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Analysis of Lawn Rebate Programs and Drought Tolerant Lawn Recommendations in California

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ABSTRACT

California faces persistent cyclical droughts that are expected to worsen due to climate change. The state currently operates in an overall annual water deficit, and projections suggest a 10% reduction in water availability by 2040. To combat these water shortages, Governor Newsom's administration has unveiled a water supply strategy with substantial investments in water conservation policies, including rebate initiatives to encourage residents to replace lawns with drought-tolerant (DT) plants and non-living hardscapes. However, questions have arisen about the overall effectiveness and environmental impact of these costly programs. This study delves into the potential consequences of replacing living lawns with non-living hardscapes, specifically whether it might elevate local microclimate temperatures, akin to urban heat islands (UHI) caused by the substitution of natural land cover with man-made, impermeable surfaces. The research examines existing rebate programs across the state, assessing their reimbursement structures and variations. Surface temperatures of commonly recommended lawn alternatives are measured and compared, including comparisons between different alternatives and drought-tolerant ground cover plants. Additionally, the study includes an experiment involving a drought-tolerant ground cover seed mix to replace a traditional lawn. The findings indicate that hardscape lawn alternatives generate significantly higher temperatures than any of the drought-tolerant ground cover plants analyzed. Furthermore, there is notable temperature variability among the hard-scapes studied. Consequently, this paper proposes modifications to the existing rebate programs and emphasizes the importance of ensuring that environmental solutions introduced to address one issue do not inadvertently exacerbate related problems.

Introduction

California and Drought

In California, droughts occur often. The most significant droughts that have occurred statewide in California during the 20th and 21st century have happened during the years of 1976-1977, 1987-1992, 2007-2009, and 2012-2016[1]. The Provisions of California's Emergency Services Act has only declared the 2007-2009 and 2012-2016 droughts as statewide drought emergencies. This means that significant action to reverse the drought has only been made mandatory two times. More recently and following 3 of the driest years recorded in California's history[2], a series of 31 atmospheric rivers in 2023 brought rains delivering record breaking amounts of water[3], temporarily ending the period of drought-like conditions[4]. According to California's Farm Bureau Water expert Chris Sheuring, California is known to perpetually cycle between droughts and the accumulation of rainfall[5]. Though the record rainfall has been a relief, and has added an estimated 3.8 million acre-feet of water into depleted groundwater reservoirs as well as record snowpack in the mountains, due to how over-pumped and depleted California's groundwater reservoirs and aquifers are, it will take years if not decades of rainfall to reach sustainability[6]. Ground water, the source of between 40-60% of California's annual water supply[7], has been depleting precipitously over the last 20 years according to scientist J.T. Reager of JPL [8]. Our current understanding of climate change predicts that there are going to be more and worse droughts moving forward in the future, and higher temperatures which will exaggerate these conditions. The 2013 Southwest Climate Assessment[9] explains expected drought-related occurrences due to climate change. One of the most realistic outcomes of the current climate conditions is that droughts will become "more frequent, more intense, and longer lasting, resulting in water deficits not seen during the instrumental period." The 2013 Southwest Climate Assessment also noted that, since 1950, the West and Southwest have been warmer than any comparable period in at least 600 years. Warmer temperatures affect the percentage of precipitation and mountain snowpack, which consequently affects the spring water runoff and water percentage that is saved and collected during the winter months when California receives most of its rainfall. Furthermore, water managers and scientists are anticipating that California can expect a 10% reduction in water availability by 2040[10].

California's Water Plan

In order to mitigate the effects of a warming climate, and cyclical droughts on California's water availability, Governor Newsom's administration has published a Water Supply Strategy, "*Water Supply Strategy: Adapting to a Hotter, Drier Future*[10]*."* This plan commits billions of dollars of investment and outlines 4 main strategies: 1. Water Storage - create more water storage capacity to capture water from rain events and melting snowpack; 2. Create new water - make new water available by recycling waste water and desalinating ocean water and salty ground water; 3. Improve data collection and management – specifically water rights considerations, 4. Conserve water - reduce demand for water with policies to reduce water use in towns and cities and by oversight of ground water use through the Sustainable GroundWater Management Act (2014)[11]. One of the key and most specific water conservation goals outlined in Governor Newsom's plan is to incentivize homeowners to replace their turf lawns with lawn alternatives that use less or no water. The stated goal is to remove 500 million square feet of turf lawn by 2030. This is estimated to generate around 66,000 acres-feet of water savings annually.

Lawn Replacement Rebate Programs

To motivate Californians to replace their lawns, the State, in partnership with local agencies, sponsors rebate programs for lawn removal. These programs are usually run by the metropolitan water districts and their water agencies and offer financial compensation in order to incentivize residents to replace their lawns with approved alternatives. Lawn rebate programs, otherwise known as "cash for grass" or "turf replacement programs" (TRP's), were initiated in 2009 and continue to the present day. In 2022, Newsom's Administration signed the law (AB 2142) to further try and encourage citizens to replace their lawns. This law exempts lawn replacement rebates from state income tax[12]. While rebate programs vary, one thing they have in common with one another and with the State's recommendations is encouraging residents to incorporate more hardscape options in their landscaping, including: stone, gravel, pavers, mulch, artificial turf, or a combination of these hardscape and drought tolerant plants (xeriscaping). Studies of similar rebate programs that incentivize turf grass removal and xeriscaping (landscape that requires little or no irrigation) in Nevada have demonstrated a household water savings of 18%[13] in a rebate program that required 50% of turf removal area to be planted. In a second and smaller study, up to 30% water reduction is shown[14]. The results of both studies indicate that xeriscaping does help to conserve water, but it does not take into account the surface temperature of the surrounding area or the other impacts that surface temperature changes might have on the environment.

