THE EFFECTS OF TOPSOIL REAPPLICATION ON VEGETATION REESTABLISHMENT

Final Report: March 1994
Research Technical Agreement 54H666

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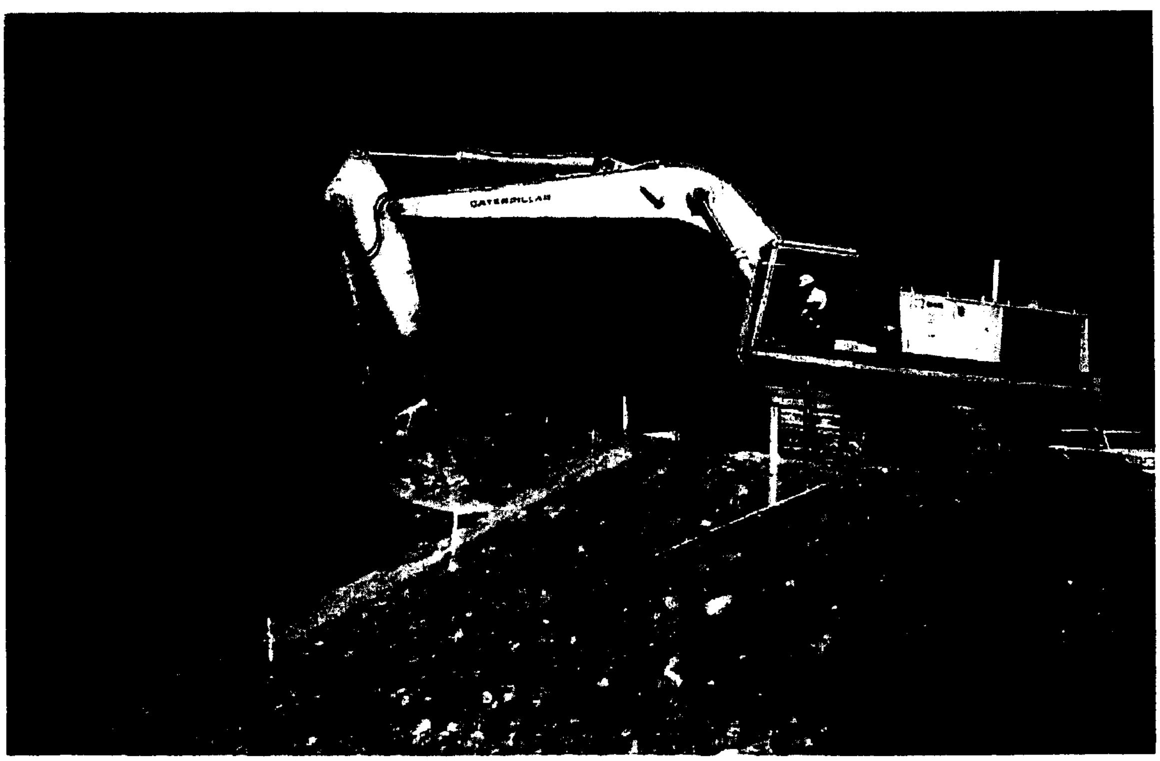
Federal Highway Administration



STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

MR-1242 (Rev. 11/90)

1. Report No. FHWA-CA-TL-94/18	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Effects of Topsoil Reapplication on Vegetation Reestablishment		5. Report Date March 1994
		6. Performing Organization Code
7. Authors Claassen, V.P. and Zasoski, R.J.		8. Performing Organization Report No.
9. Performing Organization Name and Address Soils and Biogeochemistry Section Dept. of Land, Air and Water Resources University of California, Davis Davis, CA 95616-8627		10. Work Unit No.
		11. Contract or Grant No. RTA 54H666
12. Sponsoring Agency Name and Address Division of New Technology, Materials and Research Environmental and Engineering Services California Department of Transportation P.O. Box 19128 Sacramento, CA 95819		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code California Department of Transportation

15. Supplementary Notes

In cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract Topsoils were harvested and stockpiled during road construction in northern California. After five months in storage, topsoils were reapplied to barren fill slopes (1.5:1 to 1:1). Early rains caused slumping and gullying on many of the plots. The remainder of the plots were used to compare plant growth on topsoiled and nontopsoiled plots and to compare soil nutrient content and biological activity of stockpiled topsoil with fresh topsoil which had not been stockpiled. A parallel greenhouse experiment allowed more detailed comparison of soil properties.

Topsoil reapplication improved plant growth by 250 % after three years compared to fill slopes which had no topsoil, but had equivalent application of all other nutrients, erosion control and seed materials. Topsoiled plots were predominantly covered by grasses, while the fill slopes were covered by clovers. Topsoil was not degraded in the stockpiling process. Indicators of plant growth, soil nutrient content, mycorrhizal infection and microbial biomass showed no decrease compared to treatments using fresh topsoil rather than stockpiled topsoil. Topsoil fraction had to exceed 20 % of soil volume before significant improvements in plant growth and soil characteristics occurred. Higher rates are recommended in more severe environments. Moderate fertilization improved plant growth without decreasing mycorrhizal root production. Mineralizable nitrogen was shown to be predominantly derived from soil microbes. Topsoil stockpiling and reapplication are strongly recommended for improved regeneration of plant-soil systems. Stockpiling had little or no negative impact on topsoil quality.

17. Key Words erosion control, topsoil, revegetation, mycorrhizae, plant establishment, plant nutrition, native plants, fertilizer	18. Distribution Statement No restrictions. This document is available to the public from the National Technical Inform. Service, Springfield, Virginia

19. Security Clasif. (of this report)	20. Security Clasif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	52	

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Financial Disclosure Statement

This research was funded by the State of California, Department of Transportation (Contract No. RTA-54H666). The total revised ceiling amount was $107,917.00. The research is reported in the final report titled "The Effects of Topsoil Reapplication on Vegetation Reestablishment."

Implementation Statement

Information from this research activity will be disseminated through distribution of copies of this report, through presentations to technical and general conferences workshops and through published journal articles. Further details are included in the implementation section following the report conclusions and in the list of presentations in Appendix 2.

SUMMARY

The influence of topsoil and fertilizer applications to nutrient poor and biologically sterile road fill material was evaluated for improvement of vegetation reestablishment and for influence on microbial activity within the stockpiled topsoil after storage. Topsoils were removed from the forest floor of a mixed hardwood and conifer site, stockpiled for five months, and then reapplied to the site following construction. The effects of topsoil amendment on plant growth, soil fertility, mycorrhizal infection and an index of microbial biomass were measured in field and greenhouse experiments. Plant growth on field plots amended with topsoil was greatly increased relative to treatments with fertilizer but no topsoil. Three years after establishment, dry weight production on the topsoiled treatment was about 250 % of the non-topsoiled treatment even though the same seed and fertilizer amendments were applied to both plots. Greenhouse experiments were designed to compare plant growth and microbial activity in fresh, dried, and stockpiled topsoil. These experiments indicated that storage of the harvested topsoil for five months in a stockpile had minor effects on plant growth, soil fertility, mycorrhizal infection and microbial biomass. Topsoil:total soil volume mixtures greater than 20 % were necessary to achieve statistically significant effects. Plant growth and biological activity continued to increase as the percentage of topsoil in the mixture increased. Percentage of roots with mycorrhizal infection was greatest in topsoil treatments without fertilizer. Addition of fertilizer increased plant growth but reduced the percentage of roots forming mycorrhizae. However, when the total weight of infected roots was calculated, infection was greatest with a moderate level of fertilizer equivalent to approximately 27 kg N/ha and 39 kg P/ha

(24 lb N/ac and 35 lb P/ac). Total weight of infected roots was less in both higher fertilizer treatments and in unfertilized treatments. This increase in total infected root length is critical for continued growth of the plant communities. Topsoil amendment increased the amount of nitrogen contained in microbial biomass but fertilizer treatment did not. Fertilizer nitrogen did not remain in the soil after an intensive greenhouse growing cycle. Harvesting, stockpiling and reapplication of topsoil from construction sites greatly increases vegetation reestablishment and is strongly recommended wherever possible.

ACKNOWLEDGEMENTS

This study was funded by the California Department of Transportation and Federal Highway Administration. We thank John Haynes of the California Department of Transportation, Division of New Technology, Materials and Research, for administrative support and field assistance, and Larry Orcutt, resident engineer, District 2, for access to the site and heavy equipment. The soil description was provided by Terence Huff.

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INTRODUCTION

Revegetation of cut and fill slopes following road construction typically involves exposed subsurface materials rather than the normal topsoils in which plants grow. These "degraded soils" are a result of excavation of the new grade surface below natural soil profile development or by burial of the original topsoil under fill material. If the exposed surfaces are low in fertility and biological activity, reestablishment of vegetation is difficult. The poor nutrient cycling capacity of subsurface material results in poor retention of natural or amended nutrients, thereby restricting the establishment and persistence of vegetative stands.

Clary (1983) indicates that plant communities established on "problem soils" amended with commercial fertilizers show vigorous initial growth, but that vegetative cover often becomes sparse or nonexistent within several years. For example, grass establishment on serpentine soils was excellent the first year but, by the end of the second growing season, "very little grass was observed. Apparently, plants had exhausted most of the available nitrogen during the first year of growth" (Clary, 1983; pg 49, 50). Plants established in an acid sand with fertilization also failed to persist while a similar treatment with 4 to 6 inches of topsoil maintained a solid vegetative cover when revisited over ten years later (Clary,1983; pg 65). Trials for woody plant establishment indicate that out of nine fertilization or mulching treatments, only topsoil application increased woody cover (Clary, 1983; pg 41). A similar pattern is observed in reestablished plant communities on mine spoil. Schafer and Nielsen (1978) observed that these communities tend to be highly productive for two to five years followed by a sharp decline in plant growth and nutrient availability.

Reapplication of topsoil to subsurface materials enhances reestablishment of vegetation by increasing nutrient availability, water holding capacity, and microbial activity (Hargis and Redente, 1984). The increased nutrient availability can result from the greater extent of weathering of the parent material minerals, as well as from the occurrence of organic forms of nutrients, such as amino acid nitrogen and organic phosphorus compounds. Water holding capacity is increased by adsorption of water by organic humic materials, as well as by the increased pore space which develops as a result of aggregate formation between minerals and these organic coatings.

Improved soil conditions such as slowly available nutrient pools and greater water holding capacity promote increased microbial activity. These microbes actively cycle nutrients, processing nutrients released by plant decomposition and storing part of the nutrients within their tissues. In a study of forest soils, Myrold (1987) showed that the nitrogen pool which was available to plants was predominantly derived from nitrogen contained in microbial cells growing in the forest topsoils. When microbial populations are low, low amounts of nitrogen are able to be processed or stored by microbial pools. Large leaching losses are then possible if the nutrients released from plant decomposition are not rapidly reincorporated into soil microbes or new plant tissue (Skeffington and Bradshaw, 1981).

The presence of mycorrhizal fungi is another aspect of soil microbial activity which is important to revegetation success. These beneficial fungi form a mutualistic relationship with plant roots of many species. In this relationship, the plant provides energy for the fungus which, in turn, provides phosphorus (P), water and perhaps nitrogen (N) and trace metals for the plant. It is unclear if mycorrhizal infection allows access to additional pools of P compared to uninfected plants or if the same pools are merely exploited more efficiently by the fungal hyphae which are more numerous and more finely divided than plant roots. Bolan, *et al.*, (1984) find that increased P uptake did not deplete soil solution or extractable P levels, indicating that mycorrhizae had access to separate supplemental P pools. Jurinak, *et al.*, (1986) hypothesized that mycorrhizal fungi produce oxalic acids which accelerate weathering and P release from soil minerals. Other authors maintain that nutrient pools are qualitatively the same for both infected and uninfected plants (Sanders and Tinker, 1971) and hypothesize that it is the greater density and surface area of the mycorrhizal hyphae compared to the uninfected root which allows more efficient nutrient uptake per unit soil volume (Allen, 1991, pg 46-49). Because mycorrhizal fungi increase P and micronutrient uptake and are critical for plant growth on low nutrient sites, the spores and infected root propagules which are often missing from the barren construction site soils must be reintroduced. Viable topsoil can provide mycorrhizal spores and hyphal fragments which serve as an inoculum for infection of the colonizing plant roots.

Because of the importance of topsoil and organic matter, attempts to restore permanent plant communities have often involved additions of various types of organic material and microbial inoculum as substitutes for actual topsoil. For example, mycorrhizal infection on processed oil sands was increased by peat amendment (Zak and Parkinson, 1982). Visser, *et al.*, (1978) found that introduction of a non-labile carbon source such as peat or sewage sludge increased microbial biomass in mine spoils while inorganic fertilization did not. In a review of mine spoil reclamation, Hargis and Redente (1984) cite topsoil reapplication depths of 4 to 30 inches. While details of the relationships among soil organic matter, soil microorganisms and nutrient cycling may not be well understood, microbial biomass can be used as a relative indicator of the degree of disturbance or recovery of soil nutrient cycling capacity (Smith and Paul, 1990). Consequently, many experiments have attempted to link soil properties to indices of microbial biomass.

Application of topsoil is recommended in the Caltrans Highway Design Manual (July 1, 1990, section 706.2) and spread duff is specified as a special provision. These treatments have enhanced revegetation at several California Department of Transportation revegetation sites as reviewed by Clary (1983). However, analytical measurements of soil, plant and microbial components were not made in these studies. Since the process of harvesting, stockpiling and reapplying topsoil involves additional expense and effort, a careful analysis of results from sites with topsoil applications would provide the necessary information for cost-benefit analysis and would indicate possibilities for improvement in the efficiency of the process. The effects of placing topsoil in stockpiles during construction were also of interest since, in other studies, the quality of the material for revegetation has been found to decline with storage (Stark and Redente, 1987; Rives, *et al.*, 1980). The present study was designed to evaluate changes in microbial biomass, mycorrhizal infection and plant growth which occur during the process of soil handling and revegetation of highway construction sites.

MATERIALS AND METHODS

Field study

The field site used in this study was located at a California Department of Transportation highway construction project (Contract No. 02-041784) located along Interstate-5 approximately 60 km (35 mi) north of Redding, CA. The site was located on the outside fill slope of the Gibson Curve interchange located at PM 53 (Figure 1).

The geography of the area consists of steeply dissected foothills covered by a mixed black-oak (*Quercus kelloggii*) and ponderosa pine (*Pinus ponderosa*) woodland with an understory of manzanita (*Arctostaphylos patula*) and herbaceous species. The elevation is approximately 550 m. Winters are cool and wet while summers are hot, often with extended drought. Annual precipitation averages 1300 mm. Soil parent materials are metasedimentary with some volcanic mineralogy. Local topography was a uniformly sloping (5 °) terrace with a southeastern aspect and the soil was classified as a fine loamy mixed mesic Ultic Haploxeralf, i.e., a well weathered topsoil with a clayey subsoil.

Site preparation began with removal of the vegetative cover of oak, conifer, and manzanita. The surface 20 cm of the soil (forest floor O and A horizons) was scraped off by heavy machinery in May, 1989, formed into a windrow and pushed to a storage area immediately adjacent to the construction site (Figure 2). The stockpile formed a pyramid measuring roughly 6 X 8 meters wide and 2 meters high (20 X 25 X 7 feet) containing 63 m^3 (75 cu yd) of topsoil material. A variety of organic matter became incorporated into the stockpile as a result of stockpiling, including forest floor topsoil, decayed organic material and litter (duff), and fine and coarse root material. The soil

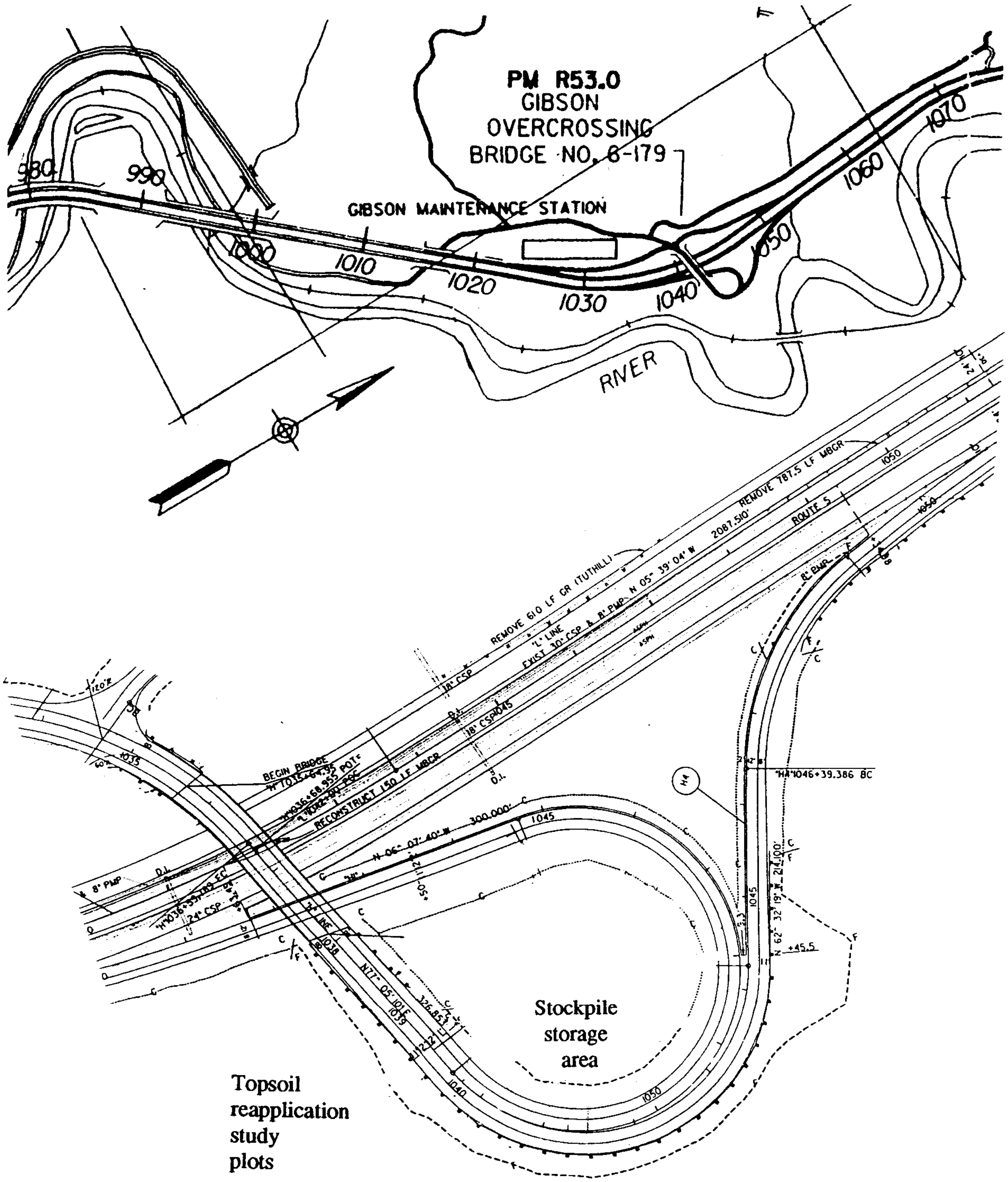

Fig. 1. Map of construction project along Interstate-5 in northern California. Study site is located on south to south-southeast facing slope of interchange and topsoil storage area in in the center island.

Figure 2. Stockpiled topsoil stored for five months within the center island of the interchange during construction.

