Original Research Article

The water infiltration, hydraulic conductivity and water retention effects of ground soapwort (*Saponaria officinalis* ~~(~~L.) root as a soil surfactant

ABSTRACT

Climate change is affecting precipitation patterns and intensity; increasing regional drought conditions and reducing precipitation infiltration times, respectively. The use of soil surfactants presents an opportunity to improve soil water content and infiltration in soils. As aridity and drought vulnerability increase globally, improving water infiltration and retention is becoming increasingly important for agriculture as water resources are scarce and climate change shifts precipitation patterns. While surfactants are widely available for agricultural use, most or all are unapproved in sustainable and organic production. Ground soapwort (*Saponaria officinalis* ~~(~~L.) root produces saponins, natural surfactants used in several industrial applications, including soap and soil contaminant recovery. To determine its potential to improve soil water interactions its effects on soil hydraulic conductivity, water content, infiltration and drainage rates were tested in washed sand, heavy clay soil and clay loam soil. When compared to untreated soils, drainage and infiltration was slowed ~~in~~ (P < 0.05) in sand and loam with soapwort applications while no significant differences in any variable were present in clay soil compared to any treatment. Soil water content was not significantly different in any treatment. While soapwort did not increase infiltration rates it did markedly slow drainage rates in sand and loam. The benefit of this may be realised as longer opportunity for plant available water in the root zone.

Keywords: drought vulnerability, saponins, ~~–~~ground soapwort, soil surfactant, soil water content

1. INTRODUCTION

Global cropland is estimated at 1.82 billion hectares, 455 million hectares are considered dryland [1]. Further, more than 30% of the worlds crop supply is produced on irrigated lands [2]. Water is fast becoming a resource restraint in crop production with increased groundwater depletion and climate change. Most major arid region aquifers are being over-drafted with depletion leaving residual low quality water [3, 4].

Climate change is a driving force behind water and crop production issues. The wider impacts of global climate change on water availability are the increases of variability in seasonal precipitation [5, 6]. There are indications the variability not the overall amount of rainfall has and will continue to change [6]. This includes a reduction in the duration and increase in the intensity of precipitation events [7]. The increased precipitation intensity has also led to increased runoff and reduced infiltration globally, with North America experiencing greater runoff than most other continents [8]. Regionally, the southwestern U.S. droughts are strongly linked to El Ni~~n~~ño events; whether these represent increasingly common occurrences, long-term or cyclic events, El Nino cycling appears to be responsible for the ongoing severe to exceptional drought in the arid U.S. southwest (2009 to 2015) [9, 10]. The Intergovernmental Panel on Climate Change (IPCC) projects continued drought over the coming century [7].

In arid regions soil properties are greatly influenced by development in a dry climate. They tend to lack organic matter because of low productivity [11]. The lack of organic matter inhibits the development of aggregates, reduces porosity and water retention. These soils also contain higher concentrations of soluble ions, such as Ca^{2+} and Na^{+}, because of lack of precipitation driven leaching. Arid developed soils also tend to have clays with high shrink-swell capacity, which increase the tendency for sealing [12]. Sealing reduces the opportunity for water to infiltrate and increases runoff loses. Plant waxes are also more common in these soils and they coat soil particles with a hydrophobic film [13]. All soil types can have hydrophobic conditions present, but some soils are more prone and hydrophobic soils are now seen as more common than previously thought [14, 15]. This hydrophobicity causes soils to repel water rather than infiltrate readily. Thus arid soils have multiple factors reducing water infiltration.

Soil surfactants offer several opportunities to improve soil water management. One is reducing the infiltration time by attaching to the hydrophobic tails of the repellent coatings of the soil surface and aggregates, leaving the hydrophilic head exposed to infiltrating water. They also reduce surface tension of water and allow for freeing movement of the water into soil pores. Lastly, surfactants behave as an adsorbent, holding water in the soil pores, reducing the soil water drainage time, thus increasing the water volume and contact time for plant roots.

Typically agricultural use of soil surfactants has been exclusively in turf management for athletic fields and golf courses [15]. However, more recently there has been an increase in the use of soil surfactants to improve water use in agriculture [16, 17]. They have been used to increase infiltration, increase soil water content, and therefore plant available water (PAW), and generally increase water conservation [15].