California Water Use

How is water used in the state of California and how much goes specifically to lawns? According to a 2015 study by University of California Extension on California's annual water use[15] (Figure 1) the vast majority of water used in California (over 77%) is for Agricultural production and only 9% goes to outdoor irrigation for residents, parks and sports fields. Of that 9%, lawns use 40-60%. The authors entitled their study: "The Case of the 9%", making the point that even if all irrigation to all lawns were completely eliminated (i.e., not replaced with drought-tolerant plants that still require irrigation), the absolute maximum of water savings for the State would be 3.5-5% of the total water used annually. To get a more accurate estimation of just how much residential lawns could account for, I used their data of 7% water for outdoor residential water use and the 40-60% for lawns to calculate an even lower water savings of 2.8-4.2% of California's water that lawn removal could deliver. I then applied the percent of household water savings achieved in the studies of the Nevada rebate programs cited above (18-30%), to calculate an expected statewide water savings of 0.5%-1.26% (estimated by taking 18% of 2.8 – 30% of 4.2). This is an extremely small amount of water savings. Hodel and Pittenger (2015) further argued that the 3.5-5% water savings from their study could easily be made up in more efficient irrigation practices that have already been tried and tested, all while preserving the many benefits that lawns provide, including: recreation, enjoyable environments, habitat (at least more than replacements that require no water), providing water to adjacent vegetation, rain capture, erosion control, carbon sequestration, and local cooling via evapotranspiration. A 2023 study by S. Addink of UC Irvine[16] supported the finding that residents used 40% more water than their lawns required. This study reasonably concludes that most water savings from lawn replacement programs are from more efficient irrigation systems and resident behaviors, and not plant type: "Good Landscape Water Management is More Important Than Plant Material Change." I was interested in the fact that while lawn replacement programs have the potential to lower water use (albeit a very small percent of California's overall consumption), reducing the overall green space and increasing hardscape could possibly also have negative effects on the local environment that are not being considered by the policy. In particular, I was concerned that the recommendations by the policy are counter to other environmental research and policies that have been done addressing local and global warming. These other policies and research encourage the incorporation of more green landscape elements into city and urban planning (rather than less like the studies done in Nevada) to lessen urban heat island effects (UHI)[17]. UHI's are areas of higher surrounding temperatures, created by the increased energy absorption caused by substituting natural land cover elements with man-made and/or impermeable ones.[18,19] Turf grasses, in combination with other kinds of vegetation have been shown to help mitigate UHI effects.[20] Increased urban heat islands are also relevant to a discussion of water savings because higher ground temperatures are shown to increase local water loss via evaporation from soil, and increased transpiration (and stress) in adjacent trees and vegetation. [21] These programs may be saving water in areas by replacing grass partially with hardscapes, but these savings may be offset by the increased water needs of plants in the surrounding environment in order to counter the higher temperatures.

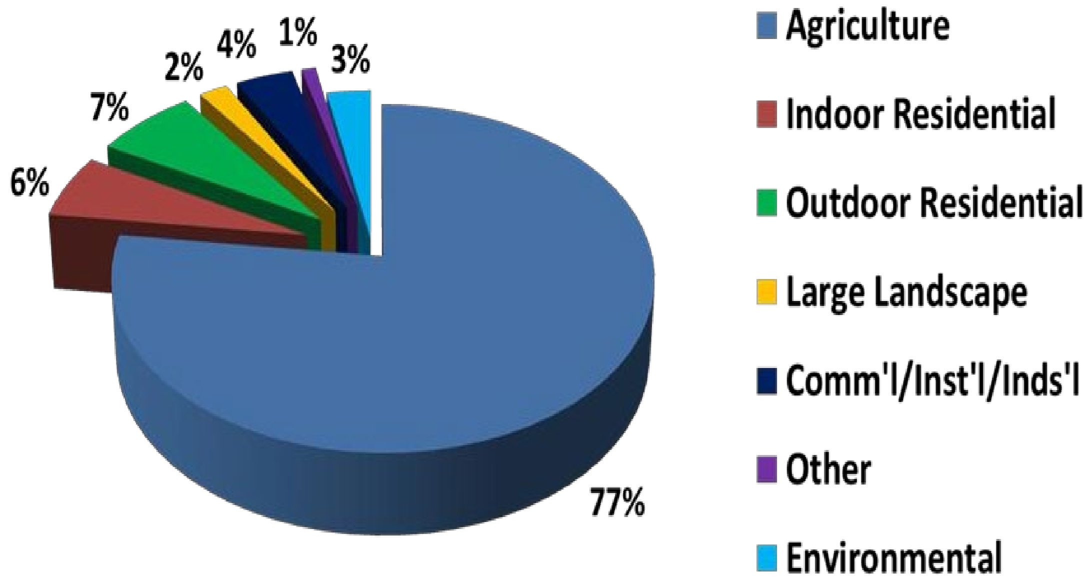

Figure 1. Average percentages of developed water use in California during a non-drought year (Sources: Calif. Dept. of Water Resources, 2013 California Water Plan Update Chapter 3. UCLA Institute of Environment and Sustainability, So. Calif. Environmental Report Card, Fall 2009).

The objective of my study was to evaluate California's lawn replacement rebate programs (sometimes called turf replacement programs or TRP's), assess the effect of different lawn replacement options with respect to their surface temperature, soil temperature and moisture, compare different drought tolerant ground cover options, and lastly to discuss the pros and cons of the recommended lawn alternatives in the context of the overall environment. I look at how these perspectives might inform state recommendations, local rebate programs, and help individual Californians weigh their decisions in trying to reduce their water use in landscaping.

