RESEARCH REPORT

Forest Restoration in Campgrounds at Kings Canyon National Park, California

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ABSTRACT

Intensive campground use at the Grant Grove area of Kings Canyon National Park, California, has compacted the soil and left areas without understory vegetation or tree recruitment. To better inform the restoration of these sites after closure, we tested natural regeneration potential and planting and soil restoration methods. The tested methods included planting with container stock and direct seeding, fencing, and soil treatments of tilling, mulching, and gypsum and humus additions. Container stock had high survivorship (69–100%), while germination and survival from direct seeding was low (0.6–4.1%). Wood chip mulch was beneficial to planting woody species, but detrimental to resident herbaceous species. Plots treated with tilling and gypsum, and humus amendments exhibited highest growth rates of container stock and greatest herbaceous species richness and cover. However, tilling without the other soil treatments reduced herbaceous cover and seedling recruitment (natural and sown). In tilled plots, gypsum treatments and humus treatments often had neutral or detrimental effects individually, but their combination greatly increased the success of direct seeding, growth of container stock, and herbaceous cover and richness. Fencing increased volunteer tree recruitment tenfold compared to outside the plots. Some treatments in this study were beneficial to species of one morphological group but detrimental to another.

Keywords: active and passive restoration, incense cedar (*Calocedrus decurrens*), Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*)

Intense use of parks and other public lands has resulted in widespread degradation of high-use areas, including soil compaction and trampling of native vegetation (Foin et al. 1977, Bright 1986, Demetry and Manley 2001, The White House 2001, Roovers et al. 2004). The soils and vegetation of campground and trail areas receive the brunt of these impacts (Sutherland et al. 2001, Reid and Marion 2004, Andres-Abellan et al. 2005). Land managers need information on the effectiveness of specific restoration methods to increase the success rate and cost effectiveness of campground restoration.

Disturbance from visitors to the Grant Grove region of Kings Canyon National Park, California, has produced soil and understory degradation that appears to be limiting understory vegetation and the recruitment and survival of new seedlings. Results from our own comparative surveys of campgrounds in the Grant Grove region revealed that even after being closed for two or three years, these campground areas exhibit very limited recovery of litter depth and herbaceous species richness and no recruitment of woody species, compared to nearby relatively undisturbed sites (Infalt, unpub. data). In addition, a native moth infestation (Douglas-fir tussock moth, *Orgyia pseudotsugata*) in the area in the late 1990s killed most of the mature overstory trees. Park managers are interested in understanding the best ways to repair the local damage around campgrounds, in this case also in the context of a disturbed overstory.

We undertook a comparative study of several restoration methods. The tested methods included planting with container stock and direct seeding, fencing, and soil treatments of tilling, mulching, and gypsum and humus additions. The objectives of this study were to 1) examine the potential for natural regeneration (passive restoration); 2) test the effectiveness of soil treatments alone at increasing natural regeneration (low input active restoration); and 3) test the effectiveness of soil treatments at increasing natural regeneration in combination with horticultural planting treatments (high input active restoration). Although each of these methods have been individually tested at different forest sites with compacted soils, this is the first to test all at the same time and site, and as we will show below, combinations of treatments produce results not predictable from individual effects.

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Review

Soil compaction through trampling is a common form of degradation in campsites. Trampling can harm plants directly as well as indirectly by altering their growing environment. Trampling induces soil compaction, and associated decreases in water infiltration rates and soil moisture have greater impacts on vegetation as site use increases (Cole 1986). Increases in soil bulk density can reduce growth of young seedlings (Froehlich et al. 1986, McNabb 1994). The reaction to trampling disturbance varies among species and with the intensity of disturbance (Whinam and Chilcott 1999, Roovers et al. 2004). Some degraded areas may be capable of natural regeneration after the removal of human disturbance (Marion and Cole 1996, Roovers et al. 2005), but others are very slow to recover (Rydgren et al. 2004, Cole 2007), and require intervention to allow plant reestablishment or to increase the rate of recovery.