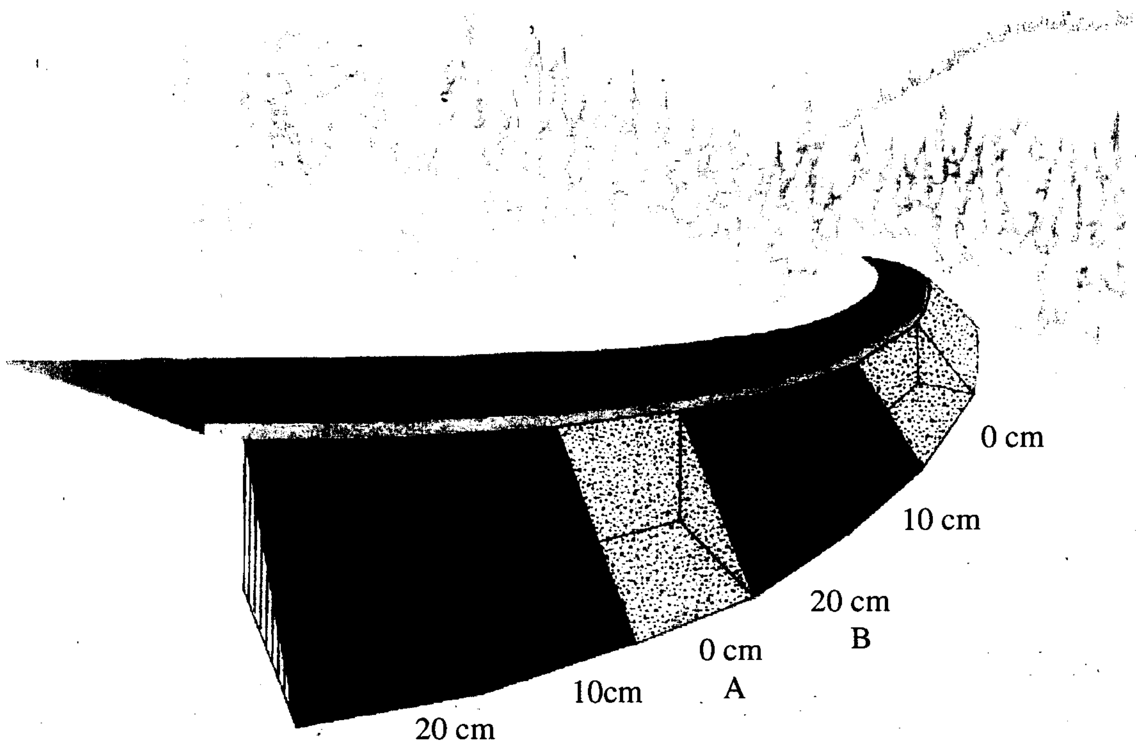

Figure 3. Perspective drawing of topsoiled plots looking north. Numbers beneath plots indicate the original depth of topsoil reapplication. Letters "A" and "B" indicate the two undamaged plots used for monitoring purposes.

remained moist for the five months of storage and had no plant cover during this period. Internal temperatures of the stockpile reached 40 °C (104 °F) due to decomposition of organic residue.

The elevated slope surface was constructed with broken, pulverized fill material with metamorphosed sedimentary mineralogy which was brought in from cut slope excavation nearby. Angles of the completed fill slope ranged from 34 to 45 ° above horizontal with a south to south-east aspect (Figure 3).

Revegetation plots measuring approximately 8 meters (26 feet) square were established on the outside of the elevated road grade so that plant growth and soil conditions could be measured after applications of 0, 10 and 20 cm (0, 4, and 8 inches) of stockpiled topsoil. The 0 cm treatments (no topsoil, but with complete erosion control treatments) served as the experimental control. Each treatment was replicated twice bringing the total number of plots to six.

In November, 1989, the loose surface of the fill material was tamped and firmed using the backside of the bucket of a large backhoe. Next, a front mounted bucket loader was used to shuttle topsoil from the storage area to the fill slope where it was placed at the top of the slope. Topsoil was then spread evenly down the face of the slope at the desired depth using the bucket of the large backhoe with a metal blade welded across the teeth of the bucket (Figure 4).

Before erosion control amendments could be applied, heavy and unseasonably early rains caused severe slumping and rill erosion on the plots. Precipitation during this event was estimated to be approximately 12 cm (5 inches) within a 24 hour period, with

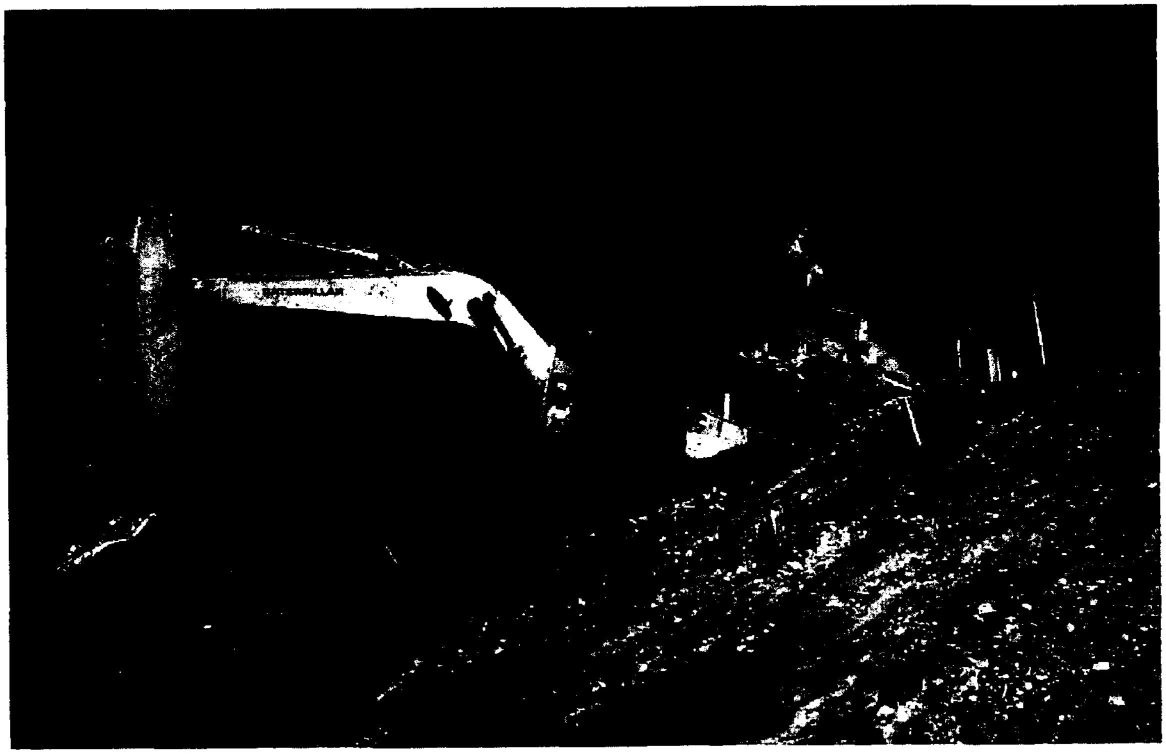

Figure 4. Placement of topsoil at the top of the slope and distribution down the slope face using a metal blade welded across the teeth of a backhoe bucket.

Figure 5. Slumping and erosion of topsoil and loose fill material to the foot of the 1:1 slope caused by heavy rains before erosion control applications.

several previous days of 5 cm (3 inches) precipitation per day. The unsettled topsoil material saturated, liquified and slumped to the foot of the slope on about a third of the plots (Figure 5). Another third of the slope, both topsoil amended and bare, was cut by gullying down to the underlying compacted fill material. Approximately a third of the slopes and topsoil treatments remained intact.

The tamping treatments were not thought to have promoted the slumping and movement of the topsoil material based on two observations. First, where slumping occurred, both topsoil and fill material were eroded through the tamped layer, down to the fill which had been compacted by the vibrating roller. Second, the tamped and firmed slope surfaces without topsoil amendment at the edge of the experimental area had less sheet and rill erosion than the adjacent areas which were not tamped with the backhoe bucket. In addition, after the soil had settled and firmed during this initial period, little additional erosion was observed, even on comparably steep slopes. Therefore, we anticipate that the use of irrigation and/or mechanical tamping to settle the topsoil amendments immediately after application would have prevented some of the slumping observed during the first rains.

A much more reliable way to prevent physical loss of soils and planting materials is to specify construction of shallower slope angles. Slopes which approach 1:1 in steepness are at the limit of what can be successfully revegetated. Fertilizers, fine soil particles, seed and water rapidly run off of these slopes, reducing the ability of the plant materials to sustain growth. Specification of slopes of less than 2:1 (run:rise, or 27°) are strongly recommended.

Two remaining relatively undamaged plots were monitored for field demonstration purposes. These plots were located adjacent to each other and consisted of a control plot (0 cm topsoil) and a topsoil plot (10 cm after regrading). All plots, both damaged and undamaged, were subsequently treated with the specified erosion control treatment.

The erosion control treatments consisted of four applications: legume seed, grass seed and fiber, blown straw and a final fertilizer and tackifier application. The legume mix included 28 kg/ha (25 lb/ac) Crimson clover (*Trifolium incarnatum*), 50 kg/ha (45 lb/ac) Rose clover (*Trifolium hirtum*) and 2.2 kg/ha (2 lb/ac) of Sky Blue Lupine (*Lupinus nanus*) (all with ≥ 95 % purity and ≥ 75-85 % germination). The grass seed mix included 5.6 kg/ha (5 lb/ac) each of Zorro Foxtail Fescue (*Vulpia myuros*), Sherman Big Bluegrass (*Poa ampla*), Berber Orchardgrass (*Dactylis glomerata*) and Luna Pubescent Wheatgrass (*Agropyron trichophorum*) (all with ≥ 85-95 % purity, ≥ 70-85 % germination). Fiber application was specified at 560 kg/ha (500 lb/ac). All plots were then covered with blown barley straw at a rate of 3360 kg/ha (3000 lb/ac) which was not incorporated. The fourth and final application included 448 kg/ha (400 lb/ac) fiber, 112 kg/ha (100 lb/ac) tackifier and a total weight of 448 kg/ha (400 lb/ac) fertilizer.

Fertilizer amendments included application of 168 kg/ha (150 lb/ac) of 16-20-0 and 280 kg/ha (250 lb/ac) of 0-20-0 N-P-K formulations. These amounts provide 27 kg N/ha (24 lb N/ac), 39 kg P/ha (35 lb P/ac). These fertilizer rates represent typical fertilizer specification for fill slope revegetation.

Greenhouse study

Because of erosion and slumping on most of the field plots, a duplicate set of experimental treatments were established under controlled greenhouse conditions. Representative samples of natural undisturbed soil, stockpiled soil and fill material were collected at the study site and were transported to the greenhouse facilities at the University of California, Davis. Soil materials were sieved to ≤ 6 mm to remove large rock fragments but still retain any inherent soil aggregate structure. Mixtures of topsoil and fill materials were prepared in which topsoil accounted for 0, 5, 20, 40, or 60 % of the total soil volume in 1.2 L pots. The same fill material was used in all treatments, while the material used for the topsoil fraction was selected from of fresh, dried or stockpiled topsoil treatments.

Because of the great differences in fertility between wild lands soils and agricultural soils, direct comparison to agricultural experiments is not useful. Standard agricultural tests often indicate that wild lands soils are nutrient deficient, yet plant growth is normal for the native species. To evaluate nutrient contents under natural conditions, this study was set up with internal comparisons which were referenced to the undisturbed natural forest floor soil collected immediately adjacent to the construction site. Changes in nutrient contents and biological activity of the harvested, stockpiled, dried and/or reapplied topsoils was evaluated by reference to this local soil material.

The topsoil fraction of the "fresh" topsoil treatment was made up from composited samples of soils collected immediately adjacent to the construction site. These soils were quickly transferred to the laboratory and were incorporated into the pot mixtures in an undried condition. The "dried" treatment was made from the same material which had been air dried for one week at 35 °C and was designed to show the effects of the summer desiccation on topsoil conditions. The "stockpile" treatment consisted of composited samples from the original topsoil stockpile. The 0 % topsoil treatment (composited fill material only) served as the control for topsoil effects and illustrated the ability of the fill material to support plant growth.

The effect of the standard fertilizer applications on plant growth was simulated by the addition of three fertilizer levels to stockpiled topsoil, with the various percent topsoil mixtures. Treatments included zero added fertilizer (the "stockpiled" treatment), 50 µg N and P/g soil ("single") and 100 µg N and P/g soil ("double"). The single and double fertilizer application rates were designed to simulate one and two times the specified Caltrans field fertilizer application levels. However, these rates are only approximate comparisons because of the difficulty of duplicating field leaching conditions and root volumes in greenhouse pot experiments. The topsoils were mixed uniformly with the fill material to test amendment effects rather than root and topsoil distribution patterns within the confines of a greenhouse pot.

Plant materials

Pubescent wheatgrass was used as a bioassay for plant growth and mycorrhizal infection. Plants were seeded in mid-December, 1989, using supplemental lighting to extend the photoperiod to 14 hours. Seedlings were thinned to three uniform sized seedlings per pot, with three replicate pots per experimental unit. The 75 pots (5 topsoil mixtures X 5 soil treatments X 3 replications) were arranged in a completely randomized grid in the greenhouse and were bottom irrigated with distilled water as needed. Plants were harvested in late March, 1990, and dry matter production was determined after drying to constant weight at 65 °C.

Statistical analysis

All experimental treatments and laboratory analyses were replicated three times. Statistical analysis of data from preliminary analysis of soils (Table 1.) was evaluated by analysis of variance with mean separation significance established by least significant difference (LSD) ($P < 0.05$) (Little and Hills, 1978). Analysis of greenhouse experiments (Tables 2 - 6.) was done by analysis of variance with mean separation comparisons by Newman-Keuls multiple comparison test (Systat, Inc. Evanston, IL). Some data sets were transformed as needed to reduce non-homogeneity of variance residuals. When analysis of variance indicated significant interaction effects, the means of the main effects were not analyzed for significance; rather, the means of individual experimental units were rank ordered and means were compared by the Newman-Keuls test.

Soil tests

Fresh, dried, and stockpiled topsoils and the fill material were evaluated in a preliminary analysis to determine possible nutrient deficiencies or toxic metal concentrations. Nutrient cations were extracted with 1 M NH_4Cl extract (pH 4.5) and analyzed by atomic absorption using a La-CsCl matrix (Janitzky, 1986). Sulfate-sulfur was determined from a water extract by ion chromatography (Dionex series 4500i, Sunnyvale, CA). Potential metal toxicity was evaluated by measuring concentrations of Cr, Mn, Ni, and Zn extracted with dilute sulfuric-hydrochloric acid with quantitation by inductively coupled plasma spectrophotometry (ICP). Cation exchange capacity was determined by NH_4OAc saturation (pH 4.5), with analysis of retained ammonium by continuous flow, conductimetric analysis (Carlson, 1978). Soil acidity was measured in 0.01 M $CaCl_2$ with a 1 hour equilibration time.

Total nitrogen including NO_3^- was measured by micro Kjeldahl digest (Bremner, 1965), and mineralizable nitrogen was determined by anaerobic incubation (1 week, 40 °C) and extraction with 2 M KCl (Waring and Bremner, 1964). All extracts were analyzed conductimetrically for NH_4-N.

Phosphorus availability was evaluated using mixed dilute sulfuric and hydrochloric acids (Nelson, *et al.*, 1953). Total, inorganic and organic phosphorus was determined according to Mehta, *et al.*, (1954). Color of the phosphomolybdate complex was developed by reduction with ascorbic acid after extracts were neutralized with NaOH.

Microbial tests

The influence of treatments on an index of microbial biomass carbon and nitrogen was measured by the fumigation-extraction method (Tate, *et al.*, 1988; Sparling and West, 1988) using a 0.5 M K_2SO_4 extracting solution and a five day chloroform exposure. The extended five day exposure was used rather than a 24 hour fumigation period and a published k_c value (extraction coefficient, Vance, *et al.*, 1987) because no previous information was available for extraction efficiency of microbial lysates from these acid, forest floor soils. Because other studies showed a plateau of microbial lysate yield at five days (Brookes, 1985a,b; Davidson, *et al.*, 1989) this period was chosen to provide an index of microbial biomass for internal comparisons within these treatments. Carbon was analyzed by dichromate reduction (Mebius, 1960). Nitrogen was analyzed conductimetrically after digestion to reduce all extracted nitrogen to ammonium.

Inoculum potential of the various soil treatments in the greenhouse study was evaluated by bioassay using Pubescent wheatgrass or, for field samples, by examining roots washed from soil and retained on a 250 μm sieve. Mycorrhizal infections were analyzed by clearing root tissue in KOH and staining with trypan blue/lactic acid (Phillips and Hayman, 1970). The numerous samples were processed in batches with each sample contained within a screened syringe (Claassen and Zasoski, 1992). Infection was measured by a modification of the visual method of Giovannetti and Mosse (1980), using the mean of at least 100 counts to calculate the infection percentage for each experimental unit. Roots were contained in a square petri dish with a grid of 1 cm squares. Roots were scanned at 60 X magnification while following the grid pattern. Roots crossing the 0.3 cm diameter microscope field were tallied for presence or absence of infection. Samples showing infection were frequently verified under a compound scope at 100 to 400 X magnification. This method allowed the rapid scanning of large numbers of roots. Because the revegetation species are VA-mycorrhizal symbionts, a VA-mycorrhizal host was used for the bioassay even though ectomycorrhizal fungi were likely to be present in association with the oaks and conifers on the site.

RESULTS AND DISCUSSION

Soil data: chemical analysis for nutrients and metal toxicity

Nutrient contents of the various topsoil materials greatly exceeded those of the fill material. Table 1 (columns 1 - 3 versus column 4) lists analysis of nutrient contents of the various soil materials as they were collected from the field and before mixing for the greenhouse experiment. Total N, mineralizable N and organic P contents in the topsoil materials were 15 to 30 times greater than in the fill material. Total and inorganic P and K contents in the topsoils were nearly twice that in the fill material. The total N and mineralizable N contents are important since N is often the most deficient nutrient and is the most easily lost. A further benefit is that the N in topsoils in predominantly in nonleachable, slowly available, organic forms.

Topsoil and fill materials had equivalent levels of acidity, cation exchange capacity (CEC), extractable P, Ca, Mg, and SO_4^{2-}. These soil characteristics were interpreted to be not limiting to plant growth when compared to the fresh topsoil control. However, most typical subsoils can be expected to have less nutrient content and be less favorable to plant growth than the material in this study, making topsoil application even more beneficial.

Comparison between fresh and stockpiled topsoil (Table 1, columns 1 and 3) shows that the process of harvesting and stockpiling topsoil for periods up to five months has moderate or insignificant detrimental effect on soil quality. Most tests show no decreases, although total N declined by 15 % and total P and inorganic P by 27 %.

TABLE 1.

Soil analysis results of unmixed fresh, dried, and stockpiled topsoil and of subsoil fill material. All values are means of three samples. Values in each row followed by the same letter did not differ significantly ($P < 0.05$) as indicated by analysis of variance with mean separation by least significant difference. All values in mg kg^{-1} except CEC (in cmol kg^{-1}) and pH.

	Soil treatment			
Soil variable	FRESH	DRIED	STOCKPILED	FILL
pH	4.6 a	4.6 a	4.7 a	4.7 a
CEC	24.3 a	25.3 a	21.7 a	22.0 a
Total N	1865 a	1823 a	1570 a	72 b
Mineralized N	43.4 a	32.6 b	39.6 a	1.2 c
Total P	617 a	537 b	479 c	302 d
Inorganic P	487 a	419 a	357 b	302 b
Organic P	129 a	117 a	122 a	8 b
Extractable P	0.78 a	0.76 a	0.70 a	0.64 a
Ca	1333 a	1264 a	1272 a	1329 a
Mg	221 a	180 a	188 a	210 a
K	859 a	879 a	938 a	404 b
SO_4	9.8 a	8.3 a	11.7 b	8.1 a

These differences are attributed not to nutrient loss but to sampling error between the fresh and stockpiled material, as evidenced by the decline in total P which is not subject to leaching or gaseous losses as is N. A greater proportion of B horizon material was thought to be incorporated into the stockpile by the heavy equipment than was collected during hand sampling of fresh topsoil. The increase in SO_4^{2-} is interpreted as resulting from mineralization of S from organic forms to the sulfate form by decomposition processes during stockpiling. Drying of the fresh topsoil decreased the mineralizable N, presumably by desiccation of the microbial biomass in the fresh sample. In general, changes in soil nutrient availability are small or nonsignificant during the stockpiling process.

No toxic metal concentrations were measured in any of the soil materials. Possible metal toxicity was suspected because of the occasional appearance of serpentinitic rock fragments in the fill material. Nickel was the only element higher in fill material (0.39 µg/g) compared to topsoil materials (0.14 µg/g), but concentrations were not high enough to be phytotoxic (Welch, 1981). Chromium (Cr) levels were the same in both the native topsoil and the fill material (0.02 µg/g) and were not limiting. Our interpretation from these results was that the soils had no capacity to limit plant growth by metal toxicity.