Methods

I reviewed 36 current lawn replacement rebate programs throughout the state: 14 in Southern California, 5 in Central California and 17 in Northern California. I determined which lawn alternatives the program incentivized, the amount of the reimbursement available to applicants, and when information was available, what other water conservation practices they required or reimbursed. As far as I could find, there is not a singular place to find all of the programs listed, which can make it difficult for residents seeking guidance. Residents can find out if there are rebate programs in their area by checking with their water provider. I referenced a list of providers from a website called Bolder Green.[22]

After reviewing the 36 rebate programs and their recommended lawn alternatives, I decided to test all the lawn alternatives in my own backyard. Surface temperature, soil moisture and soil temperature were measured for 5 hardscapes recommended in Governor Newsom's Water Strategy Plan[23] and 4 different drought-tolerant ground covers. A linear row of plots of each lawn alternative were placed on flat open (unshaded) terrain in my yard in Saratoga, California. Hardscape replacements included blue-stone, pavers, gravel, bark mulch, and artificial-turf (Table 1). Drought tolerant ground cover plots included dwarf mondo grass, dwarf strawberries, blue myoporum, and a mixed seed ground cover (a blend of dwarf chamomile, white clover, creeping thyme and buffalo grass) (Table 1). I also included bare ground in my study as some people let their lawns die off during the summer and I was interested in how bare ground might affect local temperatures. Each plot was set in a 6.7' wide by 5' long box, separated by wooden planks. Surface temperature was measured 12 inches above the surface, using a Sovarcate Infrared Thermometer with a spot to distance ratio (S:D) of 12:1 as close to solar noon as possible. Each sampling day, two surface temperature values were recorded for each plot and the average was taken. Initial temperature readings were taken with a standard emissivity setting of 0.98. Emissivity, the ability of an object to release radiant heat, can vary greatly between substrates and influence the accuracy of the surface temperature readings. I tried to contact the manufacturer of each of the non-plant options (hardscape) in the study to get their specific emissivity values, but these were not available. I eventually found reliable emissivity values from a combination of published online scientific articles and tables of common emissivity values provided by thermometer companies online. From this point forward, in addition to taking readings with the 0.98 setting, I adjusted the emissivity setting on the thermometer for each hardscape (Table 1 with references) for more accurate data. I analyzed the data for both emissivity adjusted (Em = adj) and standard (EM = 0.98) separately. For soil temperature I tried 3 different temperature meters (AcuRite 00661 stainless steel soil thermometer, Sovarcate meat thermometer (TP300), LOSTRONAUT long stem compost soil thermometer stainless steel). Soil moisture was measured with XLUX Long Probe Deep Use Soil Moisture Meter, the Water Monitor Indicator Sensor, and the Hygrometer for Outdoor Indoor Large Pot Plants, Flower, Gardening, Farming. Soil temperature and moisture were measured at a depth of four inches below the ground (at the recommended depth for standard gardening based on the depth of roots.).

Table 1. Lawn Replacement Options and Emissivity Values

Landscape Element	Name	Material	Emissivity
Bluestone (hardscape)	Connecticut Blue Stone	Sandstone	0.925[49]
Paver (hardscape)	Venetian Concrete Paver in Pacific Blend 60 mm 8.86 in. L x 5.91 in. W x 2.36 in	Concrete	0.85[46]
Gravel (hardscape)	¾ in. black and white gravel	Basalt, Limestone, and Sandstone	0.28[48]
Mulch (hardscape)	Mulch (brown bark)	Wood	0.85[48]
Artificial Turf (hardscape)	Traffic Master Artificial Grass, Emerald Green Rug, 6 x 8 ft.	Synthetic	0.95[47]
Bare Ground (hardscape)		Dry Soil	0.92[47]
Dwarf Mondo Grass (Drought tolerant ground cover)		Organic	0.95[47]
Myoprorium (Drought tolerant ground cover)		Organic	0.95[47]
Dwarf Strawberry (Drought tolerant ground cover)		Organic	0.95[47]
Buffalo Grass (Drought tolerant ground cover)		Organic	0.95[47]
Carpet Creeping Thyme (Drought tolerant ground cover)		Organic	0.95[47]
Roman Chamomile (Drought tolerant ground cover)		Organic	0.95[47]
White Clover (Drought tolerant ground cover)		Organic	0.95[47]

Along with the lawn alternatives stated above, I planted an experimental plot of a mix of seeds that I chose because they were drought-tolerant, required less water than turf lawn, were hardy to foot traffic, and were available in my area to replace the lawn my family had stopped watering during the drought. In January, the remnants of our old dead turf lawn were removed and fresh soil was added and leveled. The mixed seeds were sown at the end of March (delayed because of the heavy flooding from the unusual rain events of this year). It took several months for the seeds to sprout and become established and cover most of the experimental plot area. Once there was sufficient ground cover (May), I took regular observations of which seeds grew and how well they served as a lawn replacement. I also took temperature readings from a mixed clover plot adjacent to the row over the entire season (March-Sept) and between these two plots I had a mixed seed/clover ground cover.

Timeline

01/16/2023 – Finalized transect design and study plan
01/30/2023 - Set up boxes for plots where each landscape element I was testing
02/03/2023 – New soil put down and leveled
02/12/2023 – All plots (hardscape and plants) installed
03/09/2023 – Planted mixed seeds in lawn replacement area
03/15/2023 – Experimented with different infrared thermometers – varied a lot
03/21/2023 – Torrential rains flooded lawn replacement area
03/30/2023 – First usable data collected (emissivity setting 0.98)
05/02/2023 – Mixed seeds matured to cover lawn replacement area
06/14/2023 – Taking data with emissivity adjusted for substrates
09/04/2023 – Last sampling day of the study

