Geoderma 310 (2018) 201–208

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil aggregate stability under chaparral species in southern California

Carrie-Ann Haydu-Houdeshell[a], Robert C. Graham[b,*], Paul F. Hendrix[c], Adam C. Peterson[c]

[a] USDA-NRCS, Davis, CA, USA
[b] Soil & Water Science Program, University of California, Riverside, CA 92521-0424, USA
[c] Department of Crop & Soil Sciences, University of Georgia, Athens, GA 30602, USA

ARTICLE INFO

Handling Editor: Edward A Nater

Keywords:
Water-stable aggregates
Chaparral
Earthworms
Fungal hyphae

ABSTRACT

Aggregation is a key soil property that increases infiltration and aeration, and reduces erosion and runoff. This study sought to determine the amount and sources of aggregation in soils under four common chaparral species in southern California: bigberry manzanita (*Arctostaphylos glauca* Lindl.), scrub oak (*Quercus dumosa* Nutt.), hoaryleaf ceanothus (*Ceanothus crassifolius* Torr.), and chamise (*Adenostoma fasiculatum* H. & A.). Research was conducted at the San Dimas Experimental Forest in the San Gabriel Mountains. Total water stable aggregation, determined by wet sieving, averaged 45% in A and 40% in B horizons and differences were not significant by soil horizon or under the four vegetation species. Organic matter, roots, fungal hyphae, macrofauna, and clay all contribute to soil aggregation, but none of these is a clear, dominant, overriding factor in these soils. Development of water stable aggregation is inhibited by low densities of earthworms, relatively frequent wildfires, and soil erosion on the steep slopes in this chaparral ecosystem.

1. Introduction

Soil aggregation is an important soil quality parameter because it increases porosity, and thereby increases infiltration and water-holding capacity, reduces runoff and erosion, and enhances plant productivity (Karlen and Stott, 1994; Barthes and Roose, 2002). Soil aggregates are often formed by physical forces, such as drying, shrink-swell, root growth, and animal activity (Eash et al., 1994; Ghezzehei, 2012), but organic materials generally play a major role in stabilizing the aggregates (Abiven et al., 2009). The effects of organic matter are more pronounced in soils with low clay contents (Kemper and Koch, 1966; Tisdall and Oades, 1982; Chaney and Swift, 1984; Karlen and Stott, 1994). Organic binding agents that determine the age, size, and stability of aggregates can be categorized as: (i) transient binding agents, including microbially produced and root-exudate polysaccharides; (ii) temporary binding agents, including roots and fungal hyphae; and (iii) persistent binding agents consisting of degraded humic material and organic complexes that bind polyvalent cations to clays (Tisdall and Oades, 1982). Soil aggregates have been classified into macroaggregates (> 250 μm diameter), which are usually enmeshed by roots and fungal hyphae, and microaggregates (< 250 μm diameter), which are often stabilized by persistent organic binding agents (Tisdall and Oades, 1982; Oades, 1984).

The relationship between organic matter content and aggregate stability has been explored in some depth. Generally, aggregate stability increases with organic matter content. For soils of the western United States and Canada, aggregate stability was found to increase very little as organic matter contents increased over 20 g kg^{-1} (13 g kg^{-1} organic carbon), while contents below 10 g kg^{-1} (6 g kg^{-1} OC) coincided with a precipitous decline in aggregate stability (Kemper and Koch, 1966). On the other hand, a positive linear correlation ($r^2 = 0.45$) between aggregate stability and soil organic carbon (SOC) was observed for a successional sequence of Mediterranean soils with SOC values ranging from 0.2 to 40 g kg^{-1} (Erktan et al., 2016). Carbon and N concentrations in soil aggregates tend to vary with vegetation species due to associated fungal biomass and differences in litterfall and litter chemistry (Scott, 1998). Organic matter contents also vary with size of aggregates, although the trends are not necessarily similar across ecosystems. In some ecosystems, organic matter content decreases with decreasing particle size (Amelung et al., 1998; Scott, 1998), but this is not always the case (e.g., Beare et al., 1994b).