Because soil handling operations disaggregate, grind and shear the soil fabric, and the stockpiled material generated considerable heat during composting, some changes in soil quality and function are inevitable. Topsoil quality can be maintained by keeping storage time as short as possible. However, because the majority of soil qualities measured were so similar between the fresh and stockpiled treatments, we conclude that stockpile storage under the conditions of this study result in little or no loss of topsoil quality.

Soil data: greenhouse experiment

The addition of various topsoil materials in greenhouse treatments resulted in organic C levels ranging from 4 g/kg in the 0 % topsoil mixture, to 21 and 32 g/kg in the

40 % and 60 % topsoil mixtures. The elevated temperature indicates that composting of the soil organic matter did actually occur, but the actual amount of organic matter converted to CO_2 was small relative to total carbon levels. Organic carbon levels in the 60 % topsoil greenhouse mixture most closely matched the carbon content of the reapplied topsoil material in the field plots. The organic C levels in the field plots were 37 g C/kg in the 10 cm topsoil plot and 6 g C/kg in the non-topsoiled (fill material) plot compared to 32 g C/kg in the 60 % and 4 g C/kg in the 0 % greenhouse treatments.

Average values of soil pH in the greenhouse experiment ranged from 4.9 to 5.1. These values were slightly higher than measured in the field soil, but are not plant growth limiting. Decomposition of organic matter in the stockpile increased soil pH slightly.

Nutrient levels were also measured at the conclusion of the intensive plant grow-out period to evaluate the reserve nutrient N contents. Soil mixtures with stockpiled or dried topsoil components had the same total N and mineralizable N contents at the harvest of the greenhouse experiment as did mixtures using fresh topsoil (Tables 2, 3).

In contrast, addition of fertilizer provided no additional residual nutrient content. Total N values of the "stockpiled" treatment (with no added N) to the "single" and "double" fertilizer treatments are not significantly different. Most of the added fertilizer N was incorporated into plant biomass, resulting in the rapid plant growth observed in soils amended with soluble commercial fertilizers. Mineralizable N decreased in the fertilized treatments compared to the unfertilized "stockpiled," dried or fresh treatments. Fertilization not only failed to provide additional reserves, but it induced growth which depleted the soil's natural reserve, or mineralizable, N content.

TABLE 2.

Total nitrogen contained in soils at harvest of greenhouse soil treatments and topsoil/fill material mixtures.
Each experimental unit is the average of three replications. Interaction between main effects is significant ($P < 0.05$) preventing statistical comparison of main effects. Values in the main table followed by the same letter are not significantly different based on Newman-Keuls multiple comparison analysis of ranked averages following $\log_{10}$ transformation. Values in mg N kg^{-1}.

	TOPSOIL ADDED TO FILL MATERIAL					
Treatment	0 %	5 %	20 %	40 %	60 %	MEANS
FRESH	42.3 a	54.7 a	119.0 b	141.7 b	264.9 c	124.3
DRIED	42.7 a	62.0 a	145.8 b	216.3 c	217.3 c	136.8
STOCKPILED	45.3 a	54.7 a	108.6 b	208.4 c	270.8 c	137.6
SINGLE FERT	49.5 a	60.9 a	121.7 b	220.6 c	212.1 c	133.0
DOUBLE FERT	52.8 a	67.0 a	122.0 b	209.9 c	300.2 c	150.4
MEANS	46.5	59.7	123.4	199.4	253.0	

TABLE 3

Mineralizable nitrogen (anaerobic incubation) at harvest of greenhouse soil treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Interaction between main effects is significant ($P < 0.05$) preventing statistical comparison of these values. Values in the main table followed by the same letter are not significantly different based on Newman-Keuls multiple comparison analysis of ranked averages following square root transformation. Values in mg N kg^{-1}.

	TOPSOIL ADDED TO FILL MATERIAL					
Treatment	0 %	5 %	20 %	40 %	60 %	MEANS
FRESH	0.17 b	0.15 b	0.58 b	1.54 d	4.29 f	1.35
DRIED	0.05 a	0.31 b	0.48 b	1.45 d	3.96 f	1.25
STOCKPILED	0.18 b	0.17 b	0.52 b	1.87 d	3.84 f	1.32
SINGLE FERT	0.18 b	0.18 b	0.40 b	1.53 d	2.86 e	1.03
DOUBLE FERT	0.25 b	0.15 b	0.63 b	1.05 c	3.05 e	1.02
MEANS	0.17	0.19	0.52	1.49	3.60	

Many of these plant acquired nutrients are released during decomposition of the plant materials at death. If the soil is functioning well, as do most topsoils, these materials are absorbed and retained for future plant uptake. If soils are not retentive or are biologically inactive, the nutrients in the residues are susceptible to leaching losses, as in fill soils. Therefore, application of fertilizers to non-retentive fill materials results in a plant-soil system which loses large fractions of its nutrient reserve each year. These degraded soils must be treated to improve their soil function, not just to boost their available nutrient content.

An additional way in which topsoils can function to retain nutrients is by increased microbial activity. The activity of microbes in the organic matrix of the topsoil provides a demand for available nutrients and serves to adsorb nutrients which would otherwise be susceptible to leaching losses. In the greenhouse study, the microbial biomass increased as the amount of topsoil mixture was increased (Table 4). The quantity of N in the microbial biomass averages about 60 % of the amount of nitrogen in the mineralizable N pool. This suggests that the mineralizable or "available" nitrogen pool is related to microbial populations and that nitrogen availability and retention will be improved if the revegetation project includes treatments which enhance microbial populations. Such treatments would include presence of partially humified organic matter which can moderate fluctuations in temperature and moisture and can provide a slowly available substrate for maintenance of microbial populations. Establishment of perennial vegetation which maintains at least some root activity throughout the year is expected to

TABLE 4

Index of microbial biomass nitrogen (five day fumigation) at harvest of greenhouse soil treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Nonsignificant interaction between main effects ($P < 0.05$) allows statistical comparison of main effects. Row and column means which are followed by the same letter are not significantly different based on Newman-Keuls multiple comparison analysis of ranked averages following square root transformation. Values in mg N kg^{-1}.

	TOPSOIL ADDED TO FILL MATERIAL					
Treatment	0 %	5 %	20 %	40 %	60 %	MEANS
FRESH	0.42	0.73	-0.32	1.54	1.06	0.69 ns
DRIED	-0.21	0.61	-0.64	0.96	3.87	0.92 ns
STOCKPILED	0.44	0.10	-0.24	0.52	1.76	0.52 ns
SINGLE FERT	0.33	0.11	0.00	1.18	2.88	0.90 ns
DOUBLE FERT	0.02	0.32	0.21	0.10	1.37	0.44 ns
MEANS	0.23 a	0.30a	-0.20 a	0.86 b	2.19 c	

TABLE 5

Total P at harvest of selected greenhouse treatments and topsoil/fill material mixtures.Each experimental unit is the average of three replications. Nonsignificant interaction between main effects ($P < 0.05$) allows statistical comparison of main effects. Row and column means which are followed by the same letter are not significantly different based on Newman-Keuls multiple comparison analysis of ranked values. Values in mg P kg^{-1}.

	TOPSOIL ADDED TO FILL MATERIAL		
Treatment	0 %	60 %	MEANS
STOCKPILED	330	424	337 a
DOUBLE FERT	395	502	449 b
MEANS	363 a	463 b	

increase microbial activity compared to annual erosion control grasses which die out during the summer.

Phosphorus levels were increased about the same amount by either topsoil or fertilizer addition, when measured at the conclusion of the greenhouse experiment (Table 5). Fertilizer derived P was not lost from the system as it was with N because P is readily retained on soil materials. The degree to which the P is tightly held on the soil material determines what fraction of the total P is available to plants. Measurements from the field plots showed similar increases in total P with topsoil addition.

Although plant available P, as measured by double acid extraction, was increased by topsoil addition, P levels were less than 1 µg P/g. Nelson, *et al.*, (1953) report that soils testing less than 10 µg P/g by this method are phosphorus deficient. While the soils appear to be low in plant available P, the presence of organic P pools (Table 1) may provide P sources not measured by the double acid extraction. The availability of these pools to plants is not known.

Plant growth

Dry weight of non-fertilized Pubescent wheatgrass increased significantly ($P < 0.05$) when topsoil/fill mixtures exceeded 20 % topsoil (Figure 6, Figure 8, pg 29). Plant dry weight was six to ten times greater in the 60 % than the 0 % topsoil addition. The dry weight production was increased by about another order of magnitude with fertilizer addition. The combination of 60 % topsoil plus fertilizer treatments yielded the highest dry weight production. Plant growth did not differ significantly between 0 % and

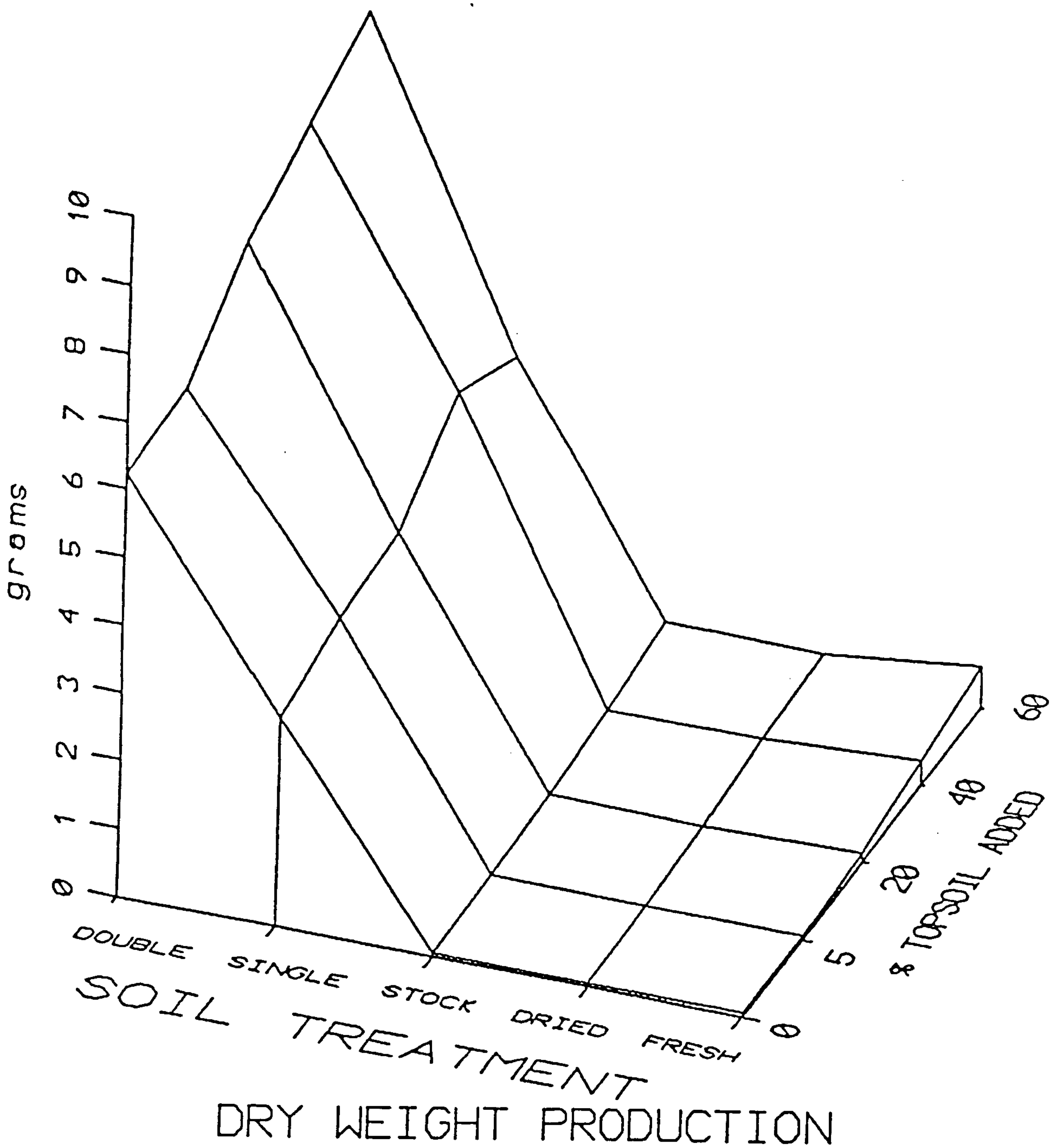

Fig. 6. Dry weight production of Pubescent wheatgrass as influenced by topsoil/fill material mixture and soil treatment. Each experimental unit replicated three times. Mean separation calculated from analysis of variance and Newman-Keuls multiple comparison test. In unfertilized treatments (stock, dried, fresh), 20, 40, and 60 % topsoil mixtures are statistically different from the 0 and 5 % mixtures. Double and single fertilizer treatments are statistically different than the unfertilized treatments. ($P < 0.05$).

5 % topsoil additions in either fertilized or unfertilized treatments. This indicated that plant growth was not responsive to small topsoil amendments, but instead required greater than 20 % topsoil addition. Topsoil amendment may also have influenced plant growth by altering bulk density, which was 20 to 30 % lower in the topsoil materials used for the greenhouse experiment compared to the fill material.

The process of air drying or stockpiling fresh topsoil caused slight decreases in plant growth, but because the effect is small relative to other constraints such as temperature and moisture conditions or fertilizer application, it is expected to be biologically insignificant in field situations. The comparison relevant to field situations where soils often dry completely during the summer months should be the dried versus stockpiled treatments. These two treatments do not show significant differences in plant growth.

Plant growth in the greenhouse experiment increased 34 % when the amount of topsoil mixed with fill was increased from 0 to 60 %. In the field, plant growth was increased 69 % between the 0 cm and the 10 cm topsoil plots at the end of the first year of growth. The greater growth increase in the field is attributed to greater root exploration volumes in the field compared to the pots used in the greenhouse.

Plant growth can often be increased on wildlands soils and construction disturbed sites by fertilizer application, as reviewed previously (Clary, 1983). The important measure of permanent plant reestablishment, however, is not growth in the first few seasons, but the ability to maintain at least modest growth through many years or decades. Excessive initial plant growth may even be harmful if the soil moisture may become depleted before the plants complete their life cycles, or if thick thatch develops which smothers seedlings in successive seasons. For these reasons, plant dry weight production was measured for several seasons after establishment of the topsoiled plots.

Topsoil application improved plant growth in the field each year of the three years monitored. Field plots yielded the equivalent of 1650 and 2787 kg dry weight production/ha the first year (1473 and 2488 lb/ac) (Figure 7). By the end of the third year the 0 cm (fill material) plot had 1980 kg dry matter production/ha (1768 lb/ac) and the 10 cm topsoil plot had 4833 kg/ha (4315 lb/ac). While the variability within the plots was great, a significant trend is indicated where plant production reaches a plateau on the non-topsoiled plots while plant growth on the topsoiled plots continues to increase. These data support the contention by Clary (1983; pg 60, 66) that plant growth declines after the first season or two in plots receiving only fertilizer and no other topsoil amendment and that continued fertilization is needed for long term plant establishment. Topsoil amendment provides several years of slowly available nutrients as well as improving nutrient retention and cycling.

Plant community composition in the field plots also changed with topsoil amendment (Figure 9). The percentage of total plant dry weight production contributed by clover species was 73 % in the 0 cm topsoil field plot but only 47 % in the 10 cm topsoil treatment. By the end of the third year of growth, clover contributed 90 % of the biomass production on the non-topsoiled plot while on the topsoiled plot biomass was 93 % grass and only 3 % clover. Because the initial seed application to both plots was identical, these data indicate that the nitrogen-fixing clover species were more competitive

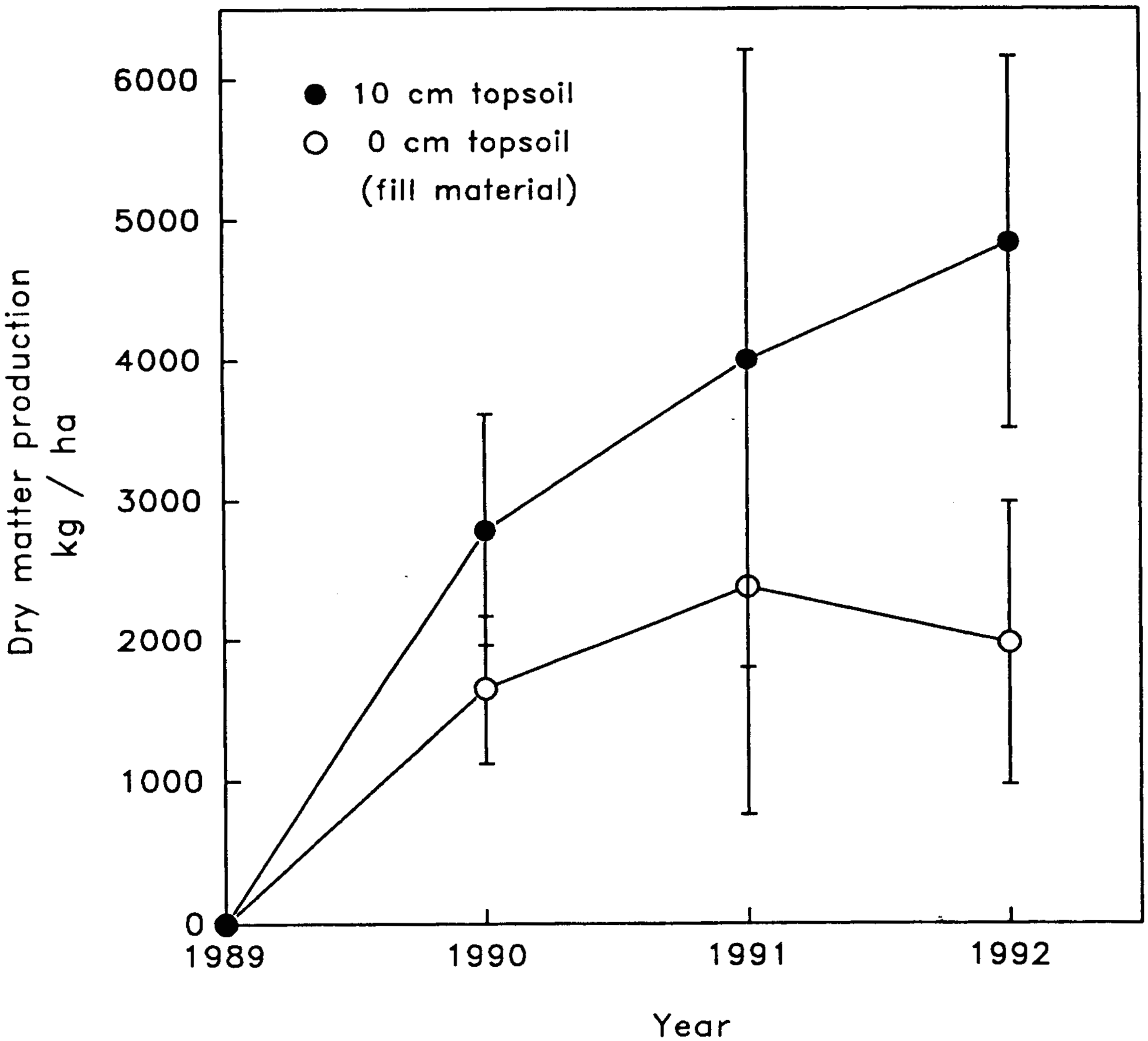

Fig. 7. Dry matter production of grass and clover in field plots on fill material with either 0 cm or 10 cm topsoil amendments. Brackets indicate 95 % confidence intervals. ($P < 0.05$). Data in kg ha^{-1}.