Soil tilling can help infiltration capacity and reduce runoff-caused erosion on severely compacted soils (Luce 1997). Tilling can help aerate and loosen soil, often resulting in increased plant growth and survival (Ashby 1997, Brady and Weil 2000, Bulmer 2000, Heninger et al. 2002, Kolka and Smidt 2004). Tilling can also break up compacted layers of soil, incorporate organic matter into the soil, and create a more favorable seed bed (Brady and Weil 2000).

Organic matter feeds fungi, bacteria, and soil animals that are important in producing and maintaining good soil aggregate structure, and it provides essential cation exchange sites (Brady and Weil 2000). Organic matter can also increase soil water-holding capacity. In practice, however, the addition of organic soil matter has produced mixed results (Zabinski et al. 2002, Walker 2003, Cole 2007).

The use of mulch can help conserve soil moisture, reduce erosion and runoff, protect the soil from compacting forces, insulate the soil from temperature extremes, and suppress weed growth. Over time organic mulches can increase soil organic matter and improve soil structure, permeability, aeration, fertility, and biological activity (Harris et al. 2004). The effects of mulch on plant density and cover have been mixed (Elseroad et al. 2003, Cole 2007), and may depend on application rates (Rokich et al. 2002).

Gypsum ($CaSO_4{\cdot}2H_2O$) can improve some soil types by increasing water infiltration, providing cations and anions to promote flocculation of soil particles, improving nutrient cycling, and decreasing erosion (Loveday 1976, Du Plessis and Shainberg 1985, Brady and Weil 2000, Hamza and Anderson 2003, Beukes and Cowling 2003, Fiorentino et al. 2003, Yamaguchi et al. 2004). Gypsum can also reduce the impermeability of hard subsurface layers, allowing better root penetration (Brady and Weil 2000) and increased productivity on acidic soils (Ritchey and Snuffer 2002). Container stock has higher survivorship than direct seeding, but it also costs considerably more, and its cost-effectiveness is not clear (reviewed in Young and Evans 2001, 2005).

Study Site

Our research was carried out from 2004 to 2007 in the Grant Grove region of Kings Canyon National Park, California, USA (36° 44' 34"N, 118° 57' 54"W; WGS84/NAD83). Sequoia and Kings Canyon Parks range in elevation from 460 meters in the foothills to 4,417 meters at the summit of Mount Whitney (NPS 2005). The climate is Mediterranean with cool, wet winters and warm, dry summers. The Grant Grove area lies at 2,000 meters elevation in the middle montane zone characterized by stands of mixed coniferous forest. The annual precipitation of 1000 to 1150 mm occurs mainly as snow from October to March, with the spring snow melt occurring between April and June. Soils are shallow, loamy, and excessively drained. They are formed from weathered granite, with a neutral pH (O'Geen 2005).

We identified and surveyed two reference sites within 1.7 km of the experimental plots to provide a target for future restoration efforts in Grant Grove. The target community agreed upon with park managers was a forest patch that had burned approximately 10 to 20 years ago and had been left to natural succession. One site had experienced prescribed burning 19 years prior to the survey, and the other site had experienced prescribed burning 22 years prior to the survey. We documented that the dominant tree species are Jeffrey pine (*Pinus jeffreyi*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), and sugar pine (*Pinus lambertiana*), with scattered groves of giant sequoia (*Sequoiadendron giganteum*). Common shrubs include dogbane (*Apocynum androsaemifolium*), manzanita (*Arctostaphylos* spp.), littleleaf ceanothus (*Ceanothus parvifolius*), whitethorn (*Ceanothus cordulatus*), chinquapin (*Chrysolepis sempervirens*), bitter cherry (*Prunus emarginata*), snowberry (*Symphoricarpos mollis*), elderberry (*Sambucus mexicana*), and gooseberry (*Ribes roezlii*) (botanical nomenclature follows Botti 2001).