Burrowing soil macrofauna, such as ants and earthworms, play an important role in soil aggregation because they digest and mix plant organic matter into surface soils (Lee and Foster, 1991; Graham et al., 1995). Earthworms are particularly effective at producing stable aggregates in the form of casts. Earthworm casts are excreted masses of soil mixed with residues of comminuted and digested plant material and they are often more stable than other aggregates (Lee and Foster, 1991). Ants are less effective at soil aggregation than earthworms because they are social insects and tend to congregate near their nests

* Corresponding author.
E-mail address: robert.graham@ucr.edu (R.C. Graham).

http://dx.doi.org/10.1016/j.geoderma.2017.09.019
Received 27 July 2017; Received in revised form 9 September 2017; Accepted 11 September 2017

(Lee and Foster, 1991).

Soil aggregate stability has been studied in agricultural systems (e.g., Chaney and Swift, 1984; Beare et al., 1994a, 1994b; Al-Kaisi et al., 2014), native grasslands (Elliott, 1986; Reinhart and Vermeire, 2016), forested sites (Scott, 1998; Xiang et al., 2015), and matorral ecosystems (Cerdà, 1998; Cantón et al., 2009). In southern California and northern Mexico, a prevalent ecosystem of dense sclerophyllous shrubs is called *chaparral*, a Mediterranean scrub biome. Aggregate stability of chaparral soils has been studied at the large lysimeters that comprise a biosequence in the San Dimas Experimental Forest (SDEF) (Graham et al., 1995). Greater aggregate stability was found within the earthworm-cast-rich A horizon under scrub oak than in the soil under pine, where earthworms were absent. Although it may be important for promoting infiltration and inhibiting erosion, soil aggregate stability apparently has not been studied for natural stands of chaparral.

This study was designed to determine the amount and characteristics of water-stable aggregates in surface and subsurface soils under native chaparral stands. More specifically, we sought: (i) to determine the influence of chaparral species and associated macrofauna on aggregate stability, and (ii) to assess possible sources of the observed aggregation.

2. Materials and methods

2.1. Environmental setting

The study area is in the San Dimas Experimental Forest, a U.S. Forest Service research facility in the San Gabriel Mountains, 56 km northeast of Los Angeles, California. The natural vegetation is mainly chaparral, a predominant ecosystem of the southern California mountains (Parker et al., 2016). At SDEF it consists mainly of chamise (*Adenostoma fasciculatum* H. & A.), hoaryleaf ceanothus (*Ceanothus crassifolius* Torr.), bigberry manzanita (*Arctostaphylos glauca* Lindl.), and scrub oak (*Quercus dumosa* Nutt.). Mean annual air temperature is 14.4 °C with a summer maximum of 37.8 °C and a winter minimum of − 3.9 °C. Precipitation occurs mainly as rain between November and March. Annual precipitation has ranged from 292 to 1224 mm, with a mean of 678 mm (Dunn et al., 1988). The bedrock is highly fractured banded gneiss and granite (Nourse, 1998). The soil parent materials are colluvium overlying paralithic material (saprock), as is typical for chaparral soils in the Transverse Ranges of southern California (Graham and O'Geen, 2016). The soils were mostly shallow Xerorthents under chamise and ceanothus and shallow Haploxerolls under manzanita and scrub oak (Haydu-Houdeshell et al., 2017).

2.2. Field and laboratory methods

Four sites were chosen in natural chaparral communities and were designated: Boneyard (BY), Hummingbird Creek (HC), Tanbark (TB), and Adam's Thicket (AT). At each site, plots were located to obtain the "single-species" effect under bigberry manzanita, scrub oak, hoaryleaf ceanothus, and chamise, which occur as complex vegetation mosaics or in small monoculture stands. The chaparral at all sites was mature, having last burned in 1960, 38 years before the sampling for this study. These sites were previously established for macrofauna population studies (Peterson et al., 2001). Elevations, slope aspects and gradients, and topographic positions of the study plots are given in Table 1.More details on the sites and soils are presented by Haydu-Houdeshell et al. (2017).

