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Elemental Drain of Fertility from a Sierra Mixed Conifer Forest Site due to Intensive Harvest of Fuels

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INTRODUCTION

There is concern about the added drain on site fertility by more intensive harvest of fuel materials from forest sites. At present, there is a lack of site-specific data on the storage of nutrient elements in the small-diameter forest residues that would be harvested in an intensive fuel harvesting program. Normally these small-diameter materials would be returned to the forest soil as slash, and their nutrient element contents of nitrogen, phosphorus, calcium, magnesium, potassium, iron, manganese, zinc, and other elements, would be returned to the soil following gradual decay. This decay would oxidize most of the organic compounds in the slash, although some slow-decaying compounds would remain as organic matter in the soil. Hence, the normal decay of small-diameter forest residues returns both fertile elements and organic compounds to the soil, adding to the soil ion exchange capacity. Also, it possibly changes pH, oxidation-reduction potential, carbon/nitrogen ratio of the soil and other characteristics.

This paper reports the results of a study conducted to determine the contents of fertile elements in different size classes of residue remaining in the forest after timber harvest.

Background

The fertile elements of a forest site are stored in the soil, in the tree crop as it grows while taking up these elements, and in the detritus which decays on the soil surface. The removal of various portions of the forest in harvest operations may remove significant parts of the fertility of the site, for example, a concern during the last century in central Europe was the common practice of farmers removing the surface detritus of a forest (leaf litter) for the fertilization of fields (Ebermayer, 1876). The result was a deterioration of site quality due to fertile element removal. A similar question now arises with regard to the intensive harvest of forest biomass being proposed in field programs.

Soil storage is an important determinant in the relative removal of elements from the site. Such soil storage of elements can be estimated from data provided by the California Soil Vegetation Survey (Zinke, 1960); Colwell, 1974), which has mapped many million acres of California forest soils, and has supported work on the chemical analyses of these soils at U.C. Davis. These maps and laboratory analyses allow an estimate to be made of the elemental storage in soils typical of each site. These data are available in maps and on microfiche (Zinke and Stangenberger, 1975). The nutrient storage in vegetation when related to this soil background storage allows an assessment of relative nutrient drain from a site.

An example of the proportionate storage of available fertile elements on a range of California forest sites from high-site redwood to low-site lodgepole pine was presented by Zinke et al. (1979). These data indicate that there will be an increasing drain of fertility from the site as a greater proportion of the forest vegetation is harvested. Of course, this occurs yearly in agriculture, but periodically at spacings of decades of time in forestry; less frequently in clearcutting, but more often and with less intensity with gradual selective cutting. To answer the questions concerning element drain, estimates of fertile element compositions by size class are needed.

Procedure

The California Department of Forestry conducted a logging residue and slash collection study in the Central Sierra Nevada in compartment 500U of the Blodgett Forest Research Station of the University of California (Parker and Stine, 1979). The area is located 30 miles east of Auburn at 4,000 feet elevation. Species composition, site, and soil types for the area have been mapped on the Soil-Vegetation and Timber Stand Map of Blodgett Forest Research Station by Crawford and Alexander (1965). The soil map indicated that the soil of this compartment is Holland Series, an ultic heploxeralf residually derived from the weathering of granitic rock. The map indicates in order of decreasing abundance white fir, incense cedar, Douglas-fir