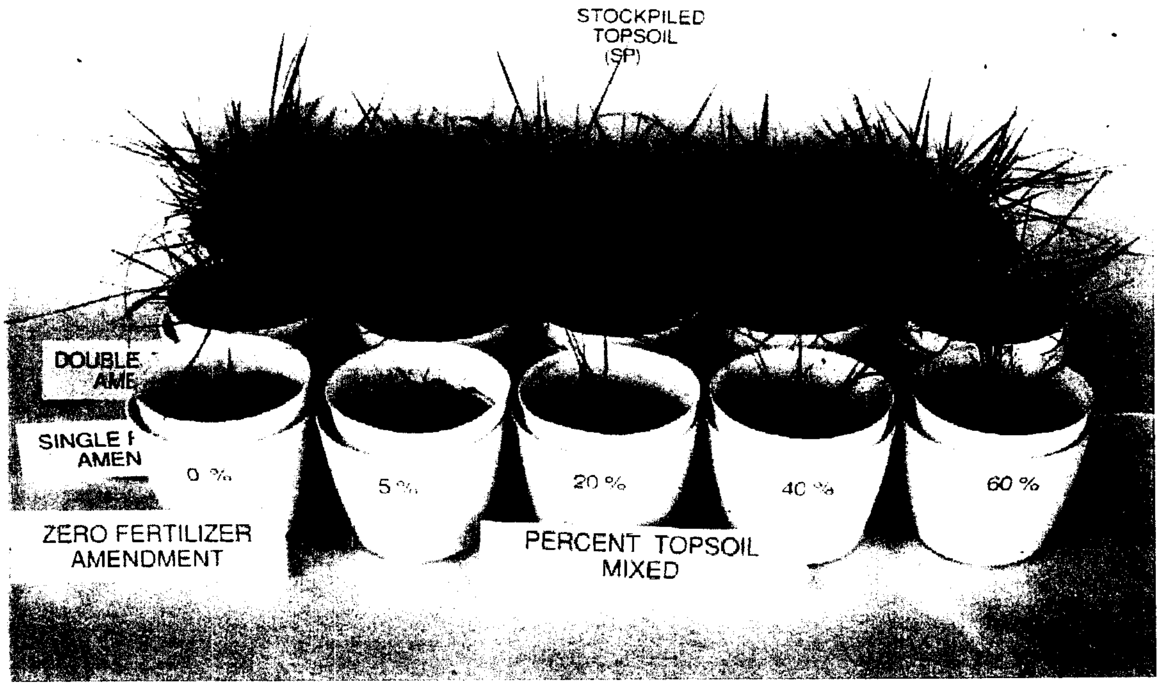

Figure 8. Plant growth in 1.2 L pots at harvest. Front row is unfertilized stockpiled topsoil, middle row is "single" fertilizer and back row is "double" fertilizer application. Topsoil:soil volume mixtures are (from left to right) 0, 5, 20, 40, 60 %.

Figure 9. Influence of topsoil application on plant growth and species composition in field plots viewed from top of slope looking down. Left treatment is 10 cm topsoil and right treatment is 0 cm topsoil (fill material only). All other seeding, fertilizer and erosion control experiments were identical.

in the nutrient poor subsoil treatment and/or that grass species were better able to capitalize on the improved soil conditions in the 10 cm topsoil amendment.

Mycorrhizal infection

Stockpile storage caused no decrease in mycorrhizal infection compared to fresh topsoil (Figure 10). While other studies have found that the process of stockpiling topsoil can potentially decrease inoculum viability (Rives, *et al.*, 1980; Stark and Redente, 1987), the five month storage period used in this study did not reduce infection levels.

Volumetric topsoil amendments in excess of 20 to 40 % significantly increased mycorrhizal infection. The 5 % topsoil additions showed no significant increase in infection between any of the soil treatments. A lack of infection response with small topsoil additions suggests that a limited amount of topsoil would be better used by being concentrated in small pockets rather than being spread as a thin blanket across the entire site. Such pockets, or microsites, should be large enough to maintain soil microbial activity, from which the rest of the site can be colonized. The minimum size for such a microsite in various soil and climatic conditions is not known.

Topsoil application to field plots increased percent of grass root length infected by mycorrhizal fungi from 3.8 % in the fill material to 13.9 % in the topsoiled plot. Mycorrhizal infection of clover species was more responsive to topsoil application. Infection increased from 3.0 % in the fill material to 31.8 % in the 10 cm topsoil

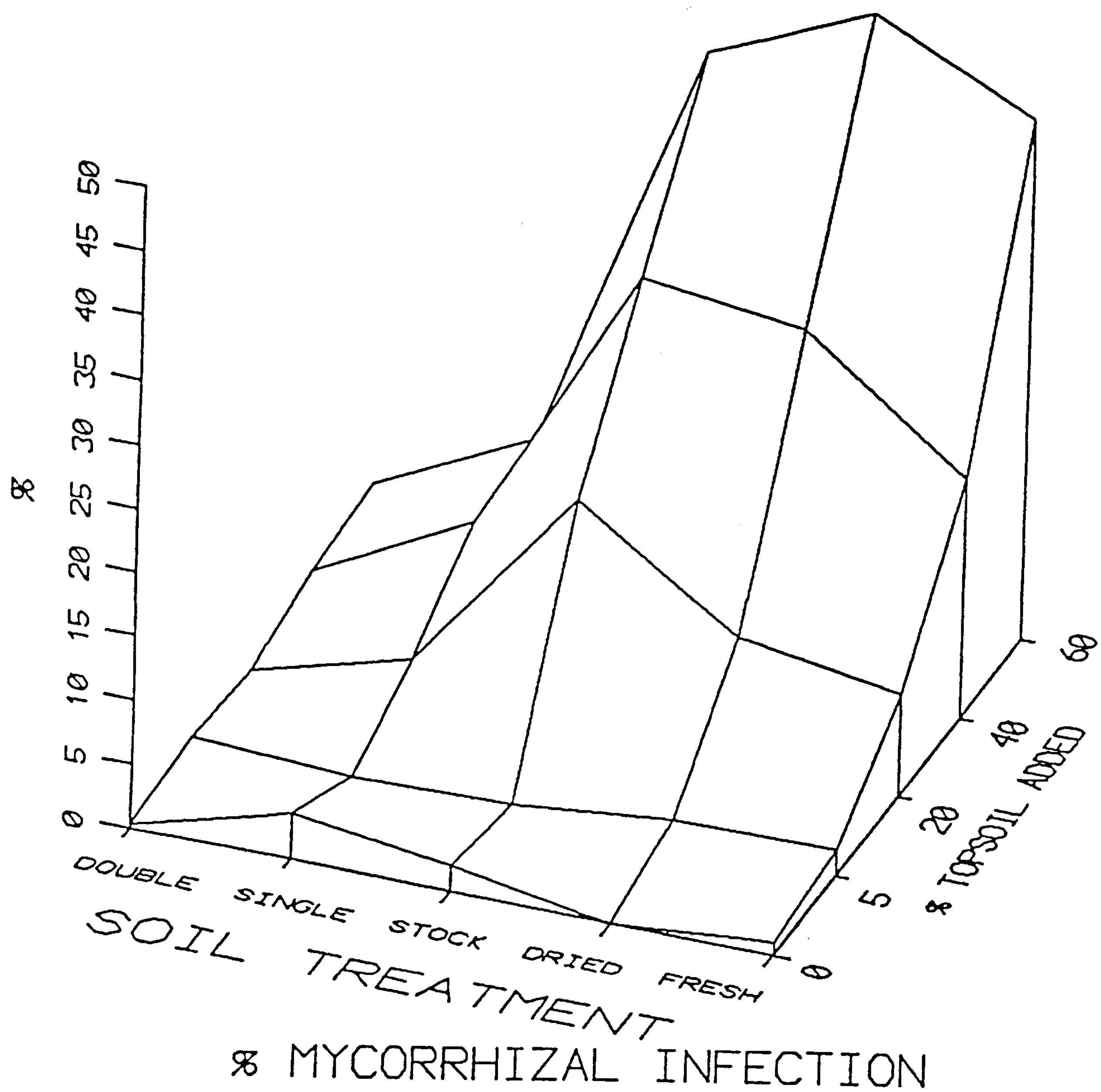

Fig. 10. Percent mycorrhizal infection of Pubescent wheatgrass as influenced by topsoil/fill material mixture and soil treatment. Each experimental unit replicated three times. Mean separation calculated from analysis of variance and Newman-Keuls multiple comparison test. Double and single fertilizer treatments are statistically different from unfertilized treatments at 20, 40, and 60 % topsoil mixtures. ($P < 0.05$).

treatments. The minimum percent infection required to facilitate plant growth has not been experimentally identified.

Although fertilization greatly increased plant growth, the higher rates also caused a large reduction in the percentage of roots showing mycorrhizal infection. Infection percentage of fertilized 0 and 60 % topsoil additions were both low. Suppression of percent infection by fertilization has been reported previously (Jasper, *et al.*, 1979).

Infected root material is the most efficient inoculum for subsequent spread of mycorrhizal infection (Hall, 1976; Rives, *et al.*, 1980). Therefore, the treatments were also evaluated on the basis of total infected root material, not just a percentage ratio. These data were generated by multiplying the percent infection times the mass (in milligrams) of dried root material. The results indicate that large increases in plant size and root production more than compensated for reduced percent infection in the single fertilizer treatment (Table 6, Figure 11). The total amount of infected root material increased significantly ($P < .05$). While the double fertilizer application further increased plant growth, the percentage infection as well as the total mass of mycorrhizal roots was reduced.

An evaluation of the total amount of infected root material is a more meaningful index for revegetation success than a percentage ratio of infection on what may be a few small plants (Gerdemann, 1968; Neill, 1974). Under the experimental conditions of this study, both plant growth and inoculum production were increased with moderate fertilization, indicating a role for starter fertilizer in reestablishment of both plant cover and mycorrhizal infection on nutrient poor soils. This result is interesting because it shows that production of beneficial fungal infection and production of vigorous erosion control plant cover are not mutually exclusive processes.

TABLE 6.

Weight of mycorrhizal roots. Calculated by multiplying percent infection times root dry weight. Interaction between main effects is significant ($P < 0.05$) preventing statistical comparison of these values. Values in the main table followed by the same letter are not significantly different based on Newman-Keuls multiple comparison analysis of ranked averages. Values in mg per pot.

	TOPSOIL ADDED TO FILL MATERIAL					
Treatment	0 %	5 %	20 %	40 %	60 %	MEANS
FRESH	0.3 a	0.7 a	8.2 a	45.6 b	130.7 b	37.1
DRIED	0.0 a	0.6 a	9.8 a	77.0 b	149.1 b	47.3
STOCKPILED	0.4 a	0.4 a	8.4 a	62.9 b	111.7 b	36.8
SINGLE FERT	59.5 b	10.3 a	112.6 b	249.1 c	197.5 c	125.8
DOUBLE FERT	12.2 a	37.5 a	0.0 a	67.3 b	70.1 b	37.4
MEANS	14.5	9.9	27.8	100.4	131.8	

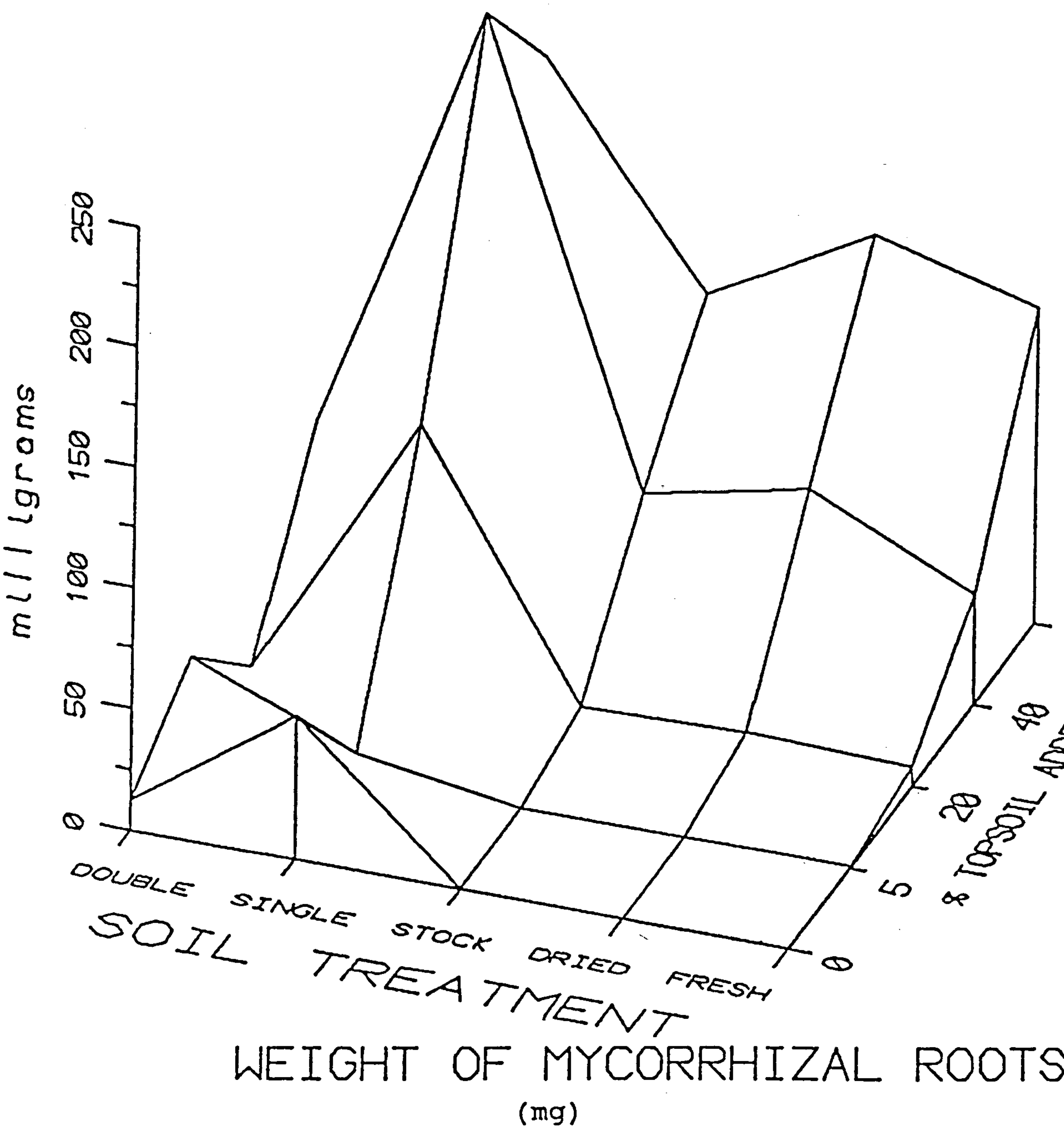

Fig. 11. Total weight of mycorrhizal roots as influenced by topsoil/fill material mixture and soil treatment. Mean separation calculated from analysis of variance and Newman-Keuls multiple comparison test. The single fertilizer treatment is statistically different from the unfertilized or double fertilizer treatments. ($P < 0.05$).

Conclusions

Reapplication of topsoil to fill slopes in conjunction with moderate fertilization has been shown to increase and sustain plant growth, mycorrhizal infection and microbial activity relative to treatments with fertilizer but no topsoil. Topsoil additions can serve as a nutrient and mycorrhizal inoculum source for revegetation of biologically inactive and nutrient poor construction fill materials. Plant growth on the topsoil amended field plots continued to increase through the third year after establishment while plant growth on the non-topsoiled (fertilizer only) plot appeared to stabilize at about 40 % of that in the topsoiled plot. Storage for five months in a stockpile had little impact on topsoil quality.

In the greenhouse experiment, topsoil effects became statistically significant when topsoil made up greater than 20 % or more of the total soil mixture. Topsoil mixtures of 40 and 60 % may be biologically important in field applications. Moderate levels of fertilizer increased plant growth and increased total mass of mycorrhizal infected roots, even though the percentage of infected roots decreased with fertilization. Microbial biomass N was a significant fraction of the mineralizable N pool. At the conclusion of the experiment, mineralizable N was nearly zero in the double fertilized treatments, but was nearly ten times greater in the topsoil treatments.

Total production of mycorrhizal root material is critical since these propagules are the inoculum source for infection and growth in subsequent seasons. For this reason, barren sites should be managed for maximum total infected root material, as opposed to maximum percentage of infection. This objective is met with moderate fertilization and topsoil amendment in the conditions of this study. Where the volume of topsoil is limited, topsoil should be concentrated in small pockets which can sustain biological activity of the soil, as opposed to spreading the topsoil thinly over the entire surface of the site. Such microsites would also reduce the required volume of topsoil substitutes such as composts or sludge for projects where topsoil is unavailable.

Recommendations

1) Topsoil harvest, stockpiling and reapplication is strongly recommended where ever possible as the best method for reestablishment of plant communities on disturbed soils. Equivalent levels of chemical fertilizer cannot substitute for the benefits provided by topsoil reapplication. Topsoil provides, in addition to available nutrients, slow release nutrient reserves, improved soil structure and water holding capacity, increased microbiological activity for nutrient cycling and retention, increased mycorrhizal infection, and a potential source of native seed. The soil material which should be harvested includes the "duff," including decomposed, broken or chipped plant material and the mineral soil material down to the color change from the darker topsoil to the redder or grayer subsoil.

2) In this study, storage of topsoil material in a stockpile for periods of up to five months is an acceptable method of handling these materials during construction. Topsoil nutrient content and biological quality was not degraded. Infection potential of mycorrhizal fungi did not decrease during stockpiling.

3) Use of moderate amounts of fertilizer can be used to increase the total amount of mycorrhizal infected plant roots. Chemical fertilizers cannot by themselves regenerate soils, but their moderate use in conjunction with topsoil application is shown to be beneficial in promoting both plant growth and increased total mycorrhizal infection. Rates of P amendment should be limited to the range of the 39 kg P/ha (35 lb P/ac) treatment because the mycorrhizal infection dropped off significantly when the P rates were doubled.

4) In the greenhouse study, topsoil amendments greater than 20 % of the total soil volume were required to generate improved plant growth and mycorrhizal response. Plant and mycorrhizal production peaked in the 60 % treatments. We extrapolate these greenhouse results to field situations by recommending 10-20 cm (4-8 in) topsoil application over fill material, if available. If a volume of topsoil equivalent to less than 2 cm (1 in) topsoil is available, it should be concentrated in smaller volumes such as in furrows or a roughened surface, rather than being spread thinly over the slope surface.

5) Revegetation success should not be based on short term growth increases in the first season or year. Fertilization of the 0 % topsoil pots gave great increases in plant growth, but after three years in the field the same treatment shows a plant community which is declining in biomass production while production in the topsoil treatment continues to increase.

6) As demonstrated at the Gibson Curve site, placement of topsoil on steep slopes can lead to sloughing. Maximum slope design for topsoil application should be 1½:1 for fill slopes and 2:1 for cut slopes.

IMPLEMENTATION

Findings of this project have been presented to a Landscape Architecture Standards Committee meeting and also to District Biologists as part of a soils workshop. Caltrans research activities have been presented in several workshops sponsored by the Society for Ecological Restoration - California Chapter. Participants have included commercial landscape and environmental contractors, state and federal agency representatives and college students. Two special workshops were presented to the Santa Clara Valley Water District (March, 1994) and to the California Department of Fish and Game (May, 1994).

Implementation of the results of this project within the California Department of Transportation will be accomplished by sending a copy of the final report to the District Deputy Directors of Project Development, District Landscape Architects and Environmental Offices. A cover letter will explain the benefits of topsoil reapplication, directing attention to the current guidelines of the Design Manual on the preservation and use of topsoil. Recommendations will be made to the Office of Landscape Architecture to further emphasize the value of saving and reapplying topsoil on construction projects. A special provision will be developed that can be inserted in the Earthwork special provisions of contract documents. Copies of the final report will be available from the Caltrans Publication Unit. The availability of the report will be advertised in professional and trade journals.

Two peer reviewed articles and several technical presentations have been generated from this research activity. The papers and proceedings from presentations are exhibited in Appendix 2.

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Appendix 1: NUTRIENT STATUS OF THE PM 52.5 STOCKPILE July 10,1990

INTRODUCTION

This analysis was requested by Larry Orcutt, Resident Engineer for the Gibson Curve project, for the purpose of evaluating the nutrient content of a potential source of topsoil material. The stockpile (PM 52.5, west side of road, about 0.5 miles south of the Gibson Curve interchange) was to be spread on the flat area on the north end of the Gibson Curve interchange north of the off ramp, south of the on ramp and east of the traffic lanes.

The nutrient content of the material was evaluated, including available nitrogen, available and total phosphorus and percent of fine material (less than 2 mm particles), using standard soil tests. Three materials are investigated for comparison: a "best available" stockpiled material from the forest floor of the oak woodland previously located on the site (OAK), the existing fill material (FILL) from the final graded surface at the north end of the interchange, and the prospective topsoil material from the PM 52.5 site (STOCKPILE).

METHODS - SAMPLING:

OAK: Five samples were collected from what remains of the oak woodland stockpile located in the center island of the Gibson interchange. Sample locations lay in a circle two yards out from the edge of the wood chip pile. Samples depths were 0 to 6 inches.

