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Effect of surface roughness and mulch on semi-arid revegetation success, soil chemistry and soil movement

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ABSTRACT

For the successful reclamation of disturbed land, the reduction of initial erosion risk must be balanced with later vegetation establishment. A combination of erosion control and revegetation practices was researched using commercial (full-sized) equipment on a semi-desert grassland site in southern Arizona, USA. Two soils with different parent materials were used to add a 30 cm cap on sites at two elevations: 1646 and 1403 m asl. There were two surface roughness treatments: smooth and rough. Three straw mulch treatments were applied: no mulch, mulch incorporated into the surface soil, and mulch tackified onto the surface. Plots were planted with a 10-species native mix dominated by perennial grasses. After two growing seasons, the incorporated mulch treatment resulted in significantly more seeded grass aboveground biomass than the no mulch treatment while the no mulch treatment had more forb and volunteer biomass than the surface mulch treatment. There was significantly higher erosion on the rough surface treatment compared to the smooth surface. Increasing perennial grass biomass was correlated with reduced erosion while forb and volunteer biomass showed no relationship with erosion. The smooth surface with surface mulch best established perennial grasses, minimized weeds, and reduced erosion. This combination of practices both minimized erosion as well as maximized vegetation establishment.

1. Introduction

Long term success in sloped-site management generally includes limiting erosion as well as establishing and maintaining the maximum vegetation that the conditions permit. Once established, vegetation has been shown to prevent erosion, catch sediments (Burylo et al., 2014; Zhang et al., 2015) and improve site aesthetics. For disturbed sites, the moisture required to establish vegetation come as rain events which occur at the time when there is most risk for erosion due to lack of vegetation. A common erosion control practice is to add mulches to the soil surface but the mulch amounts can be high enough to completely suppress vegetation (e.g. Bakr et al., 2012). In general, a practice that controls erosion cannot greatly reduce later plant establishment (Bhattarai et al., 2011) and similarly a practice to improve plant establishment generally cannot cause greatly increased erosion. While practices vary by climatic zone, fortifying sloped sites with straw mulch and creating microtopographical surface roughness (seedbed preparation) ahead of vegetation establishment are common worldwide (e.g. Hardegree et al., 2012; Gholami et al., 2013).

Adding surface straw impacts plant establishment and changes growth after establishment. A meta-analysis of the effects of plant litter concluded that litter suppressed biomass in the first three years but enhanced biomass subsequently and that litter structures plant communities by suppressing some species (Xiong and Nilsson, 1999). However, the authors note that this did not necessarily hold for deserts and grasslands. A more recent meta-analysis by Loydi et al. (2013) found that, under water limited conditions, litter amounts below 5000 kg ha^{-1} increased seedling recruitment. Amounts above 5000 kg ha^{-1} inhibited recruitment. A study in the California Mojave (Anderson and Ostler, 2002) found that 4500 to 5500 kg ha^{-1} of mulch generally improved establishment of planted species. A greenhouse study simulating southern Arizona conditions (Fehmi and Kong, 2012) found that 4500 kg ha^{-1} surface straw increased seeded biomass production without significantly changing plant establishment. Mulch has been generally recommended for increasing plant establishment.

Site specific factors determine if the cost of mulch will be worth small increases in plant establishment but mulch also reduces erosion through reduced raindrop impact on the soil surface (e.g. Pinchak et al., 1985; Gholami et al., 2013). A laboratory study of a wide range of surface-applied mulches found that mulch reduces erosion (Lakhdar et al., 1993). A review of mulch application after fires (Robichaud, 2005), found numerous examples of reduced erosion associated with mulch application. Erosion studies often use similar amounts of mulch to vegetation studies (e.g. Gholami et al., 2013), but from the purely erosion perspective, erosion decreases as the amount of surface mulch increases (Bakr et al., 2012; Shi et al., 2013). While mulch application appears straightforward, keeping it in place on

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windswept arid lands can be a challenge. Incorporating (tilling) the straw mulch into the surface soil has been one method to keep it in place and increase infiltration but this can increase erosion in some situations (Sidle et al., 1993).

Surface microtopography can have a variable effect on erosion but does not necessarily result in increased erosion in laboratory experiments (Gomez and Nearing, 2005; Darboux and Huang, 2005) although other laboratory studies have found greatly increased erosion on surfaces with more roughness (Helming et al., 1998). There are theoretical rationales for both decreased erosion with increased roughness due to decreased flow velocity, increased flow meandering, and increased sediment capture as well as increased erosion with increased roughness due to concentration of the flow (Darboux and Huang, 2005).

There are various practices for introducing surface microtopography to include contour furrowing, pitting, imprinting, and soil ripping. Surface microtopography enhances plant growth, creates additional ecological niches, creates depressions which allow water accumulation, and creates ideal conditions for establishment of more species of plants (e.g. Hardegree et al., 2012). In a field research study in South Africa, small depressions in loosened soil resulted in better germination and higher adult plant density compared to soil without depressions (Snyman, 2003). Chambers (2000) found that both surface mulch and soil depressions trapped and retained seeds, which prevented them from blowing off site. Seed burial typically increases plant germination and establishment as well as reducing seed predation (Winkel et al., 1991). Broadcast seeding onto a ripped surface helps to bury seeds at a variety of depths (Winkel et al., 1991), which can benefit a diverse seed mix. Montalvo et al. (2002) found that broadcasting seeds and imprinting the soil surface created favorable conditions for the widest range of species compared to hydroseeding and drill seeding.