Results

Rebate Programs

I was able to find details for 36 current lawn replacement rebate programs throughout the state: 14 in Southern California, 5 in Central California and 17 in Northern California. Table 2 summarizes the rebate programs, lists the lawn alternatives they approve, and how much money can be reimbursed. The most common lawn replacement alternatives recommended by these programs are drought tolerant plants, mulch, pavers, flagstone, and gravel. Refunds for replacing a lawn range from $0.50 - $4/sq ft with maximum reimbursements ranging from $500 to $30,000 per household with a median maximum refund of $3000. Some programs allowed homeowners to reapply in successive years to replace more lawn (e.g. front yard one year and back yard another year). All but one turf replacement program (TRP's) require an application for an approved plan to replace lawn turf before it is removed in order to be reimbursed. Every rebate program recommends replacing lawn with a combination of drought-tolerant plants and other non-living hardscapes (xeriscaping), but only 20 (including all 17 of the Northern Californian Programs) had requirements for minimum 'plant canopy coverage' at maturity (e.g. 50% plant coverage). Two programs required that 3 plants be planted for every 100 sq feet of lawn removed (vs replacing with only non-living hardscape options). Only one program required planting at least some native plants but 2 mentioned native plants and 2 others banned planting invasive plant species even if they were drought tolerant. Most (30/36) programs required that hardscapes be permeable to water (meaning there had to be non-grouted space between pavers, flagstones, bricks etc). Artificial turf was an approved lawn replacement for 8 of the programs. Twentythree of the programs required conversion to drip irrigation and 4 required other sustainability options such as rain gardens, rain barrels/cisterns etc. Many of the programs will not reimburse "turf like ground covers" like the ones I experimented with in this study. Twenty one of the 36 programs required mulch (usually 3 inches deep) to be placed over all the exposed soil around the plants.

Table 2. Lawn Replacement Rebate Programs Summary

Rebate Program Provider	Max ($)	Lawn Replacements Covered	PC	AT	MR	PH	CTD
Southern California							

LA Co. WaterWorks	5000	DT plants - some native, mulch, rocks, stones, DG		no	N/A	yes	N/A
SoCalWaterSmart	10000	DT plants, mulch, pavers, stones, DG	3 plants/100 ft^2	no	N/A	yes	yes
Orange County California	15000	DT plants non-invasive, mulch, rock stone, pavers, flagstone		no	yes	yes	N/A
Coachella Valley Water District	30000	DT plants, mulch, bark, compost, DG	25%	yes	N/A	yes	N/A
San Bernardino Water Department	3000	Mulch, gravel		no	N/A	N/A	N/A
San Luis Obispo Co.	6000	DT plants, mulch, hardscapes		yes	yes	yes	N/A
San Diego Co. Waterscape	10000	Dt plants, hardscapes		no	N/A	yes	N/A
City of Santa Barbara	1000	Dt plants, mulch, ≤25% hardscape	3 plants/100 ft^2	no	yes	yes	N/A
Carpinteria Valley Water District	500	DT plants, mulch, hardscape		no	N/A	yes	yes
The City of Buellton	750	DT plants, ≤50% gravel	50%	yes	N/A	N/A	N/A
City of Lompoc	1000	DT plants/natives, mulch, gravel, rock, pavers, brick, flagstone		yes	yes	yes	yes
City of Solvang's Water Conservation Program	2000	DT plants/natives, mulch, bark, gravel, pavers, flagstone	50%	yes	N/A	yes	N/A
Goleta Water District	750	DT plants, mulch, gravel,, cobble, flagstone,		no	yes	yes	N/A
City of Ventura	3200	DT plants, mulch, gravel, pavers, flagstone, brick		no	N/A	yes	N/A
Central California							
Fresno Co. Water	1500	N/A		no	N/A	N/A	N/

Conservation							A
City of Madera Water Conserv. Rebate	3000	stones		yes	N/A	yes	N/A
Monterey Pen Water Management	2500	Mulch, pavers, DG, concrete		yes	yes	yes	yes
San Benito Co.	2000	DT plants, mulch, pavers, stones, DG		N/A	N/A	yes	yes
City of Modesto	3000	DT plants, hardscapes		yes	N/A	yes	yes
Northern California							
Bay Area Water Supply & Conversion Agency (10 cities)	vary	DT plants, mulch, hardscapes	50%	no	yes	yes	yes
Contra Costa Co. Conserv. & Devel.	2000	Non-permeable hardscapes	50%	no	yes	N/A	yes
Marin Water	3000	DT plants, gravel, brick, flagstone	50%	no	N/A	yes	yes
Napa City	750	DT plants, hardscapes	50%	no	N/A	yes	yes
Sacramento Co. Water Agency	2000	DT plants, mulch	50%	yes	yes	no	yes
Cal Water Service	4500	DT plants, much, hardscapes	50%	no	yes	yes	yes
Santa Clara Valley Water	3000	DT plants, much, hardscapes	50%	no	yes	yes	yes
City of Sacramento	3000	DT plants, mulch	60%	no	yes	no	yes

DT = drought tolerant plants, PC = plant coverage minimum required, AT = artificial turf reimbursed, MR = mulch required, PH = permeable hardscape only, CTD = convert to drip required, DG = decomposed granite

