Living on the Edge II: Further Investigation of Enhanced Roadside Creosote Growth in the Mojave Desert

David K. Lynch - Thule Scientific
david@alumni.caltech.edu

Abstract

Enhanced creosote growth on ridges lining two-lane paved roads on fans in the Mojave Desert is investigated using new field measurements and approximate calculations. Clear evidence is presented for ponding of water uphill of the uphill ridge, further enhancing growth. We argue that a temporary reservoir of water may exist following a rainstorm beneath one or both ridges. Such reservoirs would promote ruderal creosote growth, as would capillary action, which is able to raise water from the ditch into the ridge. Based on the geometry of creosote root growth in the context of ridge geometry, we suggest that some root growth would be parallel to the ridges to seek ditch water.

1. Introduction

Creosote growth in the Mojave Desert is known to be enhanced on elevated ridges constructed during road building alongside two lane paved roads[1-3] (Figure 1). The first order explanation is that runoff from the paved road collects in the ditches next to the ridges, thereby providing extra water for nearby plants. Furthermore, the uncompacted ridge soil is looser than the undisturbed desert soil and this allows easier penetration of water and a better medium for root growth[4], even though the ridges are usually higher than the level of the road and certainly higher than water in the ditch. In this paper we will extend previous analyses[4] of ruderal (disturbed) creosote growth based on field observations, known soil properties and the mechanics of water diffusion in porous media. We will also speculate on root geometry in the vicinity of desert roads.

2. Field observations

In the winter of 2016 and 2017, a number of surveys were made in Death Valley National Park, Panamint Valley and the Lake Los Angeles region of the Mojave Desert in order to investigate creosote growth adjacent to two-lane paved roads. Over 1200 miles of two-lane, paved roads were observed with attention paid to roadside growth, followed by examination on Google Earth. One such visit was timed to be a day after a rainstorm and we were able to find many roadside ditches with standing water. Standing water in roadside ditches a day or two after a rain tells us that the soil is poorly drained (Figure 2). Poorly drained soil is almost always composed of small particles like silt and clay. Such soils have small pore spaces and thus water diffusion by capillary action is expected to be significant. Capillary action can move water horizontally and raise water above the level of standing water in a ditch and into the ridges. In contrast, well-drained soil is composed of large particles (sand, gravel) where capillary action is weak. In this case water percolation tends to be dominated by gravity and diffuses more-or less downward.

Figure 1. Enhanced Creosote growth on the elevated ridges on either side of Trona Wildrose Road in Panamint Valley. Note the more widely spaced and smaller creosote bushes in the undisturbed soil well away from the road.

Figure 2. Standing water in a ditch near Lake Los Angeles following rain. Creosote is growing vigorously on the elevated ridge constructed when the road was built.

Field observations show that on a fan, enhanced creosote growth tends to be strongest on the uphill ridge (Figure 3). The uphill ridge is bounded by two water sources: the uphill ditch water and water that collects immediately uphill of it (Figure 4). Also evident in the field and on satellite imagery are many discrete areas of light colored soil just uphill of and immediately adjacent to the uphill ridge. These are dried up ponded sediments composed of clay, and are almost completely absent downhill of the downhill ridge. Thus we have clear evidence of water collecting right next to and on either side of the uphill ridge. We interpret this to mean that the more vigorous growth on the uphill ridge compared to the downhill ridge is a direct result of two water sources rather than just one (downhill ditch).

Figure 3. Google Earth image of a section of Scotty's Castle road. Enhanced creosote growth is obvious on either side of the road but it is more vigorous on the uphill ridge than on the downhill ridge. Also obvious immediately uphill of the uphill ridge are areas of light soil that are dried out ponded sediments, primarily clay. These occur because the uphill ridge acts as a barrier to surface flow on the fan. Note the absence of the dried up ponded sediments on the downhill side of the road. Stronger uphill growth and ponded sediments both occur most strongly when the flow direction is perpendicular to the road.

For water to collect uphill of the uphill ridge, it must have flowed over the surface, either as sheet flow or in drainages. This again suggests that the desert surface is composed of poorly drained soil. Measurements of the hydraulic conductivity of Mojave Desert soils correspond to soils that are primarily silt or clay[5], consistent with what has been previously discussed.