The authors hypothesized that surface mulch would decrease erosion and the application of surface mulch would improve overall biomass response when compared to plots without mulch. It was hypothesized that incorporated mulch (lightly tilled into the surface) would increase overall biomass and have an intermediate effect on erosion. Finally, it was hypothesized that a roughened soil surface would have higher plant species richness than smooth sites and that the differences in surface roughness would not result in differences in erosion.

2. Materials and methods

2.1. Experimental design

Two 1.6 ha sites were selected 45 km south of Tucson AZ USA: at 1646 m asl (here after the upper site) and 1403 m asl (hereafter the lower site). The naturally sloped sites had an eastern aspect and were re-graded to a 3:1 (18-degree) slope and half of each site was capped to 30.5 cm with one of two borrow pit soils representing different, common surface soils (Tables 1 and 2). One soil was derived from a sedimentary rock mix of siltstone, sandstone and conglomerate from the Willow Canyon Formation (hereafter Chiricahua soil). The second soil was derived from a conglomerate from a late Tertiary alluvium (hereafter Hathaway soil).

Surface roughness treatments consisted of either leaving the surface rough after the sites were ripped to 20 cm or by smoothing the surface by dragging a metal screen behind the ripping implement. The smooth surface treatment was applied to randomly selected rows of plots (Fig. 1). The assignment by row was required because there was no effective way to turn the equipment around or relocate it to interior standalone smooth plots without impacting adjacent plots. A mulch treatment was applied in a random, factorial design to 6 plots within each roughness treatment in each soil type at each elevation. The mulch treatment levels included 4.5 Mg ha^{-1} of wheat straw incorporated into the soil before the ripping, 4.5 Mg ha^{-1} of straw applied to the soil surface after seeding and tackified with a polyacrylamide spray (EnviroTac II, Environmental Products & Applications, Inc., La Quinta, California, USA), or no mulch. Wheat germinated in the mulch plots forming a cool-season cover crop but the wheat did not persist on the site.

The sites were broadcast seeded with a 10-species mix of native plants at a rate of 523 seeds m^{-2}. The species were: *Digitaria californica* (Arizona cottontop, 14%), *Bouteloua gracilis* (Blue grama, 14%), *Hilaria belangeri* (Curly mesquite, 14%), *Leptochloa dubia* (Green sprangletop, 14%), *Eragrostis intermedia* (Plains lovegrass, 14%), *Bouteloua curtipendula* (Sideoats grama, 14%), *Elymus elymoides* (Bottlebrush squirreltail, 3%), *Eschscholzia californica* ssp. *Mexicana* (Mexican gold poppy, 8%), *Baileya multiradiata* (Desert marigold, 4%), and *Calliandra eriophylla* (Fairy duster, 0.1%). Seeding occurred on 21 and 30 December 2009. The untreated seeds were purchased from and mixed by a commercial vendor.

The vegetation data collection occurred between 10 September and 30 October 2011. Aboveground biomass was quantified by clipping plants 1 cm (0.4 in.) above the ground surface and separating by species in nine 40 × 40 cm (1.3 × 1.3 ft) quadrats per plot. Only biomass produced in 2011 was included which did not include any straw mulch, volunteer wheat, or plant litter. Harvested material was dried at 70 °C (158 °F) for at least 96 h. Density of each species was counted before harvesting. Volunteer species are species that occurred in the samples but were not in the seed mix. Samples were averaged to a single value per plot for analysis.

The soil sample collection occurred 13 October 2010 to 11 November 2010. Three 5.1-cm (2 in.) diameter soil cores were taken to the depth of approximately 15 cm (6 in.) per plot. Sampling locations corresponded to the quadrats used for vegetation data collection. Mulch was not collected in a soil sample; mulch was pushed aside and the soil sample was taken from the soil surface and below. The samples were composited in to a single sample per plot and sent to a commercial laboratory. Nitrate-N, NO_3-N was measured using Cd reduction and organic matter using Walkley Black.

The erosion data was estimated using 20 cm (8 in.) nails installed 31 January to 3 March 2010 with the nail head flush with the ground surface (Hudson, 1993). There were 7 randomly located nails per plot. No nails were located within 1 m (3.3 ft) of the edge of a plot. The distance between the soil surface and the top of the nails were measured with a ruler in late October 2011.

Precipitation between the two sites (elevations) varied significantly in 2010 and 2011. During 2010, the upper elevation plots received 49.6 cm of precipitation while the lower elevation plots received 37.6 cm. During 2011, the upper plots received 46.9 cm of precipitation and the lower plots received 23.4 cm. Naturally occurring precipitation was the only source of moisture in this experiment.

Table 1
Chemical analysis of composited soil samples from the two source areas (Chiricahua and Hathaway) as placed at the two sites at different elevations.

Elevation	Soil	pH (SU)	Electrical conductivity, EC (dS m^{-1})	Calcium, Ca (ppm)	Magnesium, Mg (ppm)	Sodium, Na (ppm)	Potassium, K (ppm)	Nitrate-N, NO3-N (ppm)	Phosphate-P, PO4-P (ppm)	ESP (%)	CEC (meq 100 g^{-1})	Organic matter (WB) (%)
Lower	Chiricahua	8.0	0.45	2900	730	63	180	4.2	6.3	1.3	21.3	1.6
Lower	Hathaway	8.6	0.26	3900	110	70	130	1.9	2.4	1.4	21.1	3.6
Upper	Chiricahua	7.4	0.20	1300	340	92	130	2.7	7.8	4.0	10.1	0.55
Upper	Hathaway	8.3	0.32	4100	110	32	140	5.0	3.1	0.6	21.9	4.0