Surface Temperature

Results from all temperature comparisons can be found in Table 3. When comparing all the lawn alternatives (both plant ground covers and hardscapes) for each sampling day over the season, the highest temperatures throughout the year are all reached by hardscapes, while the coolest surface temperatures are all plant ground covers (Figure 2). This is true whether analyzing the data for a standard emissivity of 0.98 (Em = 0.98, n=7) or when taking temperature data with the emissivity adjusted (Em = adj, n=5) (Table 3). Because of this, I also analyzed the data by category (ie. comparing hardscapes to one another and comparing plant ground cover types to one another). Hardscapes had much higher average temperatures and were more variable from one another in temperature than any of the plant ground cover alternatives. Specifically, the average hardscape temperature over the entire season of the Em=0.98 dataset was 111.2 °F with a standard deviation of 22.1 while the average plant ground cover temperature over the entire season was 88.8 with a standard deviation of 15.5, a 22.4 °F differential (Table 3). This difference doubled when emissivity values were adjusted giving hardscapes an average of 135 °F with a standard deviation of 23.9 as compared to plant ground covers average surface temperature of 89.5 with a standard deviation of 15.0. In other words, the average hardscape surface temperature was 45.5 °F hotter than the average plant ground covers from June – Sept. Since it is important to adjust for emissivity, from here on out I will only focus on the results from the dataset with the adjusted emissivity. As mentioned above, the variability was also much higher for hardscapes than plant ground covers. This was true of differences both between hardscapes on the same day and the range of temperatures (max-min) from different sampling days throughout the season (Table 3). Of the hardscapes, gravel attained the highest average surface temperatures (AvgT = 170.7, std 37.1) followed by mulch, bare ground, artificial turf, pavers and bluestone (Table 4). On one sunny (no cloud) day in August with an air temperature of 88 °F at the time of sampling (solar noon), the gravel plot reached surface temperatures of 221.0 °F. Dwarf Mondo grass was the hottest plant ground cover (AvgT = 94.6, std = 14.3) followed by Dwarf Strawberry, and Mixed Seed/Clover with Myoporum being the coolest (Table 4). Overall, variability was much less between the plant ground covers average surface temperatures, however the range of difference between plant covers (max-min) varied a lot by day (e.g. some days it was as low as 5.5 °F while others were 21.55 °F different (Table 3). In general, the more the soil was shaded by plant cover, the cooler and more consistent were the surface temperatures. Variability between all the landscape elements was also much less on the one cloudy day. Surface temperatures of all the different plots seemed more affected by cloud cover than air temperature, suggesting that higher solar radiation has a bigger effect on surface temperature than actual temperature.

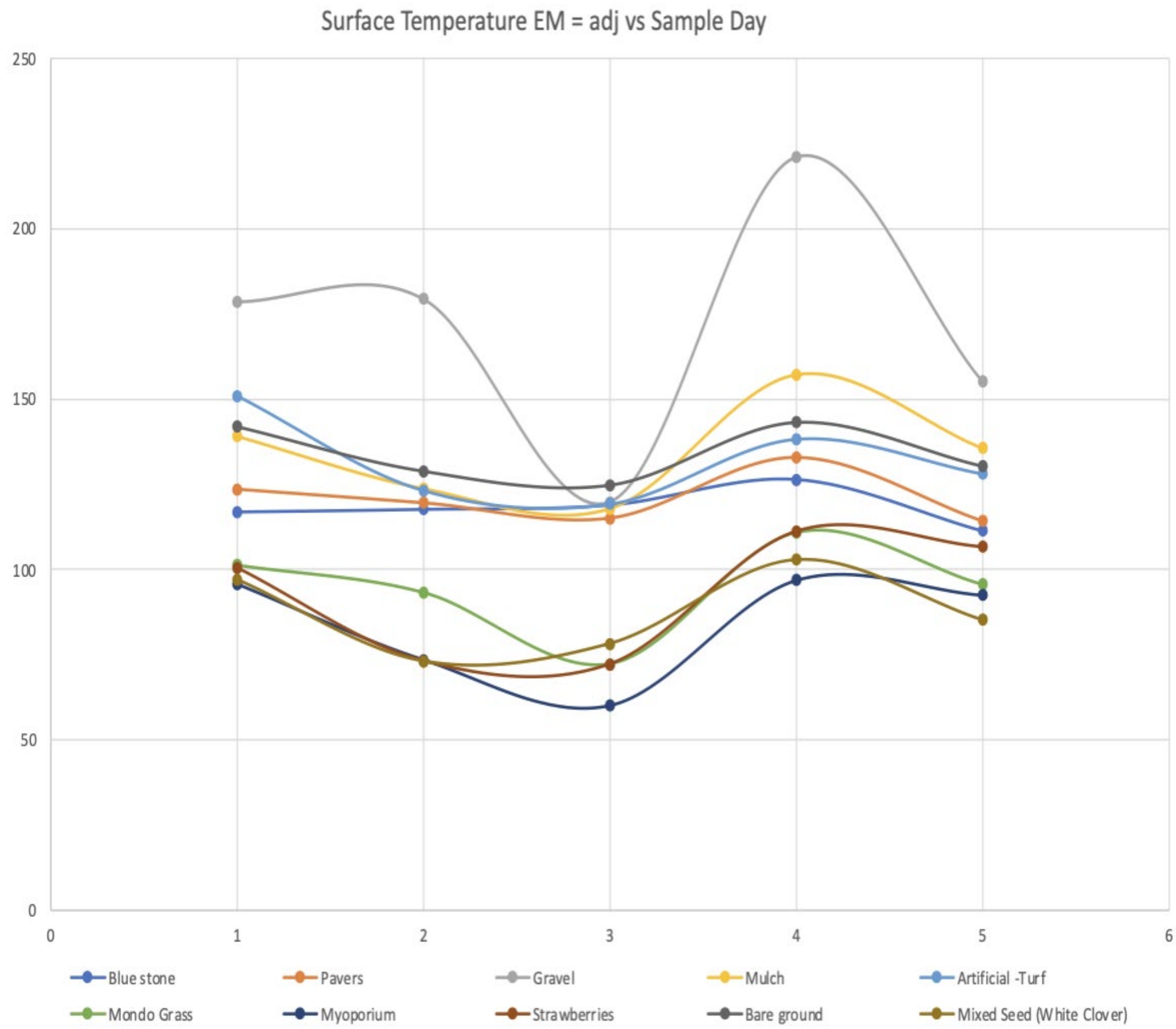

Figure 2. Surface Temperature when emissivity values are adjusted, compared to sample day.