3. Transient water diffusion in the vadose zone

Diffusion of water through unsaturated soil is described by Richards Equation[6,7], a partial differential equation with no general analytic solutions. Solutions are obtained numerically using codes such as HYDRUS 1D[8]. A key parameter in the equation is the hydraulic conductivity (denoted K in Richard's equation) that has units of speed (m/s), though this is not the speed at which water diffuses, only being proportional to it. K is a 2nd rank tensor[9.10], the nine components of which are virtually never known, though scalar values have been measured[11]. It also varies spatially, especially vertically in different soil horizons, and can range over ten orders of magnitude depending on soil type and specifics of the measurements. The solution of Richards equation relies on applying boundary conditions and for a road, they are difficult to define numerically. For these reasons, modeling moisture flow in soils is difficult, and especially so near roads whose soils have been disturbed by road building. We will therefore perform a simple approximate numerical analysis to bound the various solutions as a guide to future investigations.

During and after a rainstorm on a fan, water can collect at three locations along the road: the downhill ditch, the uphill ditch, and uphill of the uphill ridge (Figure 4). Diffusion of this water into the soil depends on soil particle sizes. In sand and gravel, gravity is the dominant force and water tends to diffuse downward with little horizontal movement. For smaller particles sizes like silt and clay, capillary action is dominant and water diffuses in all directions and upward into the ridge. Thus we must always keep in mind that diffusion speed and direction are correlated with particle size, resulting in anisotropic diffusion.

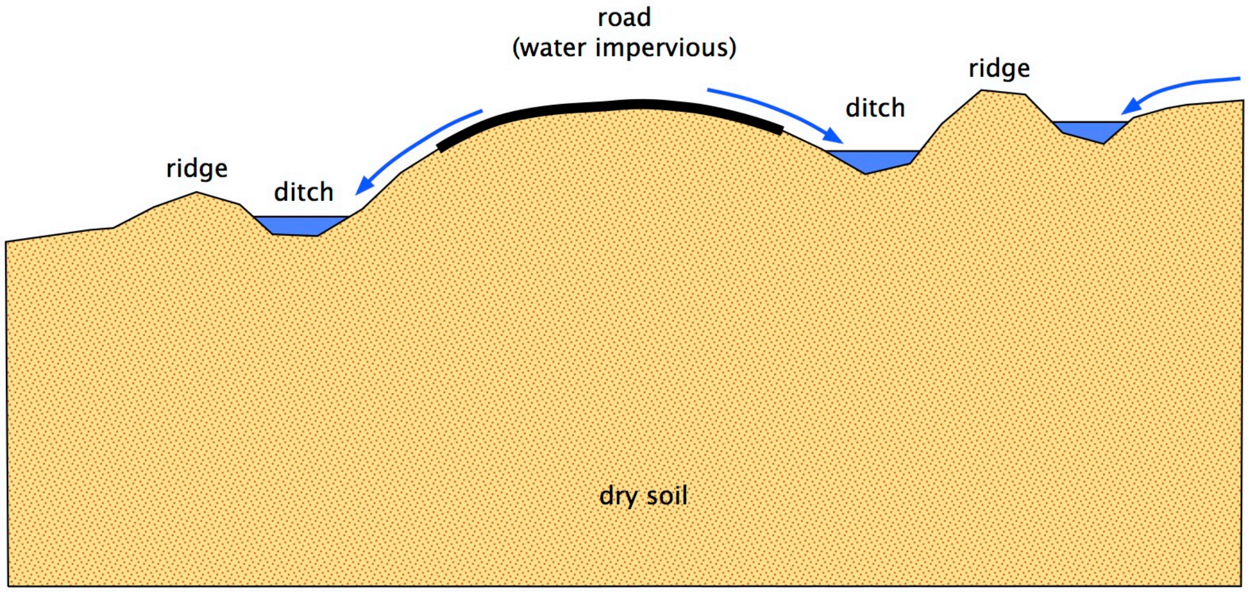

Figure 4. Section diagram of a paved desert road on a fan. Water can collect in three places: in the two ditches from runoff from the impervious pavement, and from surface flow down the fan where it ponds up adjacent to and immediately uphill of the uphill ridge.