Grant Grove has three campgrounds, covering approximately 32 ha and containing about 200 campsites. The grass, forb, shrub, and tree seedling understory is largely absent because of high visitor use and associated trampling (Figure 1). Both soil compaction and soil erosion are evident in heavily used areas and have been reducing natural regeneration for many years. In addition, from 1997 to 1999, the Grant Grove area experienced an outbreak of Douglas-fir tussock moths, part of a much wider infestation in the southern Sierra Nevada. Overstory vegetation is now lacking in large areas of the campgrounds. Hazard tree removals and the long-term trampling of the Grant Grove campgrounds have produced a highly degraded and nonsustainable

Figure 1. White fir (*Abies concolor*) snags in the left background, outside of the limits of tree removal in campground area (left); unvegetated, degraded areas within campgrounds (right) at Grant Grove, Kings Canyon National Park, California. All photos by S.B. Infalt

forest structure and have decreased or eliminated wildlife habitat.

This soil and vegetation degradation is representative of similar impacts experienced in campgrounds in other parks (Foin et al. 1977, Cole 1986, Marion and Cole 1996, Demetry and Manley 2001, Zabinski et al. 2002, Reid and Marion 2004, Cole and Spildie 2006, Infalt, pers. obs.). Park managers desire restoration treatments that will produce a forest structure similar to adjacent reference sites (Infalt, unpub. data). Park rangers were also concerned about creating visual screens between campsites to increase aesthetic value and help reduce negative interactions among campers.

Figure 2. Post and rope fencing around 6– x 6-m experimental plot with randomized planting and mulching subplot treatments. Flagging materials were removed after completion of installation.

Restoration Methods Experiment

Twenty-five 6 m × 6 m plots were located around Crystal Springs campground in areas with moderate degradation between individual campsites. Plots were enclosed with post and rope fencing to exclude humans (Figure 2). We applied five soil treatments in five randomly selected replicates: 1) control; 2) soil tilling; 3) soil tilling and gypsum addition; 4) soil tilling and humus addition; and 5) soil tilling with gypsum and humus additions. Plots receiving the tilling treatment were cultivated to a depth of 10 cm with a small rototiller. Gypsum was applied to plots at a rate of 225 g/m² and tilled in to a depth of 10 cm. For humus treatments, decomposed bark (ground fir and pine bark, ≤ 6 mm particle size, 0.2–0.4% nitrogen, 4.0–5.0 pH) was spread to a depth of 5 cm and tilled.

Each plot was divided into 36 1 m × 1 m subplots. In each plot, nine treatment combinations were assigned to each of four tree species: Jeffrey pine, incense cedar, white fir, and sugar pine. Subplots were assigned one of three planting-stock treatments: control (no planting), 1-gallon container stock, and direct seeding. The control plots were used to monitor background levels of seed rain/natural recruitment, as well as an area off the southeast corner outside of each plot of the same size and shape. The container stock was produced as bare-root seedlings at the USDA Forest Service Nursery in Placerville, California, with seeds collected from the Grant Grove area. After one year, the bare-root stock was then shipped to the park and immediately potted by the Sequoia and Kings Canyon nursery. Plants were 2–5 years old (depending on species) at the time of planting. Seeds for direct seeding treatments were also supplied by the USDA Forest Service Nursery from seeds collected in Grant Grove.

Each subplot was also assigned a mulch treatment: control (no mulch), wood chip mulch, or native litter/duff mulch. Wood chips produced on site from the tussock moth logging operation were used for the woodchip treatment subplots. Native litter was collected from outside the campground boundary for the native mulch treatments. Mulch was applied to the entire subplot area to a depth of 5 cm.