Table 3. Surface Temperature Results

All Lawn alternatives (Hardscapes and Drought Tolerant Plants)	EM = 0.98 (n =7)	EM = adj (n = 5)
Rank Order:		
hottest (max)	Mulch Artificial Turf/Bare ground	Gravel Mulch/Bare ground
coolest (min)	Mixed seed/Clover myoporum	myoporum Mixed seed/Clover
Hardscape Surface Temps (º F) comparisons (hard vs hard)		
Range of differences between hardscapes on any given day throughout the season	4.1-35.2	9.8-94.7
Max - Min Temps over the season	67.1-151.3 (84.2)	111.4 - 221.0 (109.6)
Range of Average daily temps over season	80.9-135.1	119.2 - 153.1
Average Hardscape Temp over whole season	111.2 std 22.1	135.0 std 23.9
Plant Ground Cover Surface Temps (º F) comparisons (plant vs plant)		
Range of difference between plant ground covers on any given day throughout the season	3.7 - 34.1	5.5 -21.55
Max - Min Temps over the season	63.2 - 117.3 (54.1)	59.9 -111.2 (51.3)
Range of Average daily temps over season	68.2-105.4	70.6 -105.4
Average Hardscape Temp over whole season	88.8 std 15.5	89.5 std 15.0
Difference in Average Temp (º F) (comparisons hard vs plant)		
Range of average differences between plant and hardscapes on any given day throughout the season	7.4-34.6	34.2-53.8
Difference in Average Temp (Hard vs Plant) (º F)	111.2 - 88.8 = 22.4	135-89.5 = 45.5

Table 4. Avg Temps/Landscape Element EM = adj

Lawn Alternative	Average Temp ºF	Standard Deviation
Gravel	170.7	37.1
Mulch	134.6	15.3
Bare ground	133.8	8.2
Artificial -Turf	131.9	12.8
Pavers	121.0	7.7
Blue stone	118.2	5.3
Dwarf Mondo Grass	94.6	14.3
Dwarf Strawberries	92.7	18.7
Mixed Seed/Clover	87.2	12.5
myoporum	83.7	16.3

*Em = adj; n = 5, 6/14-9/4

Soil Temperature and Moisture

Soil temperature and moisture levels were much harder to measure over the course of the study, rendering much of this data inconclusive. The historic atmospheric rivers (late 2022 to April 2023) brought record rainfall into Californian at the start of the study, completely flooding the test plots, especially the plots with vegetation. During the early parts of the study this caused several problems. First, early on, the 2-3 inches of standing water made soil moisture readings impossible. When the yard was flooded, the ground was too wet for the probes to recognize that they were in soil, resulting in little data, and the data collected was incredibly inaccurate. Some of the data stated that the soil was 100 °F or higher when the weather outside had not hit anything warmer than 50 °F for days and the mud/soil was cold to the touch. Once the season fazed out of Spring and into Summer, and the flooding receded, I found that a whole new set of issues arose with the soil moisture and temperature meters. At this point, the ground was so hard and dry that the probes bent and broke when being pushed into or pulled out of the soil. This led to inaccurate results as the metal probes were no longer straight, and in some cases were completely broken off.

Experimental Mixed Seed/Clover Lawn Replacement

The same issues affecting soil temperature and moisture rendered my lawn replacement experimental plot unsuccessful. As mentioned above, the rare occurrence of an atmospheric river brought record rainfall into the Californian area and flooded the Mixed seed/Clover test plot with 2-3 inches of water runoff and mud. This drowned out most of the drought tolerant seeds that I planted and was planning on taking data on before the plants were fully matured (or even sprouted). This resulted in most of the plants that sprouted after the flooding to be robust, water loving weedy volunteers that thrived during the heavy rainfall. To record what plants actually grew in the experimental plot I used an Artificial Intelligence-enabled App called "PictureThis" to identify the different plants growing at 3 different time points in the study. PictureThis identifies over 1 million species of plants with a 98% accuracy.[24] As seen in Table 5, only two of the seeds originally planted survived as was recorded by "PictureThis." Because of these results, I cannot claim whether my experimental blend of drought tolerant seeds could actually be a viable replacement to lawns, rendering the entire purpose of the experimental plot useless. Table 5 shows the list and succession of plants that grew in the experimental plot.

Table 5. Succession of Plants in Experimental Plot for Drought Tolerant Ground Cover

Seeds Planted: 3/9/23	Status	4/26/23	6/1/23	6/20/23
Buffalo Grass	Cultivated native to NA			Y
Creeping Thyme	Cultivated Exotic			
Roman Camomile	Exotic			
White Clover	Exotic		Y	Y
Annual Bluegrass	Exotic	Y	Y	
Beardless Wildrye	Native	Y	Y	Y
Bermuda Grass	Invasive		Y	Y
Black Medick	Exotic		Y	
Blessed Milkthistle	invasive	Y		
Buffalo Grass	Cultivated/Native to NA			Y
Bur clover	Invasive	Y	Y	Y
Cheeseweed	Exotic		Y	Y
Common Dandelion	Exotic	Y	Y	Y
Common Fumitory	Exotic			Y
Common Sowthistle	Invasive		Y	
Desert Saltgrass	Native			Y
Fourleaf manyseed	Exotic		Y	Y

Seeds Planted: 3/9/23	Status	4/26/23	6/1/23	6/20/23
Buffalo Grass	Cultivated native to NA			Y
Creeping Thyme	Cultivated Exotic			
Lesser swinecress	Exotic		Y	Y
London rocket	Invasive			Y
Marsh Parsley	Exotic			Y
Needleleaf sedge	Native			Y
Nettle-leaved goosefoot	Exotic		Y	Y
Perennial ryegrass	Invasive		Y	Y
Prikly lettuce	Exotic			Y
Prostrate knotweek	Native	Y	Y	Y
Rosy Sandcrocus	Exotic			Y
Rosy sandcrocus	Exotic		Y	
Shortpod mustard	Invasive			Y
Stinkwort	Invasive		Y	Y
Tall Fescue	Exotic			Y
White Clover	Exotic		Y	Y
Willowleaf lettuce	Exotic		Y	Y

Data Limitations

Sample sizes for this study were very low (Em=adj, n=5 sampling days; Em=0.98, n=7 sampling days). I encountered a combination of challenges including: needing to test several different thermometers because some were not consistent, issues with flooding and rain shortening the sampling season, soil meters were not accurate and broke, finding emissivity values was challenging, sampling at solar noon (the sun perpendicular to the surface) limited the days I could collect data because of school and travel. Furthermore, on days that were breezy or had variable cloud cover (mostly in the spring), I could not get accurate data even for each plot separately. The very small sample size limits the ability to determine statistical significance of these findings.