Since the flow is transient, let's ask how long it would take for water to diffuse from the three regions and into two locations: under a ridge and under the road. This question is motivated by the suggestion that there may be enduring water reservoirs under and near the road after a rain.

Let us assume that the typical desert rainstorm lasts two days. We demonstrate here that it matters very little if the time we choose varies by a factor of two (e.g., one day or four days). The horizontal distance from a ditch to a ridge is about 1 m, and the distance from a ditch to a location directly beneath the road is about 10 m. Thus the minimum speeds at which water can diffuse to reach the ridge and the road center in two days are 0.5 days and 5 days, respectively (i.e., 1m/2 days and 10m/2 days). Based on published infiltration and percolation rates[12,13], the speed to reach the ridge corresponds to silt or clay. The much higher speed to reach the road center corresponds to sand. But diffusion in sand is dominated by gravity and with little or no capillary action to spread the water sideways; the water would be expected to move downward, not laterally under the road.

Infiltration and exfiltration take place at different rates (hysteresis)[14-16], the former being 2-3 times faster than the latter. Infiltration is driven by the hydraulic head (standing water depth) and exfiltration is controlled by diffusion to the surface followed by evaporation. While it may take two days for water to infiltrate, it will take four to six days for it to exfiltrate, i.e., dry out and leave the subsoil dry again, or in its pre-rain state. Thus if there is a reservoir under a ridge, it will endure for several more days (~4) than it would in the undisturbed desert field away from the road, giving the creosote a few more days of moisture after each rain. If there are six rains per season, the ruderal plants have an extra ~24 days of available moisture during which to grow.

The observations of Figures 1-3 are typical of most roadside creosote distributions, but there are exceptions too. Many factors influence creosote growth that can dominate the processes outline above. Occasionally one may find places where no enhancement is found or enhancement that is slightly stronger below the downhill ridge. Sometimes small creosote bushes are found growing in the ditch between the road and the ridge, though they are invariably smaller than those growing on the adjacent ridge. Other enhancements are found away from the road in water courses and obvious drainages, unsurprising because water collects there. In general, however, most two lane roads through the desert where creosote grows show roadside enhancement.

4. Geometry of creosote growth on a ridge

Creosote roots in undisturbed soil tend to be shallow, typically about one meter in depth, though some have deeper-reaching tap roots[17]. One meter is also approximately the height of the roadside ridges, and thus there may be a coincidental match between root depth and ridge height that optimizes root growth.