We established plots in August and September 2004 after collecting baseline measurements of soil and vegetation conditions. First, plots were delineated and fenced, and then the soil treatments were added. Container stock was planted over a two-week period in September of 2004. Six liters of water were added to the planting hole. After the water percolated into the soil profile, we planted the container stock, backfilled the holes with native soil, created small berms around the trees, and provided an additional 6 L of water per tree. Two additional biweekly waterings were carried out until the rainy season began. Directly seeded subplots received either 10 Jeffrey pine seeds, 10 white fir seeds, or 9 sugar pine seeds in a grid pattern (to aid in later identification as either directly seeded germinants or volunteers). No incense cedar seed of local genetic stock was available at the time of seeding, and a limited number of sugar pine seeds were available. Plots with the direct seed and mulch treatment were first mulched, then holes were poked through the mulch bed and seeds were placed on bare mineral soil. Seeds were covered with soil to a depth twice their diameter.

Plots were surveyed after one year for growth (height and caliper) of planted trees, germination and survival of planted seed, seedling establishment from natural seed rain, herbaceous and shrub species richness and cover, and soil penetration resistance. We visually estimated cover on each subplot aided by a 1-m^2 quadrat with 10-cm grid. In September 2007 (three years after initiating the experiment), the plots were resurveyed. All planted container stock was assessed for survivorship and height growth. Plots were surveyed for percent herbaceous cover, number of herbaceous species, and number of woody species.

Results were analyzed using split-plot ANOVA. Independent variables were tillage, gypsum, humus, mulch and mulch type, planting treatments, and treatment species. Percent survival of direct seeding was ln-transformed for analysis. A posteriori comparisons of multiple means used Tukey's Honestly Significant Differences (HSD). We expected tilling to increase soil penetrance, but not other soil treatments. We expected all soil treatments to increase both the survival and growth of planted species.

Results

Planting Treatments

Although the four planted tree species differed significantly in first year (2004–2005) survivorship rates in the one-gallon planting stock ($p < 0.001$), all exhibited high survivorship (69%–100%). Survivorship between 2005 and 2007 was also high (73%-94%). First-year diameter growth did not differ significantly among species, but incense cedar and Jeffrey pine grew in height twice as fast as sugar pine, with white fir being intermediate ($p = 0.019$). Between 2005 and 2007, Jeffrey pine grew significantly more in height (9.8 cm) than the other three species, which exhibited no net growth overall ($p < 0.001$), mostly because of shoot-tip herbivory.

Germination establishment success differed significantly among species, but was very low overall. On average, 2.5% of all seeds sown into the plots had germinated and survived to the end of the first year (4.1% of Jeffrey pine, 2.9% of sugar pine, and 0.6% of white fir; $p < 0.004$).

Subplots with a planting treatment (container stock or seed addition) had slightly lower average herbaceous species cover than subplots that were assigned no planting treatment (9% vs. 11%, $p = 0.05$). This difference is small, but it does suggest that either the disturbance at the time of planting or seeding or the competition from the woody species additions will slightly reduce herbaceous cover, at least initially.

Mulch Treatments

Woodchip mulching increased first-year survivorship of container stock compared to the control and native-litter mulching (Table 1), but not survivorship between 2005 and 2007. Similarly, volunteer tree seedling recruitment was greatest on subplots with woodchip mulch, followed by subplots without mulch, then subplots with native litter mulch (Table 1). In contrast, herbaceous species cover and species richness were greater in the absence of mulch, and the woodchip mulch was more detrimental than the native litter mulch (Table 1).

Tilling, Gypsum, and Humus Soil Treatments

Tilling was successful at reducing soil compaction (Figure 3). Plots that additionally received humus had the greater reductions in penetration resistance, changing the average from 339 psi before plot installations to 300 psi for plots without humus, and from 355 psi before treatment application to 223 psi for plots with humus ($p = 0.042$).