However, there are still relevant results and trends that are worth discussing from the small amount of data I collected.

Discussion

Lawn Replacement and the Pros and Cons of Xeriscaping

All of the drought tolerant (and volunteer weed) vegetation in this study had lower surface temperatures (whether sparse or full soil coverage) than any of the hardscape options. This was true even with the "turf-like" ground covers in this study. Hardscape lawn replacement options had much higher surface temperatures, so if we are concerned about increasing the temperature of the microclimate and heat island effects stressing adjacent plants in our landscape, rebate programs should make sure to encourage replacing turf lawns with other living vegetation or at least include guidelines for minimum plant coverage. My supposition that higher surface temperatures associated with a higher percentage of hardscape coverage can result in higher microclimate air temperatures is supported by a study from Arizona State University[25] that measured surface and air temperature from 3 different landscaping options: 1) mesic: a combination of traditional high water demand landscape plants and trees with turf lawn, 2) oasis: a combination native and non-native shrubs and trees with a tiny patch of turf lawn, and 3) xeric: drought tolerant plants and trees with sparse leaf coverage, drip irrigation and no lawn (more hardscape). They found that the surrounding temperature of the oasis landscape was 5 °F warmer than the mesic site and the xeric landscape was 7 °F higher than the mesic landscape over the vegetation surface. They did not directly measure water demand but did find that the estimated water depth was lowest in the xeric landscape. However, the study had differences in irrigation, making it difficult to compare.

In addition to likely higher temperatures in xeriscapes, it is worth considering if xeriscaping will necessarily save water. Dr. Linda Chalker-Scott, Ph.D., an associate professor and Urban Horticulturist publishes informational articles about common horticulture practices including "The Myth of Xeriscaping".[26] She mentions a few studies providing evidence that xeriscaping does not actually reduce water demand for 2 reasons: 1. xerophytes (plants that can survive drought) sometimes actually take up and store more water than established non-xerophytes when water is available, and 2. While xerophytes may be able to survive severe water shortages, they thrive, grow more and are more aesthetically pleasing when they have access to ample water. In fact, the very adaptations that make them drought-tolerant (e.g efficient absorption of water when it is available, and then dropping their leaves and going dormant when water is scare) are the reason why even conservation-minded homeowners may inadvertently be using more water to keep their drought tolerant plants looking healthy.

Hardscape (Non-Living) Lawn Replacements - Pros and Cons

Mulch

Mulch was recommended in most rebate programs. In fact, many programs required 3 inches of mulch/bark/wood chips on any exposed soil around plants. Some studies show that mulch can slow soil moisture evaporation, limit water sucking weeds, and moderate the soil temperature [27, 28]. However, other studies have found that mulch actually raises soil temperatures,[29] and importantly, mulch can create a higher risk of fires, especially during the dry summer months that California experiences. This is because mulch is only beneficial to holding soil moisture when it is in full shade. If in direct sunlight, mulch will dry out and can become hazardous, and is known to occasionally spontaneously combust, becoming a fire hazard for houses and surrounding foliage.[30] In some areas, safe use of mulch relies on watering it to keep it moist, and/or the use of fire retardant to lessen the risks of combustion. I was not able to get accurate soil moisture data under the mulch, but the surface temperature results from my study find extremely high surface temperatures for mulch (AvgT = 134.7, std = 15.4). After gravel, it was the 2nd hottest hardscape and more importantly, the only flammable one, a significant issue in California's increasingly high fire risk environment. Finally, if the mulch is too deep (or the precipitation/watering is very light) water and nutrients can not penetrate to the root zone of the plants.[31] These factors combined call into question the rationale for mandating mulch as a requirement of so many lawn replacement rebate programs (specifically requiring 3-4 inches) given the goal of water savings and California's very dry climate. One of the rebate programs did specify that mulch could not be used in very high fire risk areas, but, in California summers, most areas are considered high fire risk.

Gravel

Gravel is also a lawn replacement option in most rebate programs. Gravel stands out as having the highest surface temperatures of all the lawn replacement options in my study, oftentimes too hot to touch while sampling (and would be dangerous for foot traffic, particularly small children, and pets). Studies of UHI's show that the increased heat capacity of certain materials can lead to increases in local air temperature, a reduction in humidity and soil drying. Together, the UHI effects have been shown to increase transpiration rates, slow photosynthesis and cause stress or even mortality to trees.[32] It's likely that similar effects could stress out nearby plants especially those we embed in the hot gravel in xeriscapes. In fact, the plants most associated with gravel planting are succulents (because they can deal with the heat) which are often non-native, and are unable to sequester carbon and therefore provide very little nutrients to pollinators. It is important to note however, that gravel reaches extreme temperatures at solar noon with no cloud cover. The differences between hardscape temperatures were much lower on the day with cloud cover. From this finding, it can be reasonably inferred that gravel would be a more acceptable replacement for lawns if it was under plant cover for shade. Another consideration with gravel is that it is mined, which is not only carbon intensive, but requires the removal of all vegetation (loss of habitat), erosion, pollution of downstream waters from runoff, and sedimentation - not to mention loss of biodiversity.