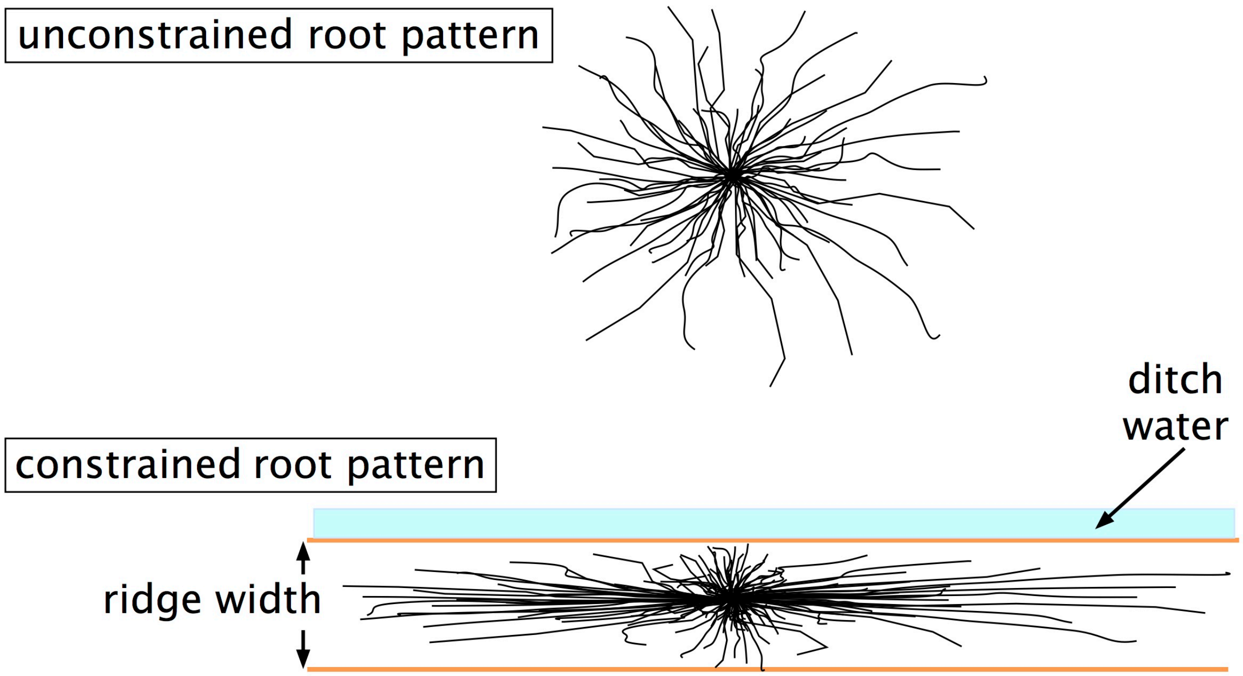

Figure 5. Map view diagram of creosote roots. In the open desert, creosote roots can grow freely in all directions. But when constrained to grow in the roadside ridges, they may grow parallel to and within the ridge. Such growth also would bring the roots in closer contact with water along the ditch, and directly above any subsurface water reservoir.

In undisturbed soil, creosote roots grow radially outward from the plant's base, extending about four-to-five meters in all directions for mature plants (Figure 5). Such radial growth is not possible on roadside ridges whose width is only about one meter. With ditch water lying parallel to and immediately adjacent to the ridges, creosote roots would be expected to grow towards the water. To do so they would have to grow inside the ridge and parallel to the ditch, forming a roughly linear bundle of roots.

5. Summary and conclusions

Field observations show that after a rainstorm in the Mojave Desert, many roadside ditches have standing water for a few days after the rain. This is due to poorly drained soil composed of small particle, silt or clay. On a desert fan, water collects on either side of the uphill ditch and this promotes more vigorous ruderal creosote growth than on the downhill ridge, though both ridges show enhanced growth compared to the undisturbed desert surface. Order-of-magnitude (or better) analyses suggest that there may be a water reservoir under the uphill ridge, and probably a lesser reservoir under the downhill ditch, both being the result of capillary action and lateral (sideways) diffusion of water. These simple calculations suggest that water can reach under the ridges but not under the road. It should be noted that ditch soils may be different than the soils in the undisturbed desert floor.

There is an apparent coincidence between mature creosote root depth and ridge heights, both being about one meter. This coincidence may enhance creosote growth compared to the undisturbed desert surface that adds to the enhancement of roadside vigor. Some creosote roots on ridges bounding desert roads may be partially constrained to grow within the ride and parallel to the ditches, as opposed to growing uniformly radially. Such constrained growth would lead to roughly linear root packages that grow inside and along the ridge, and toward the ditch water.

The results presented above do not consider evaporation of ditch water or evapotranspiration by the creosote, both of which influence water balance in the upper vadose zone. Some recent computations[18] suggest that in most cases evaporation and evapotranspiration do not significantly change the results presented here.

The observations and calculations reported here are largely qualitative and in some cases speculative. All of the results can be investigated by direct measurement and by numerical modeling. We urge the community of desert scientists to pursue the topics discussed here.

Acknowledgements.

I would like to acknowledge David C. Buesch (USGS), David M. Miller (USGS), Darren R. Sandquist (CSUF) for useful comments on this topic during the 2016 Desert Symposium. I also thank Julian A. Scott (USFS), Peter A. Livingston (CPSU) and Tony VanCuran (UC Davis) for reviewing and making valuable comments on the results presented here.