FILL: The existing fill material in the north end of the interchange was sampled at five locations in a semicircle approximately 10 yards in radius. The semicircle was centered on the concrete pads and was oriented to the west and south of the pads. Samples were collected from 0 to 6 inches deep.

STOCKPILE: The PM 52.5 stockpile was sampled at five locations along the central ridge at depths of 6 to 12 inches. Two additional samples were collected at the north end and in the middle which were approximately 18 inches deep. These depths provided information about the bulk of the stockpile rather than from the eroded and weathered surface material.

METHODS - SOIL NUTRIENT TESTS:

Nitrogen availability was estimated by a one week anaerobic incubation with a 2 M KCl extraction. An initial KCl extraction showed the exchangeable N. Phosphorus availability was estimated by extracting with dilute sulfuric and hydrochloric acid. Because the tests are calibrated with agricultural crops, the numbers are best compared within the treatments available here (OAK, FILL, STOCKPILE) rather than in absolute value. Soil nutrients were prorated by the percent of material less than 2 mm compared to total weight.

RESULTS:

The stockpile soils contain only about 3 % of the N of the oak soil, but more than the fill material which contains essentially zero N. The N in the stockpile material is equivalent to about 40 lb N per acre. Because an active legume crop can fix this amount every year, the N content may be less important than the P availability.

Phosphorus is higher in the fill material than either the oak or stockpiled soils, as indicated by the double acid extraction. This indicates that P availability will not increase by application of the south stockpile material to the fill area.

An estimate of the K, Ca, and Mg status of the fill material is given by referring to the data from soils collected for the greenhouse experiments in Davis, CA. These soils used the oak soil (SP) and the fill material from the study plots (FILL). Here the fill material is found to have adequate K, Ca, and Mg levels.

CONCLUSIONS:

Because the nitrogen level of the stockpile soil is such a small percentage of that in the oak soil and because the fraction of coarse material (> 2 mm) is so great, the suitability of the south stockpile as a nitrogen source is low. In addition, the available P in the stockpile is less than that which already exists in the fill material, so application of the stockpile material will not increase P levels. For these reasons, reapplication of the PM 52.5 stockpile is not recommended.

However, because the inorganic nutrients are only one of several components in functioning soils, the inoculation of the north interchange site with some soil-like material is recommended for the purposes of reintroducing soil microbes and mycorrhizae. The residual stockpile of forest floor material may be used as an inoculum source of mycorrhizae and other soil microbes. This material may be better used if it is concentrated in small depressions rather than spread as a thin layer over the site. The surface of the soil should be left in a rough condition so that the forest floor material can drop into the space between the soil clods and avoid drying at the soil surface.

Appendix 2: Dissemination of information generated from this project.

The following technical posters, proceedings, presentations, and articles illustrate the dissemination of the information generated from this research project.

Technical posters

Claassen, V.P., and R.J. Zasoski. 1989. Microbial decomposition of aluminum-organic acid chelates. Agronomy Abstracts, 1989 Annual Meetings, Soil Science Society of America, Las Vegas, Nevada. October 15-20, 1989.

Abstract: Microbial decomposition of organic acids was investigated as a function of pH and solution aluminum concentration. Substrates used were several pure organic acids known to chelate aluminum as well as extracts from different forest soil horizons. Substrate solutions were aerated, supplied with inorganic salts, incubated in flasks and sampled periodically. HPLC was used to identify organic acid types and quantities. Rates of decomposition in relation to substrate, pH and Al concentration will be presented.

Interpretation: Aluminum, although potentially phytotoxic, did not slow the decomposition of organic acids representative of litter and root decomposition products. Therefore, duff applications to acid soils will not be "poisoned" by chelation with soluble metals.

Claassen, V.P., R.J. Zasoski. 1990. Revegetation of disturbed soils with topsoil and fertilizer. Agronomy Abstracts, 1990 Annual Meetings. Soil Science Society of America. San Antonio, Texas. October 21-26, 1990.

Abstract: The variation in N and P pools, mycorrhizal infection and plant growth was evaluated following various fertilizer and/or topsoil applications to the unweathered geological material exposed during highway construction. Nutrient pools were defined operationally: total, mineralizable, extractable, and microbial N; total, inorganic and organic P; organic and total C. Treatments included 0, 5, 20, 40, 60 % vol/vol additions of topsoil to the unweathered geological materials and/or 0, 1, or 2 times the standard fertilizer application rate of 150 lb/ac 10-20-0 and 200 lb/ac of 0-20-0. Plant biomass increased with percentage of topsoil added in all treatments. Mycorrhizal infection was depressed with higher fertilizer treatments, but the infected root weight was greatest in the single fertilizer treatment.

Interpretation: This poster presentation summarized the research in this report. It showed that fertilizer increases plant growth, but has little residual effect at the end of a growout period. Topsoil, by contrast, has a continued ability to provide plant nutrients after successive growouts. Most literature shows the decrease in percent mycorrhizal infection as fertilization increases. This study showed that total infected root length, which benefits the recovery and plant colonization of the site, is increased by moderate fertilizer applications. The study showed that little or no topsoil fertility or biological activity was lost during the stockpiling and storage process.

Claassen, V.P., and R.J. Zasoski. 1991. Growth of Pubescent wheatgrass on degraded soils as influenced by phosphorus source, organic matter and VA mycorrhizae. Agronomy Abstracts. October 27 - November 1, 1991. Denver, Colorado.

Abstract: The possibility of using organic P amendments as a slowly available P source to supplement or replace topsoil during revegetation projects was evaluated. Analysis of field soils showed organic P levels which were 10 to 15 times higher in topsoil samples than in the subsurface material used as fill for road bed construction. Previous experimentation showed enhanced plant growth as greater volumes of topsoil were mixed with fill materials, even in unfertilized treatments. In this experiment, an organic phosphorus source (inositol hexaphosphate) or inorganic phosphate was added at 50 µg-P/g to pots containing 0, 30 or 60 % topsoil mixtures. A zero P addition treatment served as control; all other nutrients were supplemented to sufficiency. The combination of treatments was duplicated with and without mycorrhizal inoculum. Inorganic P gave much greater plant growth than organic P, which gave moderate increases over the unfertilized treatment. With inorganic P amendment, the 30 and 60 % topsoil mixtures enhanced plant growth considerably over 0 % topsoil. Mycorrhizal differences were slight across all treatments.

Interpretation: Inorganic phosphorus is a largely undefined pool in functioning topsoils. This experiment asks whether addition of organic phosphorus compounds would mimic the organic phosphorus pools in topsoil and enhance plant growth through improved availability. The organic phosphorus was shown to be less available for plant uptake, probably because of the high charge characteristics of the compound (six phosphate groups per molecule) compared to orthophosphate (one phosphate group per molecule). Mycorrhizal infection was poor, so this component of the experiment was inconclusive. The application of this experiment is that slow release P forms should be in inorganic forms, such as apatite containing minerals, rather than in organic forms.

Claassen, V.P., R.J. Zasoski, and B.M. Tyler. 1992. Identification of VA mycorrhizae by direct soil extraction and PCR amplification of fungal DNA. Agronomy Abstracts. November 1 - 6, 1992. Minneapolis, Minnesota.

Abstract: DNA from VA mycorrhizal fungi was extracted directly from a sand:soil mixture using a sodium dodecyl sulfate (SDS) procedure including enzymatic digestion of cell walls, polyvinylpolypyrolidone (PVPP) and ethanol precipitation of DNA. Mycorrhizae were established in a greenhouse culture of *Glomus clarum* with Sudan grass host plants. The density of mycorrhizal fungi in the samples was not enriched beyond ambient soil populations. Diluted extracts were then amplified by polymerase chain reaction (PCR) using an 18s nuclear small subunit rRNA sequence and an internal rRNA sequence specific to endomycorrhizae. Amplification products were detected by agarose gel electrophoresis with ethidium bromide/UV visualization. In separate experiments, DNA detection limits without PCR were at the limit of UV/EtBr visualization (500 µg fresh hyphae g^{-1} soil; 7.5 µg DNA g^{-1} soil). Alternative methods for quantification of lower amounts of DNA are presented.

Interpretation: Identification of mycorrhizal fungi in soil samples involves four to six months of greenhouse culture. This method uses the unique DNA sequence information, extracted directly from soil, to confirm identification within a day or two. It requires a library of existing mycorrhizal fungal sequence information which is under continuing development.

Proceedings

Claassen, V.P., J.F. Haynes, and R.J. Zasoski. 1991. Revegetation of disturbed soils with topsoil and fertilizer amendments. Proceedings of Conference XXII. International Erosion Control Association. February 20-22, 1991. Orlando, Florida.

The article in the IECA proceedings is reproduced in subsequent pages and contains the same information detailed in this report.

Presentations

Slides illustrating Caltrans erosion control techniques and topsoil reapplication projects around the state, details of the topsoil harvesting, stockpiling and reapplication at the Gibson Curve project, as well as other technical findings of this project have been presented to the District biologists as part of a soils class on July 28, 1993, and have been included in an on going series of workshops sponsored by the Society for Ecological Restoration - California Chapter. Participants have included commercial landscape and environmental contractors, state and federal agency representatives and college students. Two sessions were specifically presented to the Santa Clara Valley Water District (March 9, 1994) and to the California Department of Fish and Game (May 16, 1994).

Articles

Two peer reviewed articles were generated during this research project and are reproduced following this section. The article accepted for publication in Landscape Degradation and Rehabilitation is a condensed version of the information contained in this final report. This article was distributed to attendants at the High Altitude Revegetation Conference, Ft. Collins, Colorado, March 16-18, 1994. The article accepted for publication in New Phytologist details a method for handling root samples during mycorrhizal evaluation.

EROSION CONTROL:
"A Global Perspective"

Proceedings of Conference XXII
INTERNATIONAL EROSION CONTROL ASSOCIATION
February 20-22, 1991
Orlando, Florida, USA

A NON-PROFIT ORGANIZATION TO PROVIDE OPPORTUNITIES FOR THE EXCHANGE OF WORLDWIDE INFORMATION AND IDEAS CONCERNING EFFECTIVE AND ECONOMICAL METHODS OF EROSION CONTROL.

REVEGETATION OF DISTURBED SOILS WITH TOPSOIL AND FERTILIZER AMENDMENTS

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ABSTRACT

The plant cover required for erosion control has been found to decrease within a few years after seeding on certain northern California highway construction sites. We hypothesize that leaching during the winter rains of California's Mediterranean climate gradually depletes the nutrients in these compacted, low organic matter soils. Field plots and a greenhouse study were designed to evaluate the effect of fertilizer versus topsoil amendments on nutrient availability and revegetation success. Plant growth and mycorrhizal infection of *Agropyron pubescens* (Luna Pubescent Wheatgrass) were measured and related to soil nutrient and microbial biomass levels. Soil treatments included 0, 5, 20, 40, 60 % volume/volume mixtures of topsoil with the construction fill material. The effect of stockpiled or air-dried versus fresh topsoil and the effect of fertilizer amendments were also tested. Stockpiling had minimal effects on plant growth and mycorrhizal colonization. Plant biomass and mycorrhizal colonization increased with greater percentages of topsoil added. The greatest amount of mycorrhizal root material occurred with a combination of moderate fertilizer and high percent topsoil amendments.

INTRODUCTION

The density of grass or grass-legume mixtures established as erosion control on some California Department of Transportation construction sites has been observed to decline within several years after establishment. Fertilizer and seed are applied and growth is vigorous for a few seasons but then stands become sparse. This exposes soil to erosion, causes degradation of highway facilities and requires additional investment in revegetation. In a previous study these declines were associated with nutrient deficiency symptoms (Clary, 1983). Several revegetation projects along the arid east slope of the Sierra Nevada showed that reapplication of topsoil and chipped brush resulted in better stand establishment. The inclusion of topsoil during revegetation is thought to provide improved water and nutrient retention and to restore the microbial activity typically associated with plant roots. This natural cycling of nutrients may offer an alternative to a cycle of fertilizer application, followed by leaching losses and plant decline. This study was designed to experimentally measure the effect of several topsoil treatments on plant growth, soil microbial activity and nutrient levels in field plots and greenhouse experiments.

The observation that nutrient deficiency may be a cause of the decline of plant cover is thought to result from the absence of topsoil as a growth medium. During construction the topsoil is often buried beyond the reach of plant roots by fill material (crushed, unweathered, siltstones and metamorphic sediments). The loss of topsoil and humus removes the major source of available plant nutrients. Loss of this organic rich material reduces soil structure, nutrient retention capacity and microbial activity (Perry and Amaranthus, 1990). Microbial activity is reduced because the loss of organic matter eliminates the food supply of plant decomposing microorganisms. With death, the microbial nitrogen is available for leaching from the plant-soil cycle (Vitousek and Matson, 1985). A continuing supply of plant supplied carbon prevents this loss.

In nutrient deficient soils mycorrhizal fungi typically function to increase nutrient acquisition by plants. This occurs when certain fungi colonize the plant root and form a mutual relationship called a mycorrhizal infection. In this beneficial infection the plant provides energy for the fungi while the fungi provide nutrients for the plant. The loss of the topsoil removes the fungal spores or hyphae which are required to begin the infection (Reeves, et al., 1979). The plant is then left without either the original nutrient rich topsoil or the mycorrhizae necessary to improve uptake. Reapplication of topsoil is expected to restore both of these conditions. Because stockpiling of topsoil during construction may decrease mycorrhizal viability, the inoculum potential of stockpiled soil is also of concern (Stark and Redente, 1987).

Topsoil materials have also been shown to improve physical characteristics important for plant growth. These non-biological effects result from the higher levels of soil carbon in the topsoil. They include increased moisture holding capacity, increased ability to retain added nutrients, moderation of temperatures and increased ease of root penetration.

MATERIALS AND METHODS

Field Site

The study site is located along Interstate 5 at a California Department of Transportation construction site approximately 40 km (25 miles) south of Mt. Shasta in northern California. The pre-existing vegetation was a black oak-ponderosa pine forest with manzanita understory on soil derived from weathered sedimentary rock. Elevation is approximately 550 m (1800 feet). The surface 20 cm (8 inches) of soil was removed by heavy machinery and stockpiled in May, 1989 (Figure 1). The stockpile stayed moist for the five months of storage but no plant growth occurred on the stockpile. Internal temperatures exceeded 40°C (104°F) due to decomposition of organic matter. Following grading of the slopes, the stockpile was redistributed during October 1989 on plots with slope angles ranging from 1.5:1 to nearly 1:1 (Figures 2, 3). Before erosion control materials could be applied, heavy rains caused slumping and rilling on most plots. This forced a redesign of the experiment in which the nutrient treatments and topsoil mixtures were duplicated in a greenhouse experiment (see following section). The remaining field plots were covered with blown straw (3000 lb/ac) and glued. Fertilizer was applied (150 lb/ac 16-20-0 plus 250 lb/ac 0-20-0) and the surfaces were hydroseeded with a mixture of grasses and clovers. Two field plots with 0 and 10 cm (4 inch) topsoil addition were undamaged enough to use as a field verification of the greenhouse study. They were sampled in July 1990 at the end of the growing season.

Greenhouse Study

Because of the heavy erosion on the field plots, soil samples were transported to Davis, Calif., in November 1989 for greenhouse studies. Coarse rock fragments were removed by sieving to less than 6 mm

Figure 1. Stockpiled topsoil.

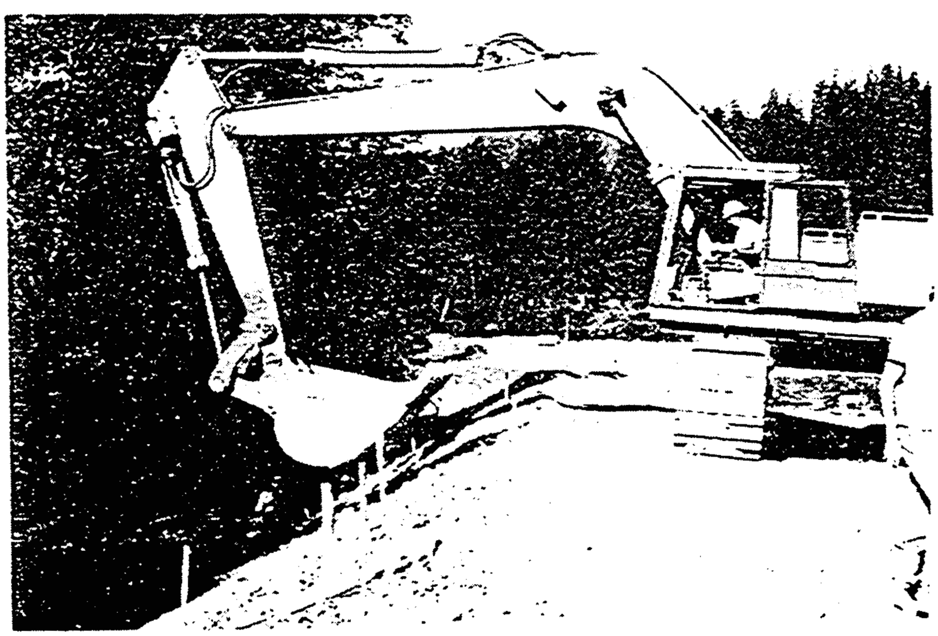


Figure 2. Reapplication of topsoil.

Figure 3. Eroded field plots.

(1/4 inch). The greenhouse study used two factors to test plant growth: percent topsoil addition and soil fertility treatment. To determine the effect of increasing proportions of topsoil, mixtures were prepared of 0, 5, 20, 40, and 60 percent topsoil to total soil volume in 1.2 L (73 in^3) pots. To compare the effect of soil fertility, the percentage mixtures were repeated for each of five different soil treatments: fresh topsoil, air-dried topsoil, stockpiled topsoil or stockpiled soil which was amended with two fertilizer levels. These treatments are referred to as FRESH, DRIED, STOCK, SINGLE (50 mg/kg N and P) and DOUBLE (100 mg/kg N and P). Soil mixtures were placed in pots with individual watering trays to prevent leaching and were sub-irrigated to field capacity as needed. Supplemental lighting was used to extend the photo period to 14 hours. Pubescent Wheatgrass (*Agropyron pubescens*) was used as a bioassay for nutrient availability and mycorrhizal inoculum potential. Plants were seeded in mid-December 1989, and harvested in late-March 1990.

Analytical Procedures

All plant material was dried at 65°C (150°F) to constant weight. Percent mycorrhizal infection was measured by sampling a representative pie shaped section of the root mat, clearing and staining with Trypan blue (Phillips and Hayman, 1970) and counting presence or absence of arbuscules or vesicles in 0.3 cm root sections (Kormanik and McGraw, 1982). Grams of infected root length data were generated by multiplying total dry weight of roots times the infection percentage. Soil pH was measured in 0.01 M $CaCl_2$. Total nitrogen was determined by micro kjeldahl digestion and ammonium analysis by Wescan auto analyzer (Carlson, 1978). Mineralizable nitrogen was determined by one week anaerobic incubation at 40° C (Keeney, 1982). Microbial biomass nitrogen and carbon were determined by the fumigation-extraction method (Brookes, et al., 1985a) with a 5 day fumigation period (Brookes, et al., 1985b). Statistical significance was calculated by LSD ($p < .05$).

RESULTS AND DISCUSSION

Plant and Mycorrhizae Data

Dry weight of Pubescent Wheatgrass (*Agropyron pubescens*) increased with greater percentages of topsoil additions (Figure 4). Addition of topsoil to unfertilized treatments increased plant growth above the 20 % level, doubling plant weight between 40 and 60%. Plant dry weight was much greater with fertilizer addition. The combination of topsoil plus fertilizer treatments yielded the highest values. Plant growth did not differ significantly between 0% and 5% topsoil additions in either fertilized or unfertilized treatments. This indicated that plant growth was not responsive to small topsoil additions, but instead required between 20 and 40% topsoil content. Plant growth was not significantly different between the air-dried and stockpiled treatments. Both of these materials had slightly less growth relative to fresh topsoil. This reduction was similar whether the soil was stockpiled or merely air-dried.

Field plots with 0 cm and 10 cm (4 inch) topsoil added produced approximately 1650 and 2790 kg dry weight plant material per ha (1470 and 2500 lb/ac). This represents an increase in dry weight production of 69% with topsoil addition in the field compared to 34% increase between the 0 and 60% greenhouse treatments. The greater root exploration volume in the field may have contributed to the greater increase in dry weight production. The combination of several grass and two clover species may also have increased production potential. In the field plots the percentage of clovers to total plant dry weight declined from 73% of total in the 0% topsoil treatment to 47% with 10 cm topsoil. While both plant types increased in dry weight production with topsoil addition, the grasses increased nearly 200% while the clovers increased 56%.