Tilling generally reduced herbaceous cover, unless it was associated with both humus and gypsum (Figure 4). Year 1 height growth (and diameter increase) of container stock was greatest in plots that received all three amendments (tilling, gypsum, and humus) and plots that received tilling and humus (Figure 5). Between 2005 and 2007, many planted seedlings experienced considerable shoot-tip herbivory that negated positive growth in some treatments. Herbaceous species richness and cover were greatest in plots with all three treatments and (in 2005) control plots. Total seedling recruitment (natural seed rain and sown seeds) was greater in untilled

Table 1. Effects (mean ± SE) of mulch treatments on herbaceous species, container stock, and volunteer seedlings. Within a column, entries that share a letter are not significantly different (Tukey's HSD).

Treatment	Herbaceous plants: Cover (%)	Herbaceous plants: Species richness (species/m²)	Container stock survivorship (%)	Volunteer seed rain (seedlings/m²)
No mulch	13.2 ± 0.7 a	1.9 ± 0.05 a	81 ± 3 a	0.39 ± 0.06 ab
Native litter	7.3 ± 0.6 b	1.8 ± 0.08 a	81 ± 4 a	0.23 ± 0.05 b
Wood chip	4.7 ± 0.4 c	1.6 ± 0.08 b	93 ± 3 b	0.50 ± 0.12 a
p-value:	< 0.001	0.015	0.022	0.11 (mulch vs. no mulch) 0.03 (chip vs. litter)

plots than in tilled plots (0.6 vs. 0.4 seedlings/m², $p = 0.042$).

Container stock in the humus addition plots increased in height 75% more between 2004 and 2005 than trees planted in nonhumus plots (2.8 cm vs. 1.6 cm, $p < 0.0001$), and increased in trunk caliper 55% more (1.5 mm vs. 0.97 mm, $p = 0.0005$). Herbaceous cover in plots with humus was 24% greater than plots without humus (10.9% vs. 8.8%, $p = 0.017$), and herbaceous species richness was 12% higher in plots with humus (1.9 species/m² vs. 1.7 species/m², $p = 0.004$). A significant tilling by mulch interaction ($p = 0.023$) revealed that tilling was more detrimental to herbaceous cover when mulch was also applied. There were fewer seedlings from sown and volunteer seeds in humus treated plots (Table 2).

Interactions between Humus and Gypsum Treatments

There was a set of interesting interactions between humus and gypsum treatments. Although gypsum alone or humus alone often had neutral or detrimental effects, the combination of both soil treatments substantially increased herbaceous species cover and richness (Figure 4) and the growth of container stock (Figure 5).

Volunteer Seed Rain

There was ten times more volunteer tree recruitment inside the fenced plots than in areas directly outside the plots (0.53 seedlings/m² vs. 0.04 seedlings/m² outside, $p < 0.01$). Of the volunteer tree seedlings, 79% were incense cedar, 15% were sugar pine, 4% were white fir, and 1% were Jeffrey pine; there were a negligible number of unidentified seedlings. There were fewer volunteer seedlings in plots that were tilled (0.32 vs. 0.51 seedlings/m², $p = 0.06$) and in humus plots that were also tilled (0.26 vs. 0.42 seedlings/m², $p = 0.05$). Although there was some shrub recruitment, there were no detectable differences among treatments.