Vertisols are a soil order with particularly problematic water infiltration issues in arid regions. They are characterized by a high percentage of montmorillonitic clay, which in dry periods causes large vertical cracks to appear with spans up to 50cm. These cracks disappear with precipitation during which time the surface seals. Thus, these are problematic soils in that they swell so rapidly that infiltration pores quickly close. The high clay content also reduces PAW by encapsulating a large portion of the soil water in the clay micropores and the dense clays reduce root penetration. Thus plants struggle to acquire enough water to maintain metabolic and transpirative needs in arid Vertisols. While not a dominant soil order, they are very productive with proper management and have a high cation exchange capacity (CEC). The largest expanses of Vertisols are in arid regions of south central India, southern Sudan and South Sudan, and eastern Australia. Water infiltration studies of Vertisols indicate tilled soils have slower infiltration, probably caused by reduced macropore continuity that results from tillage related soil pulverizing [18]. However, they are still considered prime agricultural land because the high CEC makes them very fertile.

Soil surfactant application in agricultural soils has shown promise. The use of a soil surfactant improved infiltration in a poorly drained loamy Crosby soil (Alfisols) with clayey B-horizons. The result was a 19.4% reduction in runoff [19]. Sandy loams have less shrink and swell related to clay content, and tend to drain rapidly. The rapid drainage is a result of larger pore space as sand and silt per cent is higher. However, the organic matter of loamy soils also contributes to hydrophobic conditions by developing an organic waxy coat on soil particles. Loamy sands with soil surfactants took more than twice the time to begin runoff [20].

Soil surfactant efficacy is still undergoing debate, depending on which condition is to be improved. Surfactants can improve soil infiltration [21], change preferential flows [22] or increase soil water content [23]. Nearly all of the products in use possess similar properties of a hydrophilic head and hydrophobic tail. Most are short chain organic compounds. A few are marketed for application in high value crops like vegetables [24]. All of the products are synthetic in origin and thus far none appear certified for organic operations.

Natural plant derivatives lend themselves to organic certification but there are little to no studies quantifying the effects of plant-based surfactants on soil water properties. Surfactant properties can be found in several plant derived products, specifically saponins. Saponins are present in plants of the family Sapindaceae as well as a few others. Saponins derived from plant materials have been used for soil contaminant remediation in the past. Specifically, 10% solutions of *Sapindus mukorossi* (Geartn.) has been tested for use in soil contaminant remediation with promising reults [25]. Commercially saponins are extracted or derived from, *S. mukorossi*, *Saponaria officinalis* (L.) and *Quillaja saponaria* (Molina). The compound is amphipathic, thus possessing the hydrophilic head and hydrophobic tail. Though larger in molecular weight the structure of saponin is similar to synthetic surfactants with hydroxyl groups at one end and lipophilic carbon rings at the other.

The objective of this study was to explore the effects of raw ground *S. officinalis* root on the rates of infiltration and hydraulic conductivity (K), and the water holding capacity of two arid and drought vulnerable local soils series from central Texas. The raw product is untested but has known surfactants in the form of tripterpenoid saponins [26] and is used as a surfactant in soap production [27]. The application and results of soils surfactant vary according to soil types and ground *S. officinalis* surfactant capacity is largely untested. The purpose of this study was to determine evaluate significant differences ($P < 0.05$) in infiltration rate, K or water retention as result of the application of ground *S. officinalis* to soils or sand when compared to untreated conditions (water only application).

2. MATERIAL AND METHODS

Two local soils series and washed sand were used in the study. One soil was Houston Black (heavy clay); a blackland prairie Vertisol defined as fine, montmorillonitic, thermic, Udic, Pellusterts. Blackland prairie soils are a highly productive agricultural row crop soil in Texas, but are problematic due to the high shrink swell character and low infiltration rates caused by a high percentage of clay. The other soil was Tarpley (clay loam); a gravelly Mollisol defined as clayey, montmorillonitic, thermic, lithic, vertic, Argiustolls. Tarpley is a Texas Hill Country upland Mollisols with lesser amounts of clay than Houston Black and typically used for pasture as it is not very productive, but has potential for rocky soil adapted orchard crops, such as olive (*Olea eurpoaea*). Washed sand was used as a control. Soils and sand were preparations were similar. Sand was sieved through a 2 mm mesh screen and washed in a 0.05 mm mesh screen to remove clays and silts, then dried for 24 hours at 100^{o} C. Each soil was dried for 24 hours at 100^{o} C, then screened through 2 mm mesh sieve to remove any rock fragments and large organic matter. Bulk density was taken from the Comal-Hays County WSS Soil Survey: Houston Black $P_{\beta} = 1.35$ and Tarpley $P_{\beta} = 1.27$.