In the pot study, mycorrhizal infection was increased in unfertilized treatments when topsoil content was over 40% but this trend was greatly reduced when fertilizer was added (Figure 5). A dilution effect was suspected since the larger plants had much greater root mass. Therefore, data for grams of infected root material were generated by multiplying the percent infection times the grams of dried root material (Figure 6). These data show the greatest dry weight production of mycorrhizal roots occurred not in the unfertilized treatments which showed the highest percent infection levels, but in treatments with the single level of fertilizer amendment. High levels of inoculum are desirable so that successive seasons of plants can be recolonized from spores or hyphal inoculum. High percentage of infection does not necessarily mean large amounts of inoculum if there is little root growth. Under the conditions of this experiment, both inoculum production and plant growth are increased with moderate fertilization. Trace additions (5% topsoil) did not increase infection levels above 0% levels when measured either by percent or grams of infected root. As was found with plant growth data, infection is not increased by addition of small volumes of topsoil. Infection levels, like dry weight production, do not significantly increase until 20 to 40% additions are made.

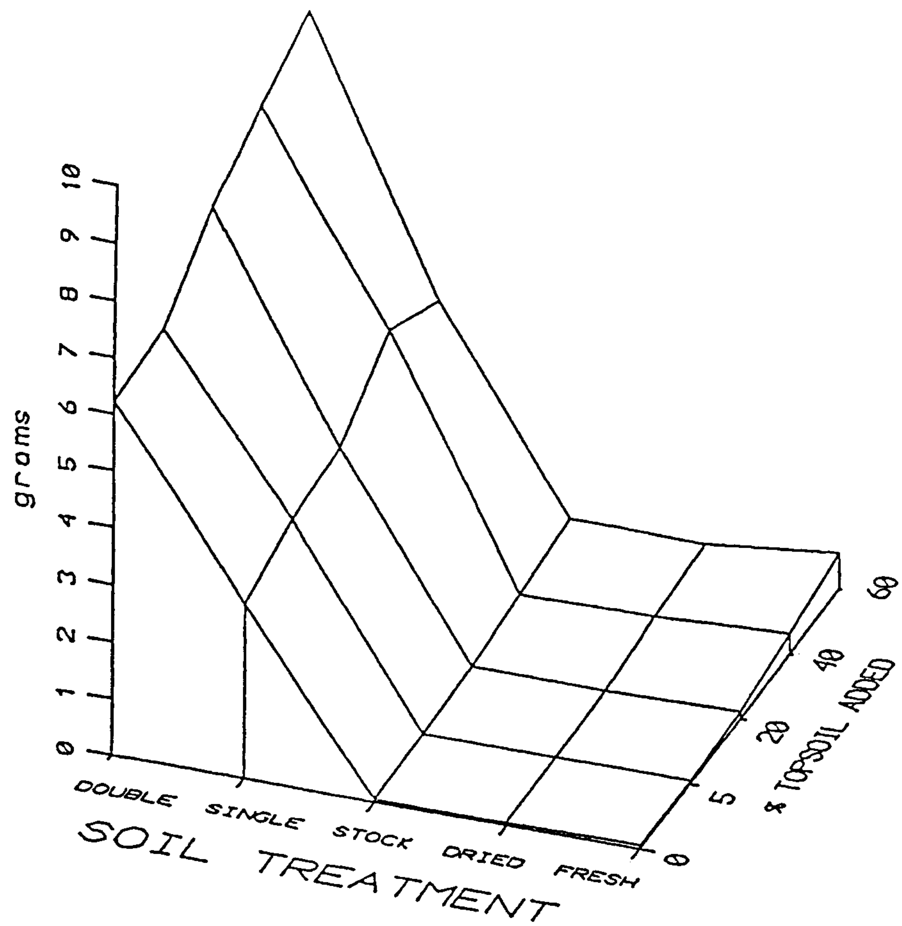
At the field site, the percent mycorrhizal infection of the grasses increased from 3.8% to 13.9% with addition of topsoil. The clover species were more responsive to infection, which increased from 3.0 to 31.8%. Although clovers developed mycorrhizae on a greater proportion of their root systems, the percentage of clover in the total plant biomass decreased with topsoil addition while grasses increased. The nitrogen fixing capacity of the clovers would benefit these species in low topsoil treatments while the fibrous root system increases the competitiveness of the grass species when nutrient availability is higher with topsoil amendments.

Soil Data

The addition of various topsoil materials in greenhouse treatments resulted in organic carbon levels ranging from 0.43% to 3.3% (weight basis). Stockpiling did not reduce the organic carbon levels significantly. Measured organic carbon levels in the field samples were 0.56% and 3.7% in the 0 and 10 cm plots. The 60% topsoil greenhouse treatment most closely represented the reapplied topsoil material.

Soil pH values ranged from 4.9 to 5.1. The lower values occurred in treatments with added fertilizer and low topsoil addition (Figure 7). The alkalinizing effect of organic matter decomposition is most evident in the higher additions of the most decomposed material, the stockpiled soil. These pH measurements had no correlation to plant growth and are probably exceeded by the seasonal swings in pH. However, the trends of acidification by fertilizer and alkalization by organic matter decomposition can have cumulative effects if repeated over several years.

Soil samples taken before the greenhouse experiment was started showed that stockpiling processes reduced the total nitrogen level by about 15% relative to the fresh and dried soils. Some of this nitrogen was converted to more plant available forms. However, by the end of the experiment, no differences between stockpiling and fresh or dried soils were measured. This suggests that stockpiling produces small and temporary changes in plant available and total nitrogen levels.



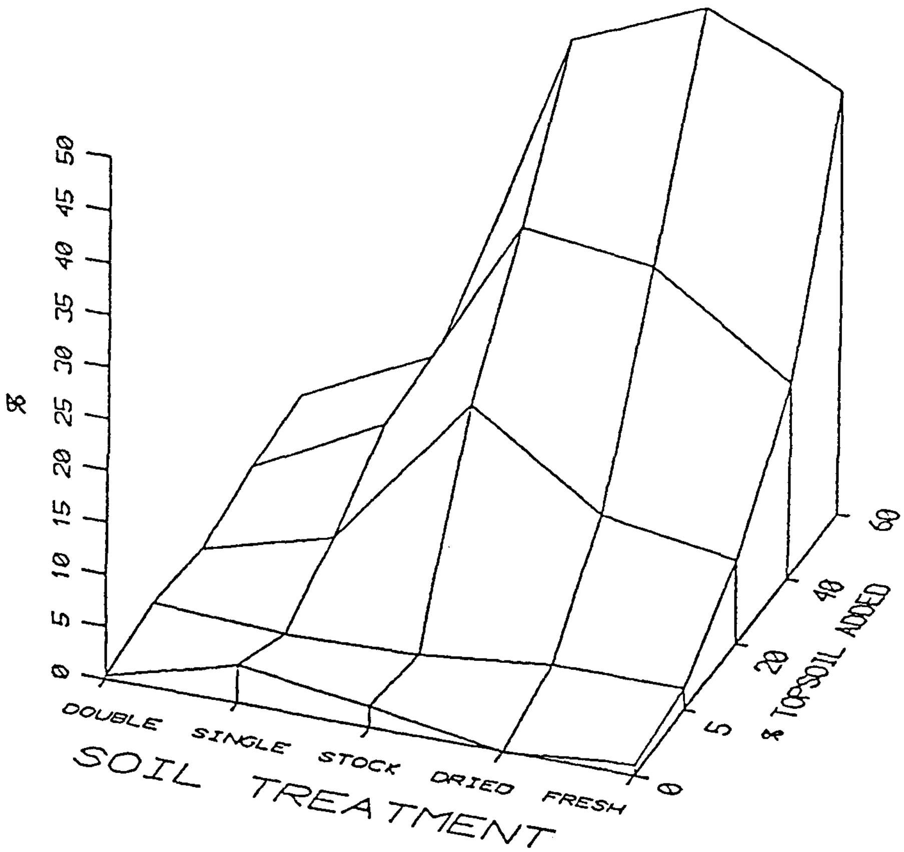
DRY WEIGHT PRODUCTION

(gms)

	PERCENT TOPSOIL ADDED					
TREATMENT	0 %	5 %	20 %	40 %	60 %	AVG
DOUBLE FERT	6.23	6.36	7.34	7.96	8.48	7.28 D
SINGLE FERT	3.07	3.40	3.52	4.48	3.86	3.67 C
STOCKPILE TOPSOIL	0.06	0.08	0.11	0.22	0.40	0.17 A
DRIED TOPSOIL	0.06	0.06	0.10	0.24	0.36	0.16 A
FRESH TOPSOIL	0.06	0.06	0.13	0.35	0.61	0.24 B
AVERAGE:	1.90 A	1.99 A	2.24 B	2.65 C	2.74 D	

VALUES FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE .05 LEVEL AS CALCULATED BY LSD

Figure 4.



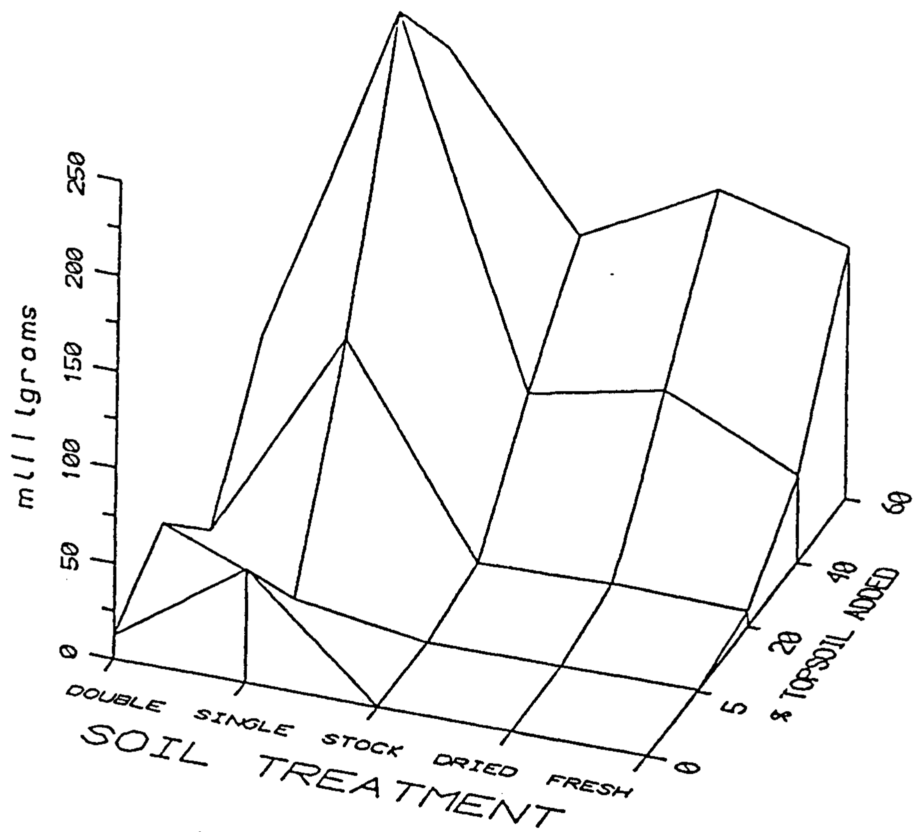
% MYCORRHIZAL INFECTION

(%)

TREATMENT	0 %	5 %	20 %	40 %	60 %	AVG
	PERCENT TOPSOIL ADDED					
DOUBLE FERT	0.3 A	1.0 A	0.0 A	1.7 A	2.3 A	1.1
SINGLE FERT	3.7 A	0.3 A	3.3 A	8.0 A	8.3 A	4.7
STOCKPILE TOPSOIL	2.0 A	0.7 A	18.3 B	29.3 B	40.7 B	18.2
DRIED TOPSOIL	0.0 A	2.0 A	10.0 A	27.7 B	46.0 B	17.1
FRESH TOPSOIL	1.0 A	2.0 A	8.0 A	18.7 B	40.3 B	14.0
AVERAGE:	1.4	1.2	7.9	17.1	27.5	

VALUES FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE .05 LEVEL AS CALCULATED BY LSD

Figure 5.



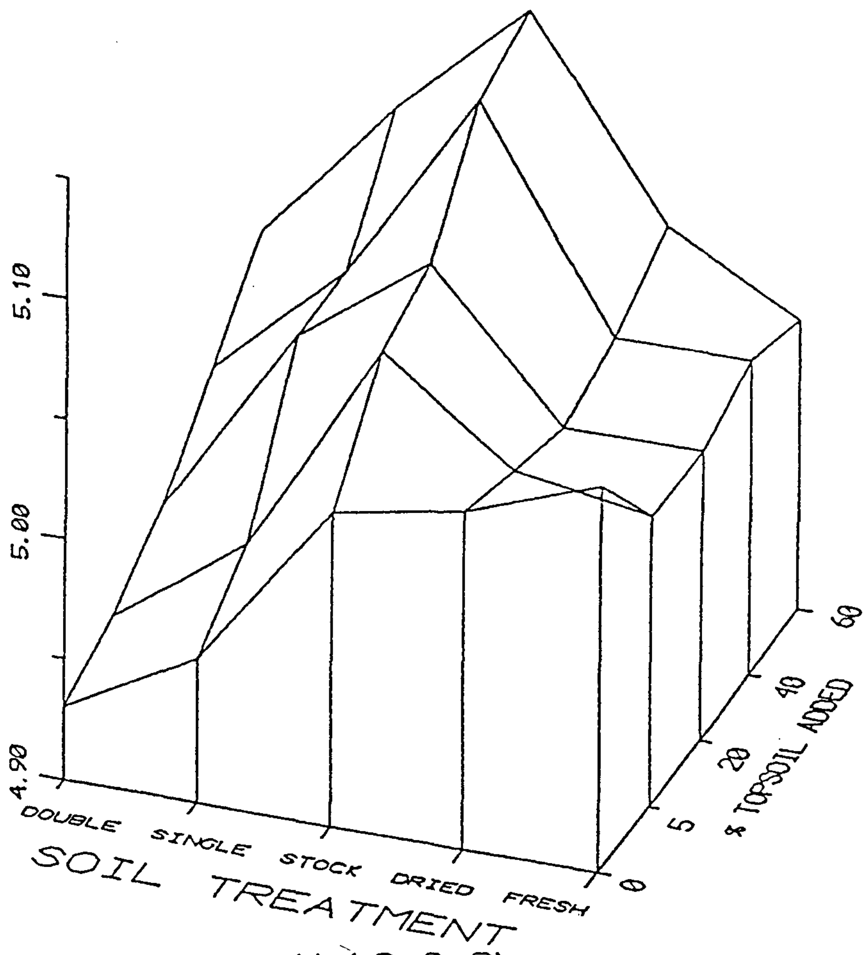
WEIGHT OF MYCORRHIZAL ROOTS

(mg)

TREATMENT	PERCENT TOPSOIL ADDED 0 %	5 %	20 %	40 %	60 %	AVG
DOUBLE FERT	12.2 A	37.5 A	0.0 A	67.3 B	70.1 B	37.4
SINGLE FERT	59.5 B	10.3 A	112.6 B	249.1 C	197.5 C	125.8
STOCKPILE TOPSOIL	0.4 A	0.4 A	8.4 A	62.9 B	111.7 B	36.8
DRIED TOPSOIL	0.0 A	0.6 A	9.8 A	77.0 B	149.1 B	47.3
FRESH TOPSOIL	0.3 A	0.7 A	8.2 A	45.6 B	130.7 B	37.1
AVERAGE:	14.5	9.9	27.8	100.4	131.8	

VALUES FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE .05 LEVEL AS CALCULATED BY LSD

Figure 6.



pH (CaCl 2)

TREATMENT	PERCENT TOPSOIL ADDED 0 %	5 %	20 %	40 %	60 %	AVG
DOUBLE FERT	4.93 A	4.94 A	4.96 A	4.99 A	5.02 B	4.97
SINGLE FERT	4.96 A	4.98 A	5.04 B	5.04 B	5.08 B	5.02
STOCKPILE TOPSOIL	5.03 B	5.07 B	5.08 B	5.12 C	5.13 C	5.09
DRIED TOPSOIL	5.04 B	5.03 B	5.02 B	5.03 B	5.05 B	5.04
FRESH TOPSOIL	5.06 B	5.02 B	5.02 B	5.03 B	5.02 B	5.03
AVERAGE:	5.01	5.01	5.02	5.04	5.06	

VALUES FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE .05 LEVEL AS CALCULATED BY LSD

Figure 7.

Total nitrogen in the greenhouse experiment increased from 46 to 253 mgN/kg with topsoil addition (data not shown). Fertilizer amendments did not increase total nitrogen level in measurements at the conclusion of the experiment. Most of the fertilizer N was accounted for in plant tissue. Mineralizable (plant available) nitrogen also increased with topsoil addition but not with fertilizer. The mineralizable fraction was approximately as large as the amount of nitrogen in the microbial biomass pools. This suggests that the mineralizable or "available" pool of nitrogen may increase or decrease with microbial growth cycles through the seasons in a dynamic response to growth conditions.

Most of the added fertilizer phosphorus was recovered at the end of the experiment (data not shown). Addition of topsoil gave approximately the same amount of added total P as did the double fertilizer additions. Field plot measurements showed similar increases in total P with topsoil addition. The plant available P was measured by acid extraction. These values were low relative to agricultural crops, but were increased by topsoil addition.

CONCLUSION

The overall agreement between field measurements and the greenhouse data indicates that the greenhouse experiment approximated field conditions for plant response to topsoil and fertilizer addition. The ten-fold increase in plant growth with topsoil addition in the unfertilized treatments shows that topsoil can increase mineralizable and available nutrient supply. While limited, this supply may be sufficient for the lower nutrient requirements of native species as opposed to high yielding agricultural plants. The decreased dry matter production of stockpiled soil relative to fresh topsoil is no greater than the decrease from air drying. These effects are small and indicate that for these conditions and a five month storage period, stockpiling is an acceptable method of handling soil during construction.

While percent mycorrhizal infection was reduced with fertilizer applications, the single level of application promoted significantly greater infected root weight as well as substantially larger plants than the unfertilized treatments. This result demonstrates a potential for enhancing plant cover with fertilizer without restricting the mycorrhizal infection and production of inoculum which is necessary for growth in successive seasons. Small topsoil additions (5% vol/vol) were not useful for introducing mycorrhizae to plant roots. Topsoil volumes of 20 to 40% were required to increase infection and plant growth. While other studies have found that the process of stockpiling topsoil can potentially decrease inoculum viability, the five month storage period used in this study did not reduce infection levels. Mycorrhizal infection of clovers increased more with topsoil additions than did grass infection levels in the field plots.

The ability of the decomposing topsoil to moderate acidic conditions was demonstrated. The absolute value of the pH differences is probably not critical, but the trend may become significant when continued for several years, as would occur when established plant comunities produce, accumulate and decompose litter.

Total and mineralizable nitrogen both increased with topsoil addition but not with fertilizer addition. The levels of mineralizable nitrogen are approximately as large as was measured for microbial biomass nitrogen. This suggests that soil microbial populations may be of sufficient size to function as a rapidly available sink for nutrients during seasonal flushes of decomposition.

In summary, reapplication of topsoil to fill slopes in conjunction with moderate fertilization has been shown to increase plant growth, mycorrhizal infection and microbial activity. Topsoil additions can serve as a nutrient and inoculum source for revegetation of biologically inactive and nutrient poor construction fill materials. The duration of storage should be minimized but, under these conditions, stockpiling had little negative impact on topsoil quality. In the greenhouse experiment, significant topsoil effects began to occur when topsoil made up 20 to 40% or more of the soil volume. These thresholds are not as clearly defined for field applications. Many construction projects have limited volumes of topsoil available making blanket applications impossible. In these situations, concentrating available topsoil in microsites scattered across the slope could expand the area treatable with a given volume of topsoil. Microsites could be developed by spreading topsoil on a roughened surface followed by standard straw, seed and fertilizer applications. The topsoil will settle into the surface cavities where it will be less susceptible to drying or erosion then a thin surface layer. These microsites could then form pockets of fertile soil for root growth and microbial activity from which the entire site could be colonized. Further research is necessary to clarify the relationship of microsite volumes and the establishment of mycorrhizae and native plant species in field conditions.