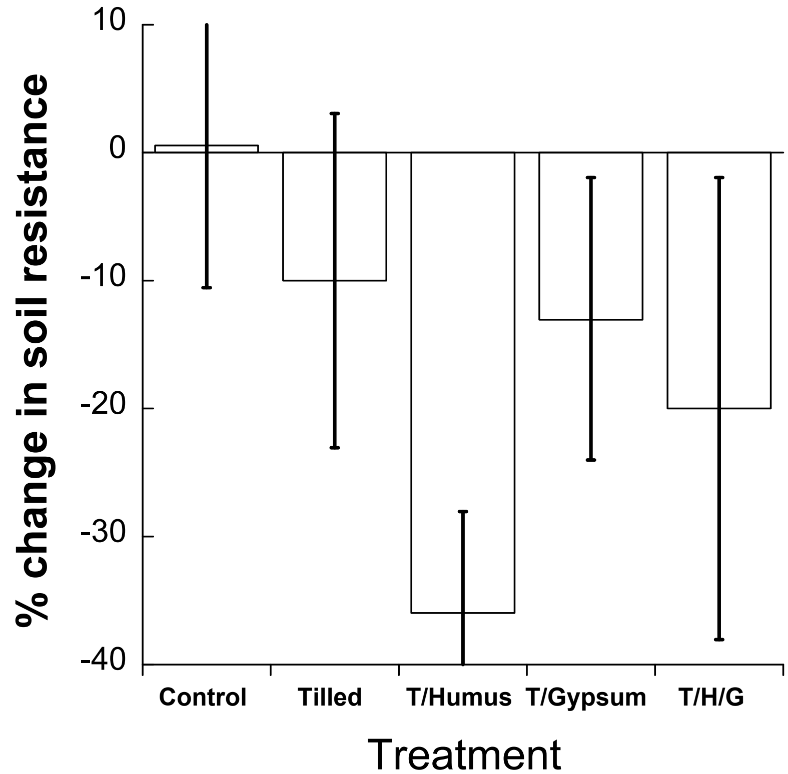

Figure 3. Mean percent change (± SE) in soil penetration resistance after soil treatments. Negative values indicate less compact soil. Treatments are control, tilling, tilling and gypsum (T/Gypsum), tilling and humus (T/Humus), and tilling, gypsum, and humus (T/G/H).

Discussion

Planting Treatments

The direct seeding treatment had very low success rates. Recruitment rates from directly sown seeds averaged 2.5%, while laboratory germination tests yielded an average of over 95% viability from the same seed lots. We suspect that this difference was due to seed predation, but we did not examine planting sites for such herbivory. In contrast, container stock had very

Table 2: Effects (mean ± SE) and significance (Tukey's HSD) of humus addition on container stock, herbaceous species, and seed success.

Treatment	Container stock growth: Height (cm)	Container stock growth: Diameter (mm)	Herbaceous plants: Cover (%)	Herbaceous plants: Species richness (species/m^2)	Volunteer seed rain (seedlings/m^2)	Direct seeded (% survival)
No Humus	1.7 ± 0.15	0.97 ± 0.08	9 ± 0.5	1.7 ± 0.05	0.42 ± 0.06	0.87 ± 0.19
Humus	2.9 ± 0.25	1.5 ± 0.14	11 ± 0.7	1.9 ± 0.05	0.26 ± 0.05	0.68 ± 0.23
p-value	< 0.0001	0.0005	0.017	0.004	0.05	0.018