Blue Stone

Blue stone and pavers were the coolest of the hardscape options for xeriscaping in my study, although still hotter than any of the plant ground covers. This is probably because of their combined higher emissivity values and reflectance. Both can also be laid with spaces between them so they are semi-permeable to water. It is worth noting however that blue stone is also mined[33] and pavers are manufactured with concrete. Pavers come in several colors and sizes and some have specifically been designed to be both permeable and maintain lower surface temperatures than most hardscape options.[34]

Bare Ground

Bare ground had surprisingly high temperatures in this study. This is worth noting because many people, including my own family, let their turf lawns die off in the summer because of the water restrictions and/or the cost of water. These areas may no longer be using water but are definitely contributing to hotter microclimates, and they don't provide any habitat. In addition, as Hodel and Pittenger (2015) pointed out, many trees and plants rely on the incidental water from irrigated lawns. Therefore trees can also be negatively affected by the loss of irrigation and the hotter nearby temperatures. Bare dirt on the ground also raises the issue of more dust in the air, damaging air quality and consequently negatively affecting the respiration health of both humans and animals.[35]

Artificial Turf

Artificial turf is fortunately excluded from most rebate programs, specifically most in the northern counties of California. In my opinion, artificial turf is the worst of the hardscape options for rebate programs and should be banned from them completely. While plants release oxygen and have natural cooling effects to soil, plastic heats up in the sun and creates a heat bubble around the surrounding land. In fact, according to a study by Penn State, “a poorly designed artificial turf can easily reach temperatures exceeding 175 °F, which makes it very uncomfortable as well as unsafe for anyone sitting or playing on such turfs" [36]. The Artificial Turf plot in my study averaged a temperature of 132 °F, and reached a high of 151 °F in 73 °F degree weather and direct sunlight. This is a temperature increase of 78 °F, which is even higher than the average temperature increase from the surrounding area for blacktop lots (around a 60 °F increase).[37] This means that artificial turf has virtually the same or worse effect as replacing grass with a blacktop lot. Artificial turf is also impermeable, resulting in fewer places for rainwater to soak into the ground. Instead of rainfall becoming groundwater, the rainwater turns into runoff and ends up in storm drains where it eventually flows into the ocean, rendering it unusable.[38] Artificial Turf is also extremely bad for the environment and toxic to all animals, including people. Chemicals used to create the plastic and rubber turf cause health issues: Research from the National Toxicology Program (NTP)[39] found that crumb rubber contains substances with known human health harms, like phthalates[40] and bisphenol-A[40] (BPA). “Crumb rubber also contains polycyclic aromatic hydrocarbons (PAHs), which are a class of chemicals that can bind to or form small particles in the air, making them easily inhaled. Research has linked PAH exposure to many forms of cancer”.[41] When adding the factor of extreme heat, these chemicals rise into the air and pollute the surrounding area. The Environmental Protection Agency is currently reviewing the safety of artificial turf.[42] Lastly, but perhaps most importantly, replacing grass lawns with artificial turf contributes to global warming.[43,44] Golden (2021) showed that the amount of additional energy absorbed into the atmosphere as a consequence of replacing lawns with artificial grass is a function of higher surface temperature. This finding is key because it suggests that any lawn replacement that significantly increases surface temperature is likely to contribute not just to warming in the local microclimate as argued in my study, but potentially to global warming as well.

Conclusions and Recommendations

Lawn Replacement Rebate Programs are expensive and resource intensive. For example, the Metropolitan Water District (representing 26 cities and water districts in Southern California) spent $350 M on TRP’s from 2014-2018.[45] The California state legislature just passed a budget for 2023 that includes $75 million to support the Save Our Water campaign, helping Californians to save water including replacing their lawns with xeriscaping. This represents a significant investment, especially considering that the findings from a combination of different studies suggest that overall water savings to California is minimal (at least with respect to percent of annual water budget). Based on all I have learned, my recommendations for lawn rebate programs would be:

1. Redirect turf removal rebates to improving irrigation efficiency (leak detection, smart controllers, irrigation education, drip irrigation, water collection from roofs and rain barrels, and incorporation of gray water systems)
2. Minimize the negative environmental impacts of maintaining lawns (e.g. encourage less frequent mowing, higher lawn height (3 inches), organic rather than synthetic fertilizers to reduce polluted water runoff, ban 2/4 stroke engines for lawn mowers (pollution and spillage) and encourage manual or electric mowers.
3. Incentivize new builds to limit lawn installation (rather than ripping out lawns and landscape plants already established).
4. If allowing hardscape to replace lawns, increase and specify minimums for the amount of plant canopy or shade to keep microclimate temperatures lower and minimize the UHI effect.
5. If providing incentives for hardscapes, I would recommend natural stone or permeable pavers over gravel

6. Rethink mulch in high fire risk areas and the depth of mulch in all areas to avoid the UHI effect and possible combustion.
7. Ban rebates on artificial turf.
8. As far as advice for homeowners considering replacing their lawns with more drought tolerant ground covers goes, based on my research, these will probably not be covered by the provider for your area, and I would not recommend drought tolerant turf if the purpose is for water conservation. If, however, the goal is to improve habitats for pollinators and increase biodiversity in your lawn, I recommend planting native grasses and wildflowers rather than non-native drought tolerant ground covers.

Given the distribution of water use in the state, it is clear that lawns are only a very small amount of what needs to change. Even if all water were to be removed from lawn usage in households, there can only be around 2.8-4.2% of water saved. Instead, policies should shift their focus to water conservation in agriculture. Agriculture accounts for around 77% of California's water usage. If we can find ways to reuse or conserve water in agriculture, we could significantly increase the amount of water available. Solving any environmental problem is complicated because natural systems themselves are complicated and interconnected. When it comes to making policies, it is important that the solutions we promote to solve one issue, do not exacerbate other related environmental challenges, but take into account a more holistic view of what we are trying to accomplish overall.

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