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LAND DEGRADATION & REHABILITATION, VOL. 4, 45–57 (1993)

ENHANCEMENT OF REVEGETATION ON CONSTRUCTION FILL BY FERTILIZER AND TOPSOIL APPLICATION: EFFECT ON MYCORRHIZAL INFECTION

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ABSTRACT

The influence of topsoil and fertilizer application on denuded road construction sites was evaluated to assess its contribution to improvement of vegetation re-establishment. The study sites were within a mixed hardwood and conifer forest on crushed, unweathered subsurface material with low fertility and low biological activity. Topsoils were removed from the site, stockpiled and reapplied to the site after construction. The effect of topsoil amendment on plant growth, soil fertility, mycorrhizal infection and an index of microbial biomass were measured in field and greenhouse experiments. Plant growth on the topsoil amended field plots were greatly increased relative to treatments with fertilizer but no topsoil. Three years after establishment, dry weight production on the plots without topsoil treatment was about 40 per cent of the plots treated with topsoil. Greenhouse experiments were designed to compare fresh, dried and stockpiled topsoil. These experiments indicated that storage of the harvested topsoil for five months in a stockpile had minor effects on plant growth, soil fertility, mycorrhizal infection and microbial biomass. Topsoil volumes had to exceed 20 per cent of the total soil volume to achieve statistically significant benefits and higher ratios showed greater benefit. The percentage of mycorrhizal infection was greatest in topsoil treatments without fertilizer. The addition of fertilizer increased growth but reduced the percentage of roots forming mycorrhizae. When the total weight of infected roots was calculated, however, infection was found to be greatest with a moderate level of fertilizer (equivalent to approximately 27 kg N ha^{-1} and 39 kg P ha^{-1}), and was less in both higher fertilizer treatments and in unfertilized treatments. Topsoil amendment increased microbial biomass nitrogen but fertilizer treatment did not.

KEY WORDS Revegetation Erosion control Topsoils Stockpile storage Microbial biomass Endomycorrhizae Mycorrhizal inoculum Mineralizable nitrogen Nutrient cycling Soil organic matter

INTRODUCTION

Revegetation of disturbed areas such as construction sites, roadways or mine spoils often takes place on exposed subsurface materials. These conditions result from excavation of the new grade surface below the developed soil profile or from burial of the original topsoil beyond the reach of plant roots. If the exposed surfaces are low in fertility and biological activity, re-establishment of vegetation is difficult. The poor nutrient cycling capacity of subsurface material results in inadequate retention of natural or amended nutrients, reducing the establishment and persistence of vegetative stands.

Current methods used by the California Department of Transportation for re-establishment of erosion control vegetation on such degraded soils include the application of straw, inorganic fertilizers and hydroseeding. Plant communities on construction sites receiving these treatments show vigorous initial growth, but vegetative cover often becomes sparse or non-existent within a few years (Clary, 1983). This pattern is similar to that observed in re-established plant communities on mine spoil; these tend to be highly productive for two to five years followed by a sharp decline in plant growth and nutrient availability (Schafer and Nielsen, 1978). Application of topsoil, previously removed from the surface of the site and stored during construction, is generally expected to enhance revegetation success and to promote establishment of a persistent vegetative cover.

0898–5812/93/010045–13$11.50

Received 18 September 1992
Revised 4 November 1992

Reapplication of topsoil to subsurface materials enhances the re-establishment of vegetation by increasing nutrient availability, water-holding capacity and microbial activity (Hargis and Redente, 1984). These characteristics accelerate the biological conversion of dead plant materials into new soil organic matter. If the total nutrient availability is low, rapid cycling is necessary to maintain a pool of available nutrients for plant growth (Skeffington and Bradshaw, 1981). Soil microbes catalyse these cycling processes and also form a substantial pool of available nitrogen. Myrold (1987) showed that microbial biomass was the primary source of available nitrogen as indicated by the commonly used anaerobic nitrogen mineralization assay. This assay, which involves a one week, 40° C, anaerobic incubation, is well correlated with plant nitrogen availability in many forest and agricultural studies.

Topsoil can also provide mycorrhizal spores and hyphal fragments which serve as an inoculum for infection of the colonizing plant roots. These mycorrhizae assist plants in the acquisition of nutrients, although it is unclear if mycorrhizal infection allows access to additional pools of phosphorus compared with uninfected plants or if the same pools are merely exploited more efficiently. Bolan, *et al.* (1984) found that increased phosphorus uptake did not deplete soil solution or extractable phosphorus levels, indicating that the mycorrhizae had access to additional, separate phosphorus pools. Jurinak, *et al.* (1986) hypothesized that mycorrhizal fungal-produced oxalic acids accelerate weathering and phosphorus release from soil minerals. Other workers maintain that nutrient pools are qualitatively the same for both infected and uninfected plants (Sanders and Tinker, 1971) and that it is the greater density and surface area of the mycorrhizal hyphae compared with the uninfected root which allows more efficient nutrient uptake per unit soil volume (Allen, 1991: pp. 46–49). As mycorrhizal fungi increase phosphorus and micronutrient uptake and are critical for plant growth on low nutrient sites, the spores and infected root propagules, which are often missing from the barren construction site soils, must be reintroduced.

Attempts to restore permanent plant communities have often involved additions of vaious types of organic material and microbial inoculum. For example, mycorrhizal infection on processed oil sands has been increased by peat amendment (Zak and Parkinson, 1982). Visser, *et al.* (1978) found that introduction of a non-labile carbon source such as peat or sewage sludge increased microbial biomass in mine spoils whereas inorganic fertilization did not. In a review of mine spoil reclamation, Hargis and Redente (1984) cite topsoil reapplication depths of 10 to 76 cm. Although details of the relationships between soil organic matter, soil micro-organisms and nutrient cycling may not be well understood, microbial biomass can be used as a relative indicator of the degree of disturbance or recovery of soil nutrient cycling capacity (Smith and Paul, 1990). Consequently, many experiments have attempted to link soil properties to indices of microbial biomass.

Application of topsoil and chipped brush has enhanced revegetation at several California Department of Transportation revegetation sites (Clary, 1983). However, analytical measurements of soil, plant and microbial components have not been made at these sites. As the process of harvesting, stockpiling and reapplying topsoil involves considerable expense and effort, research results from areas with topsoil applications would provide the necessary information for cost-benefit analysis and would indicate possibilities for improvement in the efficiency of the process. The effects of placing topsoil in stockpiles during construction were also of interest since in other studies the quality of the material for revegetation has been found to decrease with storage (Rives, *et al.*, 1980; Stark and Redente, 1987). This study was designed to evaluate changes in microbial biomass, mycorrhizal infection and plant growth which occur during the process of soil handling and revegetation of highway construction sites.

MATERIALS AND METHODS

Field study

The field site used in this study was located at a California Department of Transportation highway construction project on Interstate-5 approximately 60 km north of Redding, CA. The geography of the area consists of steeply dissected foothills covered by a mixed black oak (*Quercus kelloggii*) and ponderosa pine (*Pinus ponderosa*) woodland with an understory of manzanita (*Arctostaphylos patula*) and herbaceous species. The elevation is approximately 550 m and annual precipitation averages 1300 mm.

Winters are cool and wet whereas summers are hot, often with extended drought. Soil parent materials are metasediments with some volcanic materials. Soil at the site was classified as a fine loamy mixed mesic Ultic Haploxeralf and is located on an isolated, uniformly sloping (5 degree slope) terrace with a southeastern aspect.

Site preparation began with removal of the vegetative cover of oak, conifer and manzanita. The surface 20 cm of soil (forest floor O and A horizons) was then scraped off by heavy machinery in May 1989, formed into a windrow and pushed to a storage area immediately adjacent to the construction site. A variety of organic matter became incorporated into the soil as a result of stockpiling, including forest floor duff, litter and fine and coarse root material. The soil remained moist for the five months of storage and had no plant cover during this period. Internal temperatures reached 40° C due to the decomposition of organic residues.

Revegetation plots approximately 8 m square were established on the outside of an elevated road grade which was constructed on the cleared site using crushed, unweathered, subsurface fill material. Final slope angles ranged from 34 to 45 degrees above horizontal and had a south to southeast aspect. In November 1989, stockpiled topsoil was removed from the storage area and spread down the face of the slope by a backhoe to a depth of 10 cm after settling. Plots of unweathered subsurface fill material received no topsoil amendment and served as a control for the topsoil treatment. Seed and fertilizer were applied to plots treated with 0 and 10 cm topsoil according to standard specifications for road side revegetation used by the California Department of Transportation. This treatment includes fertilizer application of 168 kg ha^{-1} of 16–20–0 (NPK) and 280 kg ha^{-1} of 0–20–0 (NPK) formulations. These amounts provide 27 kg N ha^{-1} and 39 kg P ha^{-1}. Erosion control grasses seeded included zorro foxtail fescue (*Vulpia myuros*), sherman big bluegrass (*Poa ampla*), berber orchardgrass (*Dactylis glomerata*) and luna pubescent wheatgrass (*Agropyron trichophorum*). Legumes seeded were crimson clover (*Trifolium incarnatur*) and rose clover (*Trifolium hirtum*). The site was then covered with blown barley straw at a rate of 3360 ka ha^{-1}. Despite these erosion control treatments, heavy rain caused slumping and rilling on some of the replicated plots. Little further erosion occurred during subsequent rains after the topsoil and fill materials had settled and compacted, but shallower slopes are strongly recommended.

Greenhouse study

Although the field plots were used for validation, experimental treatments under more controlled conditions were conducted in a greenhouse study. Representative samples of natural undisturbed soil, stockpiled soil and fill material were collected at the study site, sieved to <6 mm and transported to the greenhouse to study plant response to topsoil volumes and treatments. Mixtures of topsoil and fill materials were prepared in which topsoil accounted for 0, 5, 20, 40 or 60 per cent of the total soil volume in 1·2 l plots. Although the same fill material was used in all treatments, qualitative differences between different topsoil materials was investigated by amending with either fresh topsoil ('fresh' treatment), fresh topsoil which had been air-dried for one week at 35° C ('dried'), or stockpiled topsoil ('stockpiled').

The effect of the standard fertilizer application on plant growth at the revegetation site was simulated by the addition of three fertilizer levels to a mixture of stockpiled soil and fill material. Treatments included zero added fertilizer (stockpiled treatment), 50 μg N and P g^{-1} soil (single) and 100 μg N and P g^{-1} soil (double). The single and double fertilizer application rates were designed to simulate one and two times the standard field fertilizer application levels. However, these rates are only approximate comparisons because of the difficulty of duplicating field leaching conditions and root volumes in greenhouse pot experiments. As plant root growth may be reduced near the soil surface and proliferate at lower depths in the pot soils, the topsoils were mixed uniformly with the fill material to test amendment effects rather than root distribution patterns.

Plant materials

Pubescent wheatgrass was used as a bioassay for plant growth and mycorrhizal infection. Plants were seeded in mid-December 1989 using supplemental lighting to extend their photoperiod to 14 hours. Seedlings were thinned to three uniform sized seedlings per pot, with three replicate pots per experimental unit. The 75 pots (five topsoil mixtures × five soil treatments × three replications) were arranged in a completely randomized grid in the greenhouse and were bottom irrigated as needed. Plants were harvested in late March 1990 and dry matter production was determined after drying to constant weight at 65° C.

Statistical analysis

All experimental treatments and laboratory analyses were replicated three times. Statistical analysis of data from preliminary analysis of soils (Table I) was evaluated using analysis of variance with mean separation significance established by LSD ($p < 0{\cdot}05$) (Little and Hills, 1978). Analysis of greenhouse experiments (Tables II–VI) was performed by analysis of variance with mean separation comparisons by Newman–Keuls multiple comparison test (Systat Inc., Evanston, IL, USA). Some data sets were transformed as needed to reduce non-homogeneity of variance residuals. When analysis of variance indicated significant interaction effects, the means of the main effects were not analysed for significance; rather, the means of individual experimental units were rank ordered and means were compared by the Newman–Keuls test.

Soil tests

Fresh, dried and stockpiled topsoils and the fill material were evaluated in a preliminary analysis to determine possible nutrient deficiencies or toxic metal concentrations. Nutrient cations were extracted with 1 M NH_4Cl extract (pH 4·5) and determined by atomic absorption spectrometry using a La–CsCl matrix (Janitzky, 1986). Sulphate sulphur was determined from a water extract by ion chromatography (Dionex Series 4500i, Sunnyvale, CA, USA). Potential metal toxicity was evaluated by measuring concentrations of Cr, Mn, Ni and Zn extracted with dilute sulphuric–hydrochloric acid with quantitation by inductively coupled plasma atomic emission spectrometry. These elements were monitored for increased concentrations in the soil material as they occur in high concentrations in the serpentinitic rocks which were occasionally mixed with the fill material. Cation-exchange capacity was determined by ammonium nitrate saturation (pH 4·5), with analysis of retained ammonium by continuous flow, conductimetric analysis (Carlson, 1978). Soil acidity was measured with 0·01 M $CaCl_2$.

Total nitrogen including NO_3^- was measured by micro-Kjeldahl digest (Bremner, 1965), and mineralizable nitrogen was determined by anaerobic incubation (one week at 40° C) and extraction with 2 M KCl (Waring and Bremner, 1964). All extracts were analysed conductimetrically for NH_4–N.

Phosphorus availability was evaluated using mixed dilute sulphuric and hydrochloric acids (Nelson, *et al.*, 1953). Total, inorganic and organic phosphorus was determined according to Mehta, *et al.* (1954). The colour of the phosphomolybdate complex was developed by reduction with ascorbic acid after extracts were neutralized with NaOH.

Microbial tests

The influence of treatments on an index of microbial biomass carbon and nitrogen was measured by the fumigation–extraction method (Tate, *et al.*, 1988; Sparling and West, 1988) using a 0·5 M K_2SO_4 extracting solution and a five-day chloroform exposure. The extended five day exposure was used rather than a 24 hour fumigation period and a published k_c value (extraction coefficient, Vance, *et al.*, 1987) because no previous information was available for the extraction efficiency of microbial lysates from these acid, forest floor soils. As other studies showed a plateau of microbial lysate yield at five days (Brookes, *et al.*, 1985a;b; Davidson, *et al.*, 1989) this period was chosen to provide an index of microbial biomass for internal comparisons within these treatments. Carbon was determined by dichromate reduction (Mebius, 1960). Nitrogen was determined conductimetrically after digestion to reduce all extracted nitrogen to ammonium.

The inoculum potential of the various soil treatments in the greenhouse study was evaluated by bioassay using pubescent wheatgrass or, for field samples, by examining roots washed from soil and retained on a 250 μm sieve. Mycorrhizal infections were analysed by clearing root tissue in KOH (to make it translucent) and staining with trypan blue–lactic acid which colours fungal material (Phillips and Hayman, 1970). The samples were processed in batches with each sample contained within a screened syringe (Claassen and Zasoski, 1992). Infection was measured by a modification of the visual method of Giovannetti and Mosse (1980) using the mean of at least 100 counts to calculate the percentage infection for each experimental unit. Roots were contained in a square Petri dish with a grid of 1 cm squares. Roots were scanned at 60 × magnification while following the grid pattern. Roots crossing the 0·3 cm diameter microscope field were tallied for the presence or absence of infection. Samples showing infection were often verified under a compound scope at 100 to 400 × magnification. This method allowed the rapid scanning of large numbers of roots in which infection was low. Because the revegetation species are VA-mycorrhizal symbionts, a VA-mycorrhizal host was used for the bioassay even though ectomycorrhizal fungi were likely to be present in association with the oaks and conifers on the site.

RESULTS AND DISCUSSION

Soil data: soil treatments

The four soil treatments (fresh, dried, stockpiled and fill material) were evaluated for nutrient and metal concentrations to screen for deficiencies or toxicities which would influence plant growth (Table I). Topsoil materials and fill material had equivalent levels of pH, cation exchange capacity (CEC), extractable phosphorus, calcium, magnesium, sulphate and chromium (0·02 $\mu g\ g^{-1}$). Total and inorganic phosphorus and potassium in the fill material were approximately 50–60 per cent of the fresh topsoil values. Total nitrogen, mineralizable nitrogen and organic phosphorus in the fill material were only 3–6 per cent of topsoil amounts. Nickel was the only element higher in the fill material (0·39 $\mu g\ g^{-1}$) than in the topsoil materials (0·14 $\mu g\ g^{-1}$) but concentrations were not high enough to be phytotoxic (Welch, 1981). The soils lacked potentially toxic concentrations of those elements which might have weathered from serpentinitic parent materials. As no mining activity occurs in the area and the landscape is well drained, no other elemental toxicities were observed or evaluated. Aside from very low nitrogen and phosphorus levels relative to agricultural situations, the soils appeared to be acceptable for plant growth.

Table I. Soil analysis for unmixed fresh, dried and stockpiled topsoil and subsoil fill material. All values are means of three samples. Values in each row followed by the same letter did not differ significantly ($p<0·05$) as indicated by analysis of variance with mean separation by least significant difference. All values in mg kg^{-1} except CEC (in cmol kg^{-1}) and pH

	Soil treatment			
Soil variable	Fresh	Dried	Stockpiled	Fill
pH	4·6a	4·6a	4·7a	4·7a
CEC	24·3a	25·3a	21·7a	22·0a
Total N	1865a	1823a	1570a	72b
Mineralized N	43·4a	32·6b	39·6a	1·2c
Total P	617a	537b	479c	302d
Inorganic P	487a	419a	357b	302b
Organic P	129a	117a	122a	8b
Extractable P	0·78a	0·76a	0·70a	0·64a
Ca	1333a	1264a	1272a	1329a
Mg	221a	180a	188a	210a
K	859a	879a	938a	404b
SO_4^{2-}	9·8a	8·3a	11·7b	8·1a

Drying and stockpiling of fresh topsoil had non-significant effects on all soil characteristics except total phosphorus, inorganic phosphorus, sulphate, and mineralizable nitrogen. Mineralizable nitrogen decreased in dried soil but not in stockpiled soil. The differences in phosphorus and sulphate, and possibly the slight reduction in total nitrogen concentrations between the soil treatments may result from mechanical harvesting of the stockpiled soil versus hand sampling of the fresh and dried material. A greater proportion of subsurface horizon material was incorporated into the stockpile than was collected in samples of fresh topsoil. Reductions in total and mineralizable nitrogen resulting from stockpiling of fresh topsoil were small and non-significant. Stockpile storage for this length of time appears to have no detrimental effects on topsoil quality.

Soil data: greenhouse experiment

The addition of various topsoil materials in greenhouse treatments resulted in organic carbon levels ranging from 4 g kg^{-1} (0 per cent topsoil mixture) to 21 and 32 g kg^{-1} (40 per cent and 60 per cent topsoil mixtures). Stockpiling did not reduce the organic carbon levels significantly. Organic carbon levels in the field samples (0–10 cm) were 6 and 37 g kg^{-1} in the fill material and topsoil-amended plots. The 60 per cent topsoil greenhouse treatment most closely represented the reapplied topsoil material in the field plots. The mean values of soil pH in the greenhouse experiment ranged from 4·9 to 5·1.

