1695	cde	2411	de	53	cde	56	bc
ammoniated soap of fatty acids	29,984	1635	cde	3143	cde	47	e	65	abc
maleic hydrazide	4,068								
cinnamon oil	18,435	3016	b	3634	bcd	68	b	74	abc
clove oil	18,435								
mint oil	3,007	4929	a	4632	ab	88	a	85	ab
sodium lauryl sulfate	3,007								
potassium sorbate	3,007								
acetic acid	166,870	1289	e	2732	cde	51	de	75	abc
pelargonic acid	40,966	1341	de	2041	e	54	cde	45	c
water	- - - - -	5102	a	5079	a	90	a	93	a

Table 3: Change in monocot and dicot density in Corvallis, Oregon and Las Cruces, NM. [z]Numbers followed by the same letter are not significantly different according to Tukey's HSD at a 5% level of significance.

Herbicide	Rate	Change in monocot density				Change in dicot density			
		Corvallis		Las Cruces		Corvallis		Las Cruces	
	g ai ha^{-1}	- - - - - - % - - - - - -				- - - - - % - - - - - -			
clove oil	2,669	+2	a[z]	+36	a[z]	-32	bc[z]	-87	bc[z]
caprylic acid capric acid	20,200 16,527	-35	b	+7	ab	-53	bcd	-71	bc
ammonium nonanoate	41,844	-39	bc	+18	ab	-26	b	-80	bc
d-limonene	121,652	-20	ab	+12	ab	-52	bcd	-82	bc
sodium chloride	64,591	-27	b	-3	ab	-75	cd	-92	bc
ammoniated soap of fatty acids maleic hydrazide	29,984 4,068	-61	c	+5	ab	-39	bcd	-86	bc
cinnamon oil clove oil	18,435 18,435	-18	ab	+15	ab	-50	bcd	-89	bc
mint oil sodium lauryl sulfate potassium sorbate	3,007 3,007 3,007	-32	b	+45	a	+35	a	-18	ab
acetic acid	166,870	-33	b	+14	ab	-80	d	-97	c
pelargonic acid	40,966	-26	b	-32	b	-67	bcd	-97	c
water	- - - - -	-31	b	+20	ab	+38	a	+45	a

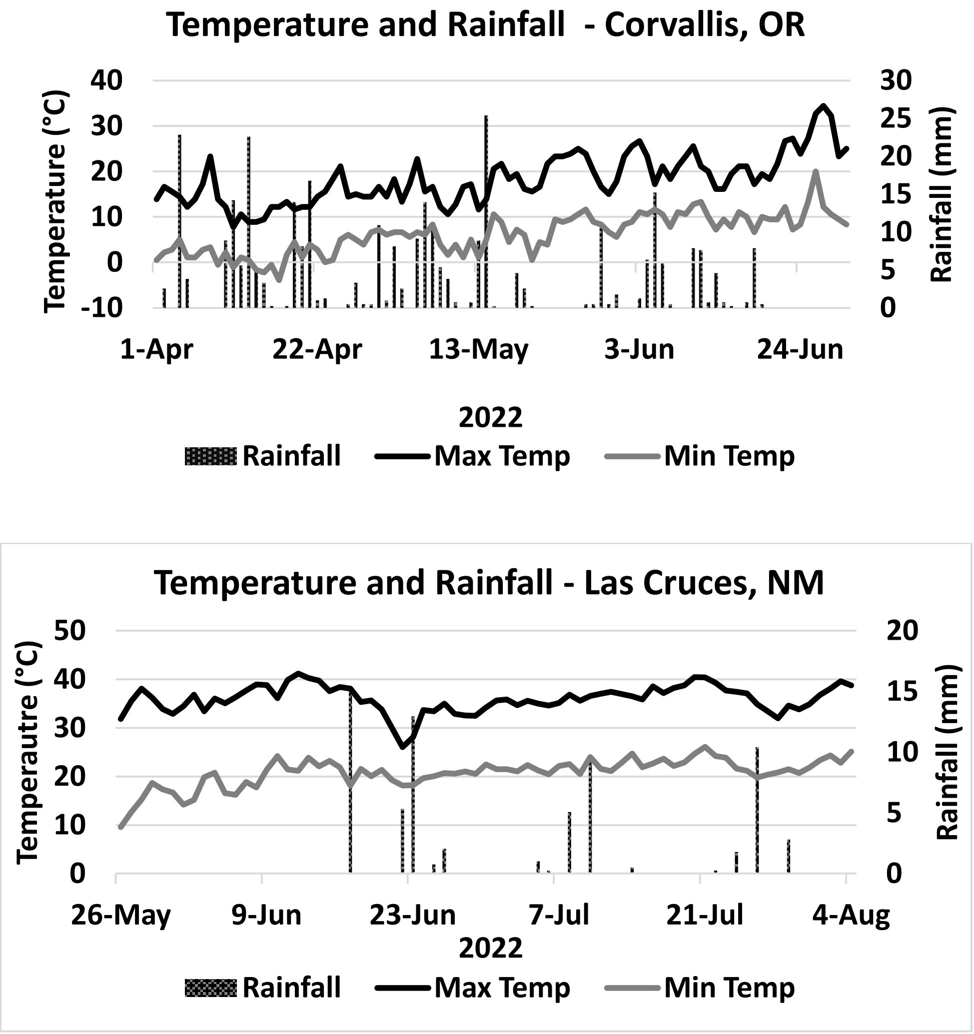

Figure 1: High and low temperatures in degrees Celsius and rainfall in mm during the 2022 experimental period in Corvallis, OR and Las Cruces, NM.