The study was conducted in the laboratory similar to other studies of K, infiltration and drainage and modelled after those [16, 28]; [16]. The design was a 3x4 factorial design; 3 soil types, 4 treatments, with 3 replications. A 40 cm long x 5 cm diameter cylinder was used to hold the soil column. The bottom was covered with a wire mesh and then covered with filter paper to prevent soil loss. Dried and sifted soil or sand was placed in the tube.

Cylinders were filled to 30 cm with soil or sand and lightly packed [16, 28~~]; [16~~]. Cylinders were suspended above a basin to catch drainage water.

The treatment, powdered *S. officinalis* root, is an untested soil surfactant for this application. There is little information regarding solution concentrations, therefore we used a study that applied a 10 g/100 ml (g/g) saponin solution concentration for soil remediation as a reference point [25]. The equivalent soil application of dry powered *S. officinalis* root using the 10 g/100 ml concentration would be prohibitive in field agriculture; therefore a soil application of 1.0 g powdered root of *S. officinalis* was chosen as a soil treatment. This was chosen as the baseline application with 0.5 g and 1.5 g as alternative soil applications, with no soil application of soapwort as the control. The treatments were knifed into the surface 2-3 cm of soil to mimic a superficial application of a dry flowable product followed by soil/turf scarification. Water was released on the surface of the soil from a 1 L Marriotte reservoir and a constant head of 3 cm of water above the soil surface was maintained [16, 28]. The water level of the reservoir was recorded in cm every minute; the start time of drainage was recorded, as was the last drainage time. Drainage water volume was recorded after 1 minute after drainage ceased. Each treatment was repeated 3 times on fresh, untreated soil or sand. The variables measured were infiltration rates, drainage time and water retained. K was calculated from these data. A general linear model (GLM) was used to statistically evaluate the difference in K, drainage time, and infiltration rates. SAS 9.3 software was used to perform the analyses.

3. RESULTS AND DISCUSSION

3.1 Results

The GLM analysis of the sand data for all variables indicated an interaction between the treatments: drainage time ~~-~~– F = 7.96, P = 0.003; infiltration rate – F = 8.76 P = 0.002; water retention – F = 6.71, P = 0.006. Contrasts were then performed between each treatment within each variable. For the clay loam soil the GLM analysis indicated only the water retention with no interaction within the treatments but for clarity contrasts were performed on all: drainage time ~~-~~– F = 4.0, P = 0.034; infiltration rate – F = 6.92 P = 0.006; water retention – F = 0.38, P = 0.815. Interactions were only present in water retention for heavy clay, but similar to the clay loam soil, contrast were preformed on all treatments and variables for clarity: drainage time ~~-~~– F = 1.39, P = 0.307; infiltration rate – F = 1.31 P = 0.330; water retention – F = 3.78, P = 0.040.

Drainage time for sand treated with any surfactant application was significantly longer when compared to untreated sand drainage rates (Table 1a~~.~~). Infiltration rates were more variable, with all soapwort applications taking longer to infiltrate compared to no application only water ~~water~~ (Table 1b~~.~~ and Figure 1). The 1 g application had the longest infiltration time compared to all others. There were no significant differences in water retention based on treatment (Table1c).

Table 1. GLM c~~C~~ontrast analysis of drainage (a), infiltration (b) and water retention (c) in washed sand with powdered soapwort application, (*n*=3). P-values are presented for each application contrast in the right three columns. (GLM = General Linear Model, StdDev = Standard deviation, SW = soapwort)

a.

Treatment	Mean drainage rate (min)	StdDev	0.5 g SW	1.0 g SW	1.5 g SW
0.5 g SW	48.29	16.26			
1.0 g SW	63.24	3.61	0.069		
1.5 g SW	53.81	10.51	0.470	0.228	
H_2O	24.62	0.52	0.009	0.000	0.002

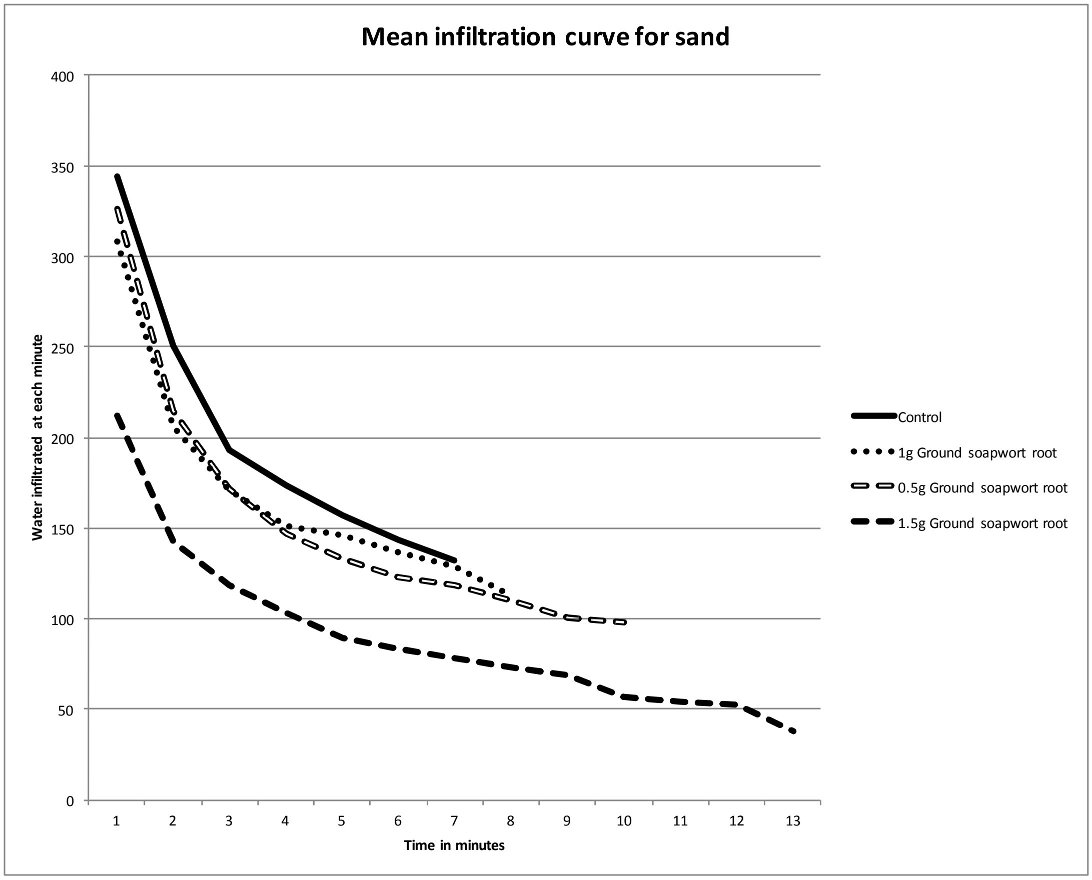
b.

	Mean infiltration rate (min)				
0.5 g SW	10.03	0.93			
1.0 g SW	8.63	0.55	0.198		
1.5 g SW	12.41	2.38	0.040	0.003	
H_2O	7.74	0.23	0.047	0.400	0.001

c.

	Mean H_2O retention (ml)				
0.5 g SW	265.00	5.00			
1.0 g SW	241.67	28.87	0.104		
1.5 g SW	246.67	2.89	0.191	0.710	
H_2O	268.33	2.89	0.804	0.068	0.128

Figure 1. Infiltration curves for ground soapwort applications in sand.



In contrast to sand, the analysis of the drainage time and infiltration rate for the heavy clay soil indicated no significant difference for any treatment (Table 2a and b, Figure 2). The analysis of water retention though, indicated significant differences based on treatment applications with water retention in a heavy clay treated with 1 g application of soapwort retained significantly more water than the 1.5 g application (Table 2c).

Table 2. GLM contrast analysis of drainage (a), infiltration (b) and water retention (c) in heavy clay with powdered soapwort application, (*n*=3). P-values are presented for each application contrast in the right three columns. (GLM = General Linear Model, StdDev = Standard deviation, SW = soapwort)

~~Contrast analysis of drainage (a), infiltration (b) and water retention (c) in heavy clay with powdered soapwort application, (*n*=3). P-values are presented for each application contrast in the right three columns.~~

a.

Treatment	Mean drainage rate (min)	StdDev	0.5 g SW	1.0 g SW	1.5 g SW
0.5 g SW	102.81	25.91			

1.0 g SW	113.35	29.94	0.666		
1.5 g SW	114.31	15.97	0.638	0.968	
H_2O	151.84	41.13	0.065	0.135	0.144

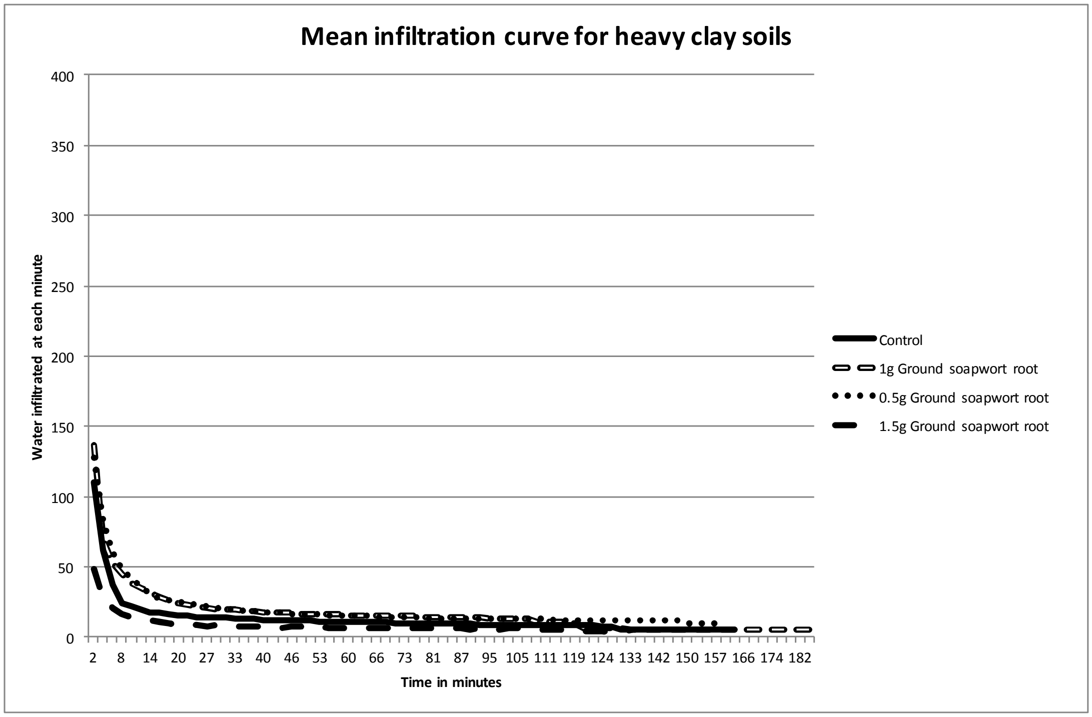
b.

	Mean infiltration rate (min)				
0.5 g SW	93.62	18.60			
1.0 g SW	111.15	77.91	0.691		
1.5 g SW	89.39	_7.21	0.923	0.622	
H_2O	170.19	84.61	0.104	0.198	0.088

c.

	Mean H_2O retention (ml)				
0.5 g SW	416.67	20.82			
1.0 g SW	455.00	30.41	0.116		
1.5 g SW	403.33	37.53	0.563	0.043	
H_2O	420.00	30.00	0.884	0.148	0.472

Figure 2. Infiltration curves for ground soapwort applications in heavy clay.



The clay loam soils have more sand and silt than heavy clay soils. Treatment effects were prevalent for drainage time and infiltration rate, but not water retention (Table 3a and b). The soapwort treatments all had significantly longer drainage times compared to water only applications. Infiltration rates were up to 3 times slower with all soapwort applications taking significantly longer than water. There were no differences in water retention for any application (Table 3c).

Table 3. GLM contrast analysis of drainage (a), infiltration (b) and water retention (c) in clay loam with powdered soapwort application, (*n*=3). P-values are presented for each application contrast in the right three columns. (GLM = General Linear Model, StdDev = Standard deviation, SW = soapwort)~~Contrast analysis of drainage (a), infiltration (b) and water retention (c) in a clay loam with powdered soapwort application, (*n*=3). P-values are presented for each application contrast in the right three columns.~~

a.

Treatment	Mean drainage rate (min)	StdDev	0.5 g SW	1.0 g SW	1.5 g SW
0.5 g SW	160.02	11.30			
1.0 g SW	192.56	67.86	0.274		
1.5 g SW	178.10	33.08	0.535	0.618	
H_2O	92.82	7.53	0.038	0.005	0.012

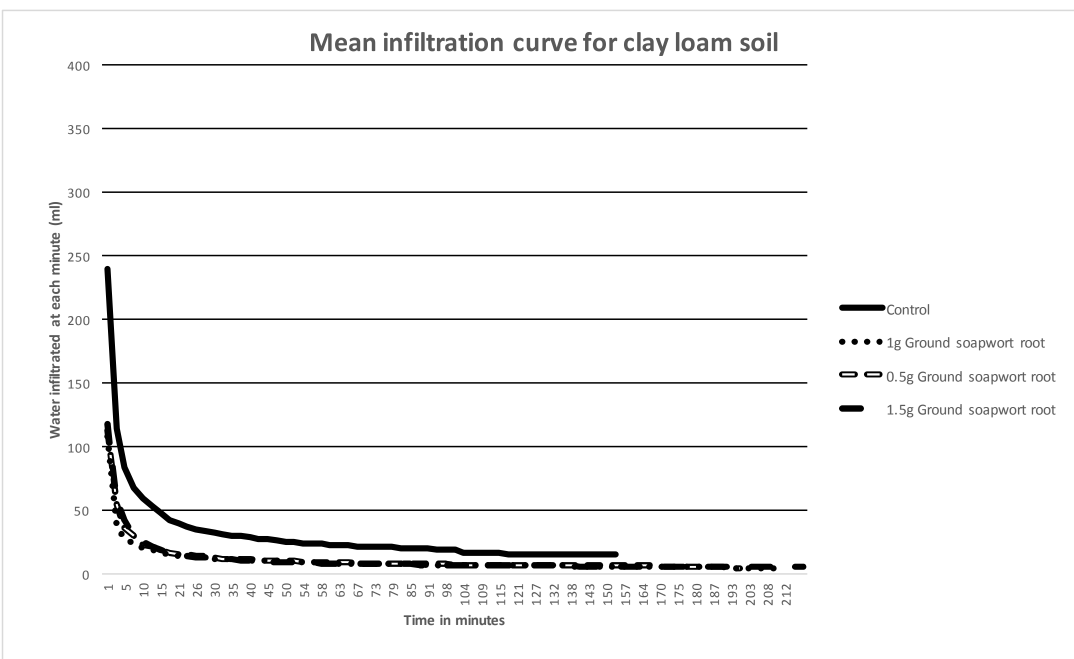
b.

	Mean infiltration rate (min)				
0.5 g SW	183.16	44.89			
1.0 g SW	203.22	60.98	0.536		
1.5 g SW	193.72	28.43	0.743	0.767	
H_2O	61.75	17.84	0.003	0.001	0.001

c.

	Mean H_2O retention (ml)				
0.5 g SW	403.33	41.63			
1.0 g SW	371.67	54.85	0.410		
1.5 g SW	376.67	60.28	0.485	0.894	
H_2O	380.00	27.84	0.540	0.825	0.929

Figure 3. Infiltration curves for ground soapwort applications in clay loam.



Hydraulic conductivity for each treatment and soil was calculated using Darcy's Law: k=[Q/(A*t)]*(H/L). As would be expected based on the analysis of time for complete drainage mean K in sand was significantly slower for all soapwort applications compared to water only (Table 4a). There was no apparent difference in K between soapwort treatments. Similarly, the effects of soapwort on K in heavy clay soils mirrored the drainage times with no difference between treatments and control (Table 4b). The effects of soapwort on K in clay loam soil were similar to sand significantly slower K in soapwort treatments; slowing by about half with any application of soapwort (Table 4c).

Table 4. GLM contrast analysis of mean K in sand (a), heavy clay (b), and clay loam (c), (*n* = 3). P-values are presented for each application contrast in the right three columns. (GLM = General Linear Model, StdDev = Standard deviation, SW = soapwort, K = hydraulic conductivity according to Darcy's Law equation)

a. Mixed effects F = 18.87, P = 0.0005

Treatment	Mean K cm sec^{-1}	StdDev	0.5 g SW	1.0 g SW	1.5 g SW
0.5 g SW	0.0012	0.00040			
1.0 g SW	0.0009	0.00000	0.131		
1.5 g SW	0.0011	0.00026	0.520	0.343	
H_2O	0.0023	0.00006	0.000	0.000	0.000

b. Mixed effects F= 1.21, P = 0.3680

Treatment	Mean K cm sec^{-1}				
0.5 g SW	0.00045	0.00014			
1.0 g SW	0.00037	0.00007	0.356		
1.5 g SW	0.00040	0.00003	0.515	0.773	
H_2O	0.00030	0.00010	0.098	0.397	0.267

c. Mixed effects F= 14.77, P = 0.0013

Treatment	Mean K cm sec^{-1}				
0.5 g SW	0.00028	0.000025			

1.0 g SW	0.00027	0.000087	0.764		
1.5 g SW	0.00026	0.000025	0.708	0.940	
H_2O	0.00050	0.000047	0.000	0.000	0.000

3.2 Discussion

This study offers only a glimpse of possibilities of soapwort as a surfactant. Soil surfactants have been proposed as treatments to increase water retention in soils, slow drainage and improve water use efficiency [29]. In compliance with our current social demands to find sustainable approaches to agriculture the use of natural plant based products appears to be a good alternative to synthetics, especially considering USDA Organic Standards do not provide for synthetic surfactant use (USDA). The soapwort application is similar to commercial soil surfactant applications in which no soil surfactant increased water content in loams or sands significantly compared to no treatment [16].

In the washed sand the drainage time was significantly longer, as was K with any application of soapwort, which could mean more opportunity for PAW during that period, however the applications of soapwort increased the infiltration time in sand. Similar effects on K were found with an anionic (Sulphonic) surfactant in a Caledon sandy loam (75% sand) [28]. Total water retention based on the soapwort applications did not differ in the sand, thus even though drainage time was longer, post drainage PAW may not differ. Again this is similar to others where applications of surfactants did not increase soil water retention compared to water control [28] [30]. In the sand treated with 1.5 g soapwort the water infiltration times were significantly longer compared to the other soapwort applications and water; and only the 1.0 g application infiltration rate no different from water. These results conflict with those where no significant difference in infiltration rates occurred [16].

Sandy soils are particularly difficult to wet evenly [31] and drain very quickly, reducing PAW and opportunity for crops to maintain turgor. In sandy soils, prevalent in south Florida field vegetable production, there may be an application for soapwort, specifically for even seedling emergence [32]. The use of soils surfactants have been shown to increase soil water content in sandy soils by up to 3 times [15], however none of the soapwort applications increase the soil water content in sand. Soil surfactants have also proven useful in turf greens management by decreasing infiltration time in sandy soils [21]. While soapwort actually appears to increase the infiltration time in sand, this study indicates drainage times could be extended by up to two times or more compared to untreated soils increasing opportunity for plants to uptake water (Table 1a and 4a). Though hydrogels are not surfactants per se, they do help soils retain water and in a sandy loam they increased the soil water content and number of days to the permanent wilting point in barley, wheat and chickpea fields [33].

When clay loam was compared to the heavy clay soil drainage times for water are very fast, but slower than washed sand. All soapwort applications increased the drainage time and infiltration rate significantly when compared to water. Others have found no differences in infiltration in their loam soil type based on the surfactants in their study [16]. Also differing from the soapwort applications are results with no significant differences in the drainage time with the use of surfactants [34]. K was significantly slower for all soapwort applications in the loam soil. Others have found all surfactant applications in their study resulted in slower

K [28]. Soapwort did not increase the retained water, which is similar to many [16, 28, 30, 34].

Heavy clay soils have very high porosity, but very low pore sizes, thus they tend to drain very slowly. Though the actual times for drainage were much faster (40 minutes) with the soapwort treatments the analysis did not indicate a significant difference in drainage times for any application. Similarly, the results for infiltration rates, K and water retention in the clay soil indicated no significant differences based on soapwort applications. The results of soapwort applications concur with the results of [34] and the surfactants applied to clay soil in their study.

4. CONCLUSION

Soapwort shows some promise slowing infiltration, reducing drainage rates and slowing K in loams or sands. It shows no apparent ability to improve water retention in any soil type used here. In clay soil soapwort had no impact on any soil water interactions compared to water. There may be application in fast draining soil types to help reduce drainage times, but only in mesic regions as drought prone regions may require the slow drainage to prevent plant water stress.

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