Although total nitrogen was slightly reduced by stockpiling (Table I), no significant differences between fresh and stockpiled soil were measured at harvest (Table II), indicating small and temporary effects from stockpiling. At the conclusion of the experiment, both total and mineralizable nitrogen increased with topsoil addition but not fertilizer addition (Tables II and III). Maintenance of increased mineralizable nitrogen even after an intensive growing cycle indicates that topsoil provides a longer term

Table II. Total nitrogen contained in soils at harvest of greenhouse soil treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Interaction between main effects is significant ($p<0·05$) preventing statistical comparison of main effects. Values in the table followed by the same letter are not significantly different based on Newman–Keuls multiple comparison analysis of ranked averages following $\log_{10}$ transformation. Values in mg N kg^{-1}

	Topsoil added to fill material (%)					
Treatment	0	5	20	40	60	Mean
Fresh	42·3a	54·7a	119·0b	141·7b	264·9c	124·3
Dried	42·7a	62·0a	145·8b	216·3c	217·3c	136·8
Stockpiled	45·3a	54·7a	108·6b	208·4c	270·8c	137·6
Single fertilization	49·5a	60·9a	121·7b	220·6c	212·1c	133·0
Double fertilization	52·8a	67·0a	122·0b	209·9c	300·2c	150·4
Mean	46·5	59·7	123·4	199·4	253·0	

Table III. Mineralizable nitrogen (anaerobic incubation) at harvest of greenhouse soil treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Interaction between main effects is significant ($p<0·05$) preventing statistical comparison of these values. Values in the table followed by the same letter are not significantly different based on Newman–Keuls multiple comparison analysis of ranked averages following square root transformation. Values in mg N kg^{-1}

	Topsoil added to fill material (%)					
Treatment	0	5	20	40	60	Mean
Fresh	0·17b	0·15b	0·58b	1·54d	4·29f	1·35
Dried	0·05a	0·31b	0·48b	1·45d	3·96f	1·25
Stockpiled	0·18b	0·17b	0·52b	1·87d	3·84f	1·32
Single fertilization	0·18b	0·18b	0·40b	1·53d	2·86e	1·03
Double fertilization	0·25b	0·15b	0·63b	1·05c	3·05e	1·02
Mean	0·17	0·19	0·52	1·49	3·60	

Table IV. Index of microbial biomass nitrogen (five day fumigation) at harvest of greenhouse soil treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Non-significant interaction between main effects ($p<0.05$) allows statistical comparison of main effects. Row and column means which are followed by the same letter are not significantly different based on Newman–Keuls multiple comparison analysis of ranked averages following square root transformation. Values in mg N kg^{-1}

	Topsoil added to fill material (%)					
Treatment	0	5	20	40	60	Mean
Fresh	0·42	0·73	−0·32	1·54	1·06	0·69 NS
Dried	−0·21	0·61	−0·64	0·96	3·87	0·92 NS
Stockpiled	0·44	0·10	−0·24	0·52	1·76	0·52 NS
Single fertilization	0·33	0·11	0·00	1·18	2·88	0·90 NS
Double fertilization	0·02	0·32	0·21	0·10	1·37	0·44 NS
Mean	0·23a	0·30a	−0·20a	0·86b	2·19c	

nitrogen source than the rapidly available inorganic fertilizer. Estimates of plant nitrogen content accounted for most of the added fertilizer. During decomposition, however, the nitrogen which is incorporated in plant material will be susceptible to leaching losses if the subsurface materials have low biological activity and retention capacity.

Leaching losses may be reduced by incorporation of nutrients into microbial biomass. Data from the greenhouse experiment indicated that microbial biomass was increased by topsoil amendment (Table IV), and that the amount of nitrogen in the microbial biomass averages about 60 per cent of the amount of nitrogen in the mineralizable nitrogen pool (Table III). This suggests that the mineralizable or 'available' nitrogen pool is related to microbial populations and that nitrogen availability will be improved if the revegetation project includes treatments which enhance microbial populations. Such treatments include the presence of partially humified organic matter which would moderate fluctuations in temperature and moisture. Establishment of perennial vegetation which maintains at least some root activity throughout the year is expected to increase microbial activity compared with the seasonal growth of annual grasses commonly used for erosion control.

Phosphorus levels were increased about the same amount by either topsoil or fertilizer addition (Table V). Measurements from the field plots showed similar increases in total phosphorus with topsoil addition, although the availability of these pools may be low. Although the plant available phosphorus (double acid extraction) was increased by topsoil addition, levels were less than 1 $\mu g\ P\ g^{-1}$. Nelson, *et al.* (1953) report that soils testing less than 10 $\mu g\ P\ g^{-1}$ by this method are phosphorus deficient.

Table V. Total phosphorus at harvest of selected greenhouse treatments and topsoil/fill material mixtures. Each experimental unit is the average of three replications. Non-significant interaction between main effects ($p<0.05$) allows statistical comparison of main effects. Row and column means which are followed by the same letter are not significantly different based on Newman–Keuls multiple comparison analysis of ranked values. Values in mg P kg^{-1}

	Topsoil added to fill material (%)		
Treatment	0	60	Mean
Stockpiled	330	424	337a
Double fertilization	395	502	449b
Mean	363a	463b	

Plant growth

Dry weight of non-fertilized pubescent wheatgrass increased significantly ($p < 0.05$) when topsoil/fill mixtures exceeded 20 per cent topsoil (Figure 1). Plant dry weight was six to ten times greater in the 60 per cent than the 0 per cent topsoil addition. The dry weight production was increased by about another order of magnitude with fertilizer addition. The combination of 60 per cent topsoil plus fertilizer treatments yielded the highest dry weight production. Plant growth did not differ significantly between 0 and 5 per cent topsoil additions in either fertilized or unfertilized treatments. This indicated that plant growth was not responsive to small topsoil amendments, but instead required greater than 20 per cent topsoil addition. Topsoil amendment may also have influenced plant growth by altering the bulk density, which was 20–30 per cent lower in the topsoil materials used for the greenhouse experiment than in the fill material.

The process of air drying or stockpiling fresh topsoil caused slight decreases in plant growth, but the effect is expected to be small relative to other constraints such as temperature and moisture conditions or fertilizer application. As soils in California can be expected to dry completely during the summer months, the comparison relevant to the field situation should be the dried versus stockpiled treatments, which do not show significant differences.

Plant growth in the greenhouse experiment increased 34 per cent between 0 and 60 per cent topsoil

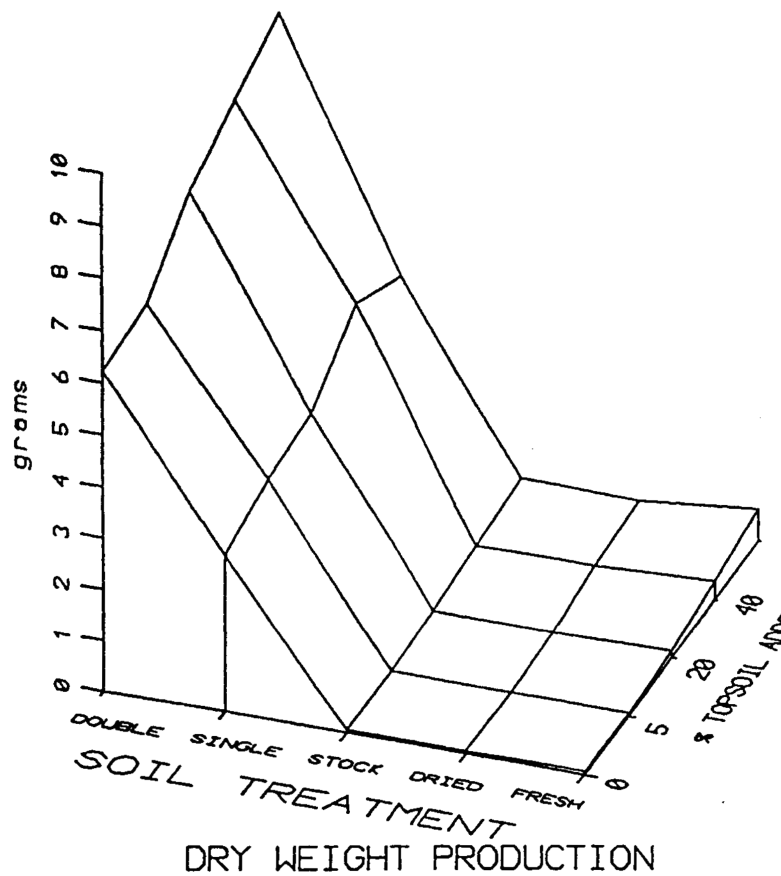

Figure 1. Dry weight production of pubescent wheatgrass as influenced by topsoil/fill material mixture and soil treatment. Each experimental unit is replicated three times. The mean separation is calculated from the analysis of variance and Newman–Keuls multiple comparison test. In unfertilized treatments (stock, dried, fresh), 20, 40 and 60 per cent topsoil mixtures are statistically different from the 0 and 5 per cent mixtures. Double and single fertilizer treatments are statistically different from the unfertilized treatments ($p < 0.05$)

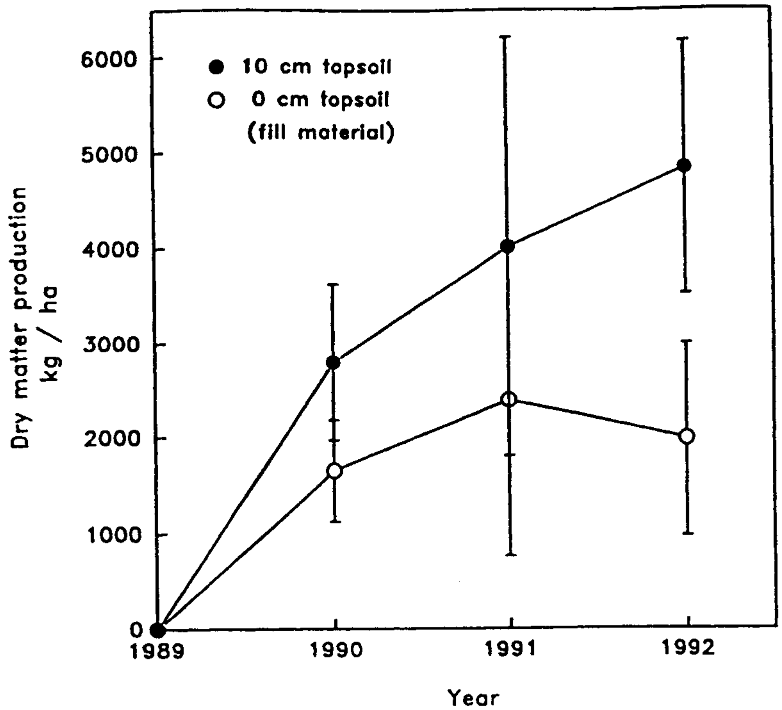

Figure 2. Dry matter production of grass and clover in field plots on fill material with either 0 or 10 cm topsoil amendments. Brackets indicate 95 per cent confidence intervals ($p < 0{\cdot}05$). Data in kg ha^{-1}

volume treatments. In the field, plant growth was increased 69 per cent between the 0 and 10 cm topsoil plots at the end of the first year of growth, yielding the equivalent of 1650 and 2787 kg ha^{-1} dry weight production (Figure 2). By the end of the third year the 0 cm (fill material) plot had 1980 kg ha^{-1} dry matter production and the 10 cm topsoil plot had 4833 kg ha^{-1}. Although the variability within the plots was great, a clear and significant trend is indicated where plant production reaches a plateau on the plots not treated with topsoil whereas plant growth on the plots treated with topsoil continues to increase.

Plant community composition also changed with topsoil amendment. The percentage of total plant dry weight production contributed by clover species decreased from 73 per cent in the 0 cm topsoil field plot to 47 per cent in the 10 cm topsoil. By the end of the third year of growth, clover contributed 90 per cent of the biomass production on the plot not treated with topsoil whereas on the plot treated with topsoil biomass was 93 per cent grass and only 3 per cent clover. These data indicate that either the clover species were more competitive in the nutrient-poor subsoil treatment or that grass species were better able to capitalize on the improved conditions available with the 10 cm topsoil amendment.

Mycorrhizal infection

The five month storage period used in this study caused no measurable loss of infection when comparing stockpiled soil to fresh topsoil (Figure 3). Previous studies generally involve longer storage periods. Singleton and Williams (1979) measured mycorrhizal infection which decreased from 68 per cent in a one year old stockpile to 24 per cent in an eight year old stockpile. Liberta (1981) also measured consistent decreases in mycorrhizal infection potential when an undisturbed old field with 85 per cent infection was compared with soil which had been stored for one, two or three years (57, 41 and 12 per cent infection). Rives, *et al.* (1980), measured a non-significant loss of infection potential in soils which had been stored for three years (91·7 per cent in undisturbed versus 81·7 per cent in stockpiled topsoil) but within the next 15 months the infection potential of the same stockpiled topsoil decreased to 50·4 per cent (Gould and Liberta, 1981).

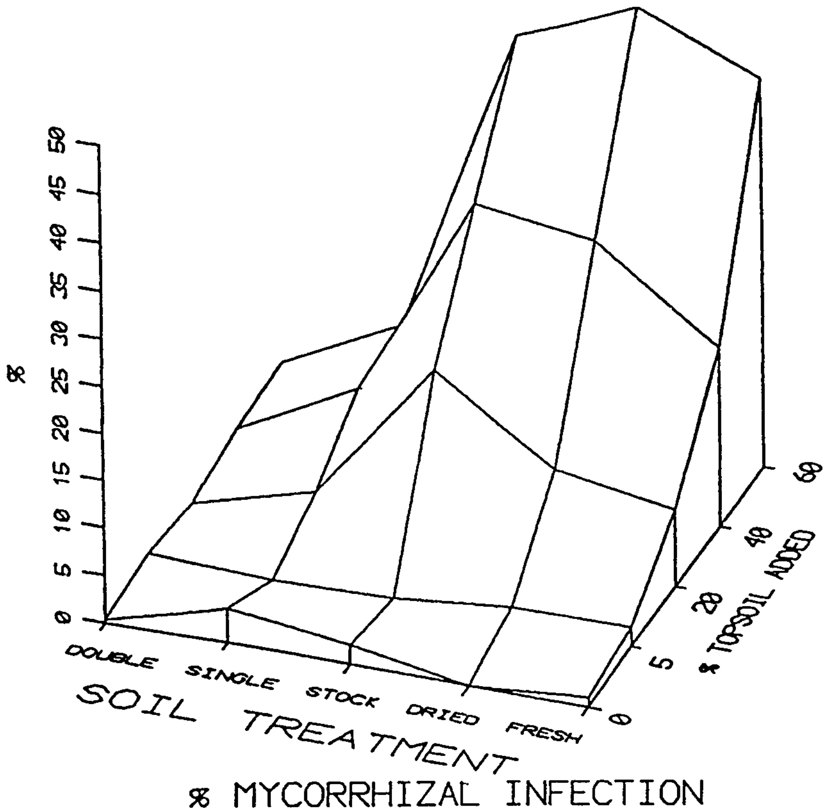

Figure 3. Percentage mycorrhizal infection of pubescent wheatgrass as influenced by topsoil/fill material mixture and soil treatment. Each experimental unit is replicated three times. The mean separation is calculated from analysis of variance and Newman–Keuls multiple comparison test. Double and single fertilizer treatments are statistically different from unfertilized treatments at 20, 40 and 60 per cent topsoil mixtures ($p < 0.05$)

Stark and Redente (1987) also measured decreased infection with storage. They noted that vegetated areas of the stockpile had a higher proportion of plant biomass composed of mycorrhizal-dependent shrubs. Portions of the stockpile which were not vegetated during storage had a higher percentage of the total plant biomass derived from grass species which were less mycorrhizal-dependent. Shrubs which grew on these previously non-vegetated soils had lower percentages of mycorrhizal infection.

In the current study, volumetric topsoil amendments in excess of 20 to 40 per cent significantly increased mycorrhizal infection. The 5 per cent topsoil additions showed no significant increase in infection between any of the soil treatments. A lack of infection response with small topsoil additions suggests that a limited amount of topsoil would be better used by being concentrated in small pockets rather than being spread as a thin blanket across the entire site. Saxerud and Funke (1991) found that uniform mixing of 10 per cent topsoil from vegetated surfaces of the stockpile with stockpiled material from 120 cm depth increased plant growth and infection, whereas a 1 per cent mixture increased infection but not plant growth, and a surface application of 1 per cent fertile stockpiled topsoil caused no infection or growth increases. Generalizing from these limited examples, a 10–20 per cent mixture of fertile soil material appears to be a lower amendment threshold. Fertile topsoil material should be placed in pockets or microsites at or above this minimum rate to allow the soil to retain its microbial activity, from which the rest of the site can eventually be colonized.

Topsoil application to field plots increased mycorrhizal infection of the grasses from 3·8 to 13·9 per cent. Mycorrhizal infection of clover species was more responsive to topsoil application. Infection increased from 3·0 per cent in the fill material to 31·8 per cent in the 10 cm topsoil treatments.

Although fertilization greatly increased plant growth, the higher fertilizer rates also caused a large

Table VI. Weight of mycorrhizal roots, calculated by multiplying percentage infection by root dry weight. Interaction between main effects is significant ($p<0.05$) preventing statistical comparison of these values. Values in the table followed by the same letter are not significantly different based on Newman–Keuls multiple comparison analysis of ranked averages. Values in mg per pot

	Topsoil added to fill material (%)					
Treatment	0	5	20	40	60	Mean
Fresh	0·3a	0·7a	8·2a	45·6b	130·7b	37·1
Dried	0·0a	0·6a	9·8a	77·0b	149·1b	47·3
Stockpiled	0·4a	0·4a	8·4a	62·9b	111·7b	36·8
Single fertilization	59·5b	10·3a	112·6b	249·1c	197·5c	125·8
Double fertilization	12·2a	37·5a	0·0a	67·3b	70·1b	37·4
Mean	14·5	9·9	27·8	100·4	131·8	

reduction in the percentage of roots showing mycorrhizal infection. With fertilization, infection differences between 0 and 60 per cent topsoil additions were not significant. The suppression of percentage infection with fertilizer amendment has been reported previously (Jasper, *et al.*, 1979; Hetrick, *et al.*, 1986; Saxerud and Funke, 1991).

Infected root material is the most efficient inoculum for subsequent spread of mycorrhizal infection (Hall, 1976; Rives, *et al.*, 1980). Therefore, the treatments were also evaluated on the basis of total infected root material. These data were generated by multiplying the percentage infection by the mass of dried root material. Large increases in plant size and root production in single fertilizer treatments more than compensated for the reduced percentage infection (see Table VI). The total amount of infected root material increased significantly ($p<0.05$) in the single fertilizer application treatment. Although the double fertilizer application further increased plant growth, the percentage infection as well as the total mass of mycorrhizal roots was reduced. An evaluation of the total amount of infected root material is a more meaningful index for revegetation success than a percentage ratio of infection on what may be a few small plants (Gerdemann, 1968; Neill, 1974). Under the conditions of this experiment, plant growth and inoculum production were increased with moderate fertilization, indicating a role for starter fertilizer in the establishment of both plant cover and mycorrhizal infection on nutrient-poor soils. Under field conditions, rapid establishment of mycorrhizal infection on plant roots increases phosphorus availability and water uptake from construction soils which are often infertile and droughty.

CONCLUSIONS

Reapplication of topsoil to fill slopes in conjunction with moderate fertilization has been shown to increase and sustain plant growth, mycorrhizal infection and microbial activity relative to treatments with fertilizer but no topsoil. Topsoil additions can serve as a source of nutrients and mycorrhizal inoculum for revegetation of biologically inactive and nutrient-poor construction fill materials. Plant growth on the topsoil amended field plots continued to increase through the third year after establishment whereas plant growth on the plot without topsoil (fertilizer only) appeared to stabilize at about 40 per cent of that in the plot treated with topsoil. Storage for six months in a stockpile had little impact on topsoil quality.

In the greenhouse experiment, topsoil effects became statistically significant when topsoil made up greater than 20 per cent of the total soil mixture. Topsoil mixtures of 40 to 60 per cent may be biologically important in field applications. Moderate levels of fertilizer increased plant growth and increased the total mass of mycorrhizal infected roots, even though the percentage of infected roots decreased with fertilization. Microbial biomass nitrogen was a significant fraction of the mineralizable nitrogen pool. At the conclusion of the experiment, mineralizable nitrogen was nearly zero in the double fertilized treatments, whereas in the topsoil treatments the mineralizable nitrogen was over ten times greater.

Total production of mycorrhizal root material is critical as these propagules are the inoculum source for infection and growth in subsequent seasons. For this reason, barren sites should be managed for maximum total infected root material, as opposed to maximum percentage of infection. This objective is met with the moderate fertilization and topsoil amendment in the conditions of this study. Where the volume of topsoil is limited, concentration of topsoil in small pockets is expected to allow increased retention of the biological activity of the soil, as opposed to spreading the topsoil thinly over the entire surface of the site. Such microsites would also reduce the required volume of topsoil substitutes such as composts or sludge for projects where topsoil is unavailable.

ACKNOWLEDGEMENTS

This study was supported by the California Department of Transportation. We thank John Haynes of the California Department of Transportation, Division of New Technology, Materials and Research, for arranging funding and field assistance, and Larry Orcutt, resident engineer, District 2, for access to the site and heavy equipment. The soil description was provided by Terence Huff. The comments of several anonymous reviewers are appreciated.

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