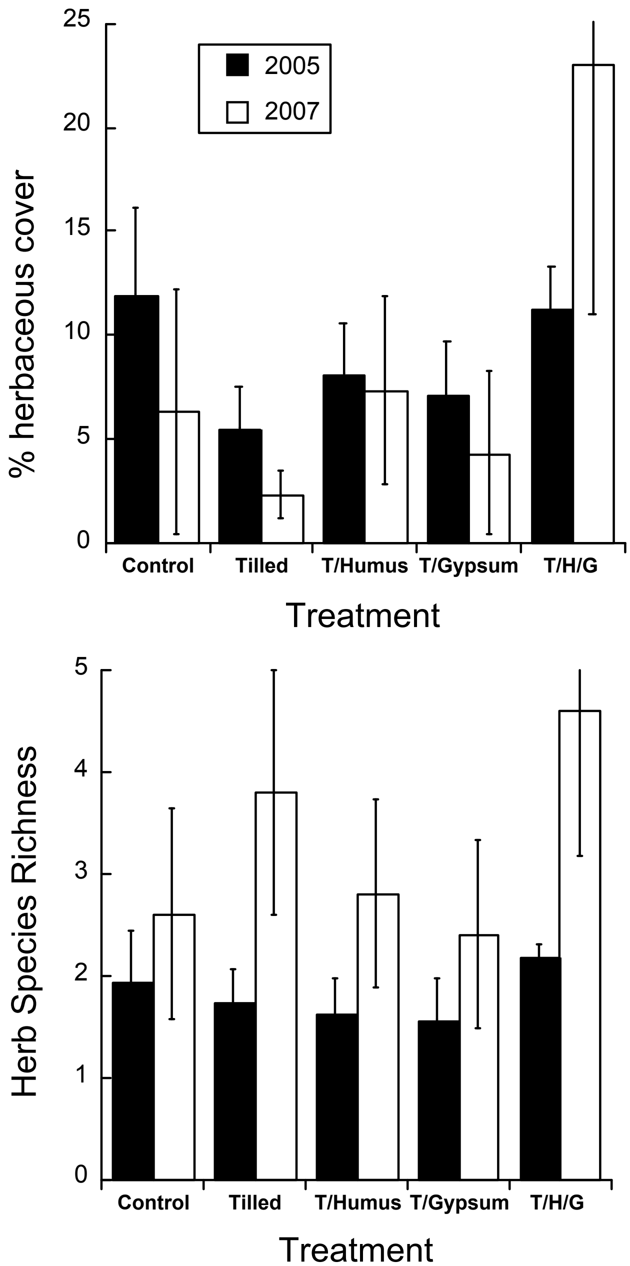

Figure 4. Herbaceous species cover (above) and herbaceous species richness (below) across all treatments. Treatments as in Figure 3. Bars indicate the standard error of the mean (*n* = 5 plots).

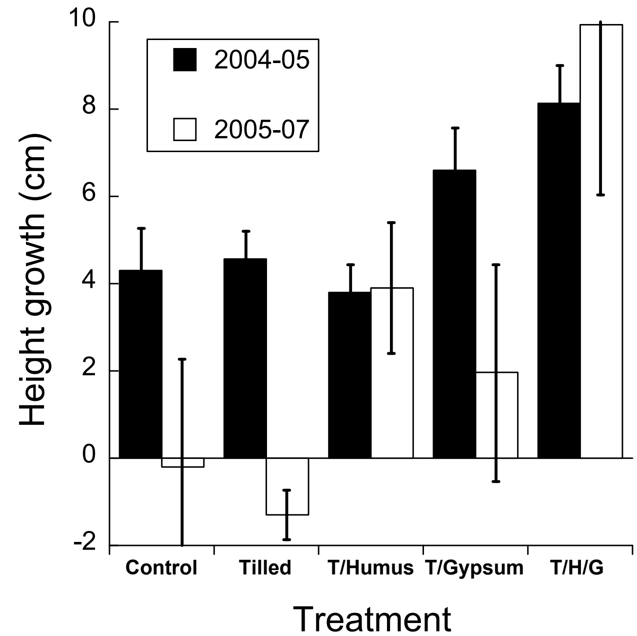

Figure 5. The mean (± SE) growth of planted container stock from 2004 to 2005, and from 2005 to 2007 (*n* = 5). Treatments as in Figure 3.

high survivorship (69–100% each year). However, direct seeding is much less labor intensive, and can be done shortly after seed collection, in contrast to container stock planting. Our data suggest that container stock would be less expensive per survivor if it cost no more than 20–30 times (Jeffrey and sugar pine) or 100 times (the smaller-seeded white fir) as much to produce and plant as direct seeding. We did not keep detailed records of labor costs for these two methods, so cannot report on actual costs.

Mulch Treatments

It is intuitive that wood chip mulch would increase the success of container stock and decrease the success of herbaceous species, compared with controls. While wood chip mulch is good for individual trees, it may not be wise to use it over large areas, where it would suppress native herbaceous species.

It is less clear why native litter mulch would have intermediate effects. We suspected that native litter mulching treatments might increase recruitment success of woody species via viable seeds present in the native litter. However, native litter had a negative impact on volunteer recruitment of woody species. It is possible that the adult litter had allelopathic effects on seeds (Bai et al. 2000). Native litter mulching may be useful in areas that managers wish to keep clear of woody vegetation, but further studies would be needed to determine the cause of the reduction in germination and the long-term effects of native mulch.

Tilling, Gypsum, and Humus Soil Treatments

Though tilling alone was successful at reducing soil penetration resistance, plots that also received humus had the greatest reduction. The incorporation of humus into the tilled soil may have reduced soil settlement after one year, as has also been observed in the accidental incorporation of the organic layer during a tilling treatment conducted by Luce (1997).

Tilling alone was detrimental to the first-year success of herbaceous species and germinating seedlings. This negative effect was overcome on plots that received the tilling, gypsum, and humus treatment. As with the mulching treatments, it is clear that objectives must be identified before treatments are applied, since the treatments in this study were often detrimental to species of one group (forbs) while being beneficial to another (tree seedlings). If herbaceous species or natural woody recruitment is the management target, the high-input tilling, gypsum, and humus treatments are no better than installing protective fencing only, and would not be worth the extra time and expense. If management goals are aimed at higher growth rates of container stock, then the tilling, gypsum, and humus treatment and the tilling and humus treatment might be worthwhile, though tilling alone does not seem to provide any appreciable benefit to sites with the moderate level of compaction found in the campgrounds of the Grant Grove area.

Interactions between Humus and Gypsum Treatments

It is unclear why the interaction between humus and gypsum had positive effects on directly sown seeds, container stock, and herbaceous species that greatly magnified or even reversed the effects of either treatment separately (Figures 4 and 5). It is possible that the calcium from the gypsum increased the positive effects of the organic matter on microaggregate formation (Yamaguchi et al. 2004), soil structural stability, or other soil physical properties (Hamza and Anderson 2002, 2003), or that the gypsum combined with the humus produced beneficial changes in soil nutrient pools and fluxes and/or soil pH (Fiorentino et al. 2003).

Volunteer Seedlings

Volunteer seedling recruitment in fenced plots was fairly high over the course of this study (0.2–0.5 seedlings/m^2), and many of the treatments were either neutral or detrimental. We had thought that the native litter mulch would create a more natural seedbed, and possibly a seed source, thus increasing the recruitment of those plots. It was not expected that the wood chip mulch would have allowed the greatest volunteer recruitment. The lower volunteer rates with native litter mulch than with woodchip mulch may suggest that chemical inhibition from adult litter limits recruitment near parent trees.

Although there was an abundance of volunteer seedlings on control plots (Infalt, unpub. data), the species composition was not proportional to that of the mature or sapling overstory. Incense cedar is extremely prolific and seedlings were observed in all microsites (shaded areas, full sun areas, bare mineral soil, and areas with a duff layer). White fir seedlings were nearly absent because most mature white fir in the area were killed during the moth infestation, but it is not clear why Jeffrey pine and sugar pine seedlings were not more abundant.

Conclusions and Recommendations

Although the treatments in this study increased the success of some herbaceous and woody species and ameliorated some of the structural soil degradation, the more intensive (expensive) methods may not be necessary to meet restoration and management goals. Human-exclosure fencing alone produced high levels of woody and herbaceous recruitment in many areas. It seems that the campgrounds in the Grant Grove area have not degraded so far that tilling and amendments are necessary to produce an acceptable level of natural recruitment. Nonetheless, some of the more compacted, exposed areas were completely void of natural vegetation after three years even with fencing, tilling, soil amendments, and seed addition. These types of areas will need to be planted with container stock to produce levels of rehabilitation similar to reference site conditions. Although the densities of natural recruitment of some species on control plots were high, planting or seeding still appears to be necessary to reestablish a natural range of species.

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