References

1. Johnson, Hyrum B., Frank C Vasek and Terry Yonkers, "Productivity, diversity and stability relationships in Mojave Desert roadside vegetation.", Bulletin of the Torry Botanical Club, 102 (3) 106-115 (1975)
2. Clark, David D, "An analysis of construction effects on vegetation and soils of the Colorado Desert : final report", California State University, Fullerton. Dept. of Biology; Systems Control, Inc; United States. Bureau of Land Management (1979)
3. Lightfoot, David C. and Walter G. Whitford, "Productivity of Creosotebush Foliage and Associated Canopy Arthropods Along a Desert Roadside", The American Midland Naturalist, 125(2) 310-322 (1991)
4. Lynch, David K., Living on the edge: enhanced roadside growth of creosote bush (Larrea *tridentata*), In Going Loco, proceedings of the 2016 Desert Symposium, R. Reynolds (ed.), Desert Studies Center, California State University Fullerton, 236
5. Young, M.H., E.V. McDonald, T.G. Caldwell, S.G. Benner, and D.G. Meadows. 2004. Hydraulic properties of a desert soil chronosequence in the Mojave Desert, USA. Vadose Zone J. 3:956-963.
6. Richards, L.A., 1931. Capillary conduction of liquids in porous mediums. Physics 1, 318–333.
7. Pachepsky, Yakov, Dennis Timlin, Walter Rawls, Generalized Richards' equation to simulate water transport in unsaturated soils, Journal of Hydrology 272 (2003) 3–13

8. https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/docs/hydrus-1d-model/
9. Duque, Carlos, Peter Engesgaard and Majken C. Looms, Full Tensor Representation of anisotropy in hydraulic conductivity: effects of simulating discharge of groundwater to lakes, XIX International Conference on Water Resources CMWR 2012 University of Illinois at Urbana-Champaign June 17-22, 2012
10. Cisler, J., On the tensor concept of unsaturated anisotropic hydraulic conductivity, Water Resources Research, 8, #2, 525–528 (1972)
11. http://www.structx.com/Soil_Properties_007.html
12. http://qcode.us/codes/sacramentocounty/view.php?topic=14-14_10-14_10_110
13 https://www.ag.ndsu.edu/publications/home-farm/individual-home-sewage-treatment-systems
14. http://www.nrcresearchpress.com/doi/pdf/10.4141/cjss62-033
15. http://ntl.bts.gov/lib/38000/38500/38567/OTCREOS7.1-11-F.pdf
16. https://nicholas.duke.edu/people/faculty/katul/93WR00094.pdf
17. Gibbens R. P. and J. M. Lenz, Root Systems of some Chihuahuan Desert Plants, Journal of Arid Environments, 49, Number 2, October 2001 , 221-263
18. Livingston, Peter A., Personal communication (2017). “The infiltration rate of a silty to clayey soil is around 0.05 inches per hour (1.2 inches per day). If the ditches have 4 inches of standing water and the storm has moved off, then the evaporation rate is probably around 0.2 inches per depending on temperature, humidity, and wind. At 1.4 inches per day the ditch would be dry in about 2.86 days. During this time 2.38 inches of water will have infiltrated into the soil. A “dry” silty clay loam soil still has about 2.6 inches of water per foot of soil This water is not available to the plant as the soil water pressure is greater than a plant can withdraw. The available water holding capacity of a silty clay loam soil is 1.8 inches of water per foot of depth, so over time the 2.38 inches of water will drain down, by gravity, to a depth of 1.32 ft. In Beatty Nevada in May, 2005[19], the bare soil evaporation was an average of .047 inches per day and the average evapotranspiration of creosote bushes in the area was 0.075 inches per day. This is for an individual plant. Assuming the plants cover 80% of the vegetated strip, then the weighted average rate of water use from the strip is 0.069 inches per day. The 1.8 inches of available water stored in the soil would actively sustain the plants for 26 days. After 26 days the plants would go into a semi dormant state.”
19. Garcia, C. Amanda, Michael J. Johnson, Brian J. Andraski, Keith J. Halford, and C. Justin Mayers, Portable Chamber Measurements of Evapotranspiration at the Amargosa Desert Research Site near Beatty, Nye County, Nevada, 2003–06, USGS Scientific Investigations Report 2008-5135 (2008)