One soil pit was excavated under each of the four vegetation types at each of the four sites. Bulk samples were taken from the A (2–7 cm thick) and B (6–25 cm thick) horizons. The soils were air-dried and the > 5000 μm fraction was removed by sieving in the laboratory prior to analysis. A < 2000-μm-fraction subsample of the bulk sample was used to determine particle-size distribution using the pipet method after removal of organic matter with 30% hydrogen peroxide (Gee and Bauder, 1986).

Table 1
Elevation, aspect, slope, and topographic position of the study sites.

Species	Site	Elevation	Aspect	Slope	Topographic position
		m		%	
Boneyard	Manzanita	789	NNW	25	Sideslope
	Scrub oak	789	NNE	30	Sideslope
	Ceanothus	790	WSW	24	Shoulder
	Chamise	790	ENE	50	Shoulder
Hummingbird	Manzanita	840	ENE	14	Sideslope
	Scrub oak	855	ENE	8	Sideslope
	Ceanothus	845	ESE	5	Sideslope
	Chamise	855	NNE	25	Shoulder
Tanbark	Manzanita	840	WSW	2	Summit
	Scrub oak	835	NNE	35	Sideslope
	Ceanothus	855	SSW	26	Sideslope
	Chamise	855	ENE	34	Shoulder
Adam's thicket	Manzanita	780	WSW	2	Summit
	Scrub oak	770	NNW	21	Sideslope
	Ceanothus	780	SSW	4	Sideslope
	Chamise	770	NNW	50	Sideslope

Aggregate stability was determined on the < 5000-μm fraction of the air-dried samples based on the method described by Beare and Bruce (1993). Using a modified Yoder (1936) wet-sieving apparatus, three 50 g sample replicates were separated into four size fractions, 5000- to 2000-μm, 2000- to 250-μm, 250- to 106-μm, and 106- to 53-μm. A subsample (3–5 g for the three largest fractions, 0.5–1 g for the 106- to 53-μm fraction) was removed from each of the final oven-dried sample fractions, dispersed in deionized water with pH adjusted to 9.5 using NaOH, and completely dispersed using a sonic dismembrator at 10% full power for 1 min. Primary particle weight correction was calculated for each of the four size fractions (Kemper and Koch, 1966):

$$\text{Aggregate stability\%} = 100\,(\text{wt. stable aggregates and sand} - \text{wt.sand}) / (\text{wt. sample} - \text{wt.sand}),$$

where "sand" includes the sand-sized grains found in each of the four size classes. Total aggregate stability was calculated by summing the aggregate stabilities of the individual fractions.

Total C and N of oven-dried, ground subsamples of aggregates were measured by dry-combustion using a C/N/S analyzer (Nelson and Sommers, 1986). In order to describe interaggregate differences in C and N concentrations, all C and N values were normalized on a sand-free basis (Beare et al., 1994b).

Macroaggregates in the 5000- to 2000-μm diameter fraction were examined with a stereoscopic microscope at 8 to 10 × magnification. Aggregates < 2000 μm diameter were mounted on Al stubs covered with carbon tape, sputter coated with Au/Pd, and examined with a Philips XL-30-FEG scanning electron microscope.

2.3. Macrofauna sampling

Earthworms were sampled by digging pits and hand sorting the contents (Edwards, 1991). Five pits (30 cm × 30 cm × 50 cm deep) were dug within each of the 16 study plots. Earthworms collected from the five pits at each plot were pooled and regarded as one composite sample. All specimens were euthanized in 70% ethanol and stored in 5% formalin solution. Surface-active macroarthropods were measured by pitfall trapping. Pitfall traps (Gist and Crossley, 1973) consisted of 9-cm-diameter cups filled with 70% ethanol. Four pitfall traps were placed at random within each of the 16 study plots and sampled at seasonal intervals. Each sample period consisted of two consecutive 24-hour "runs". Organisms collected at each plot from the four traps for both runs were pooled and regarded as one composite sample. Data presented are from February 1998 sampling dates (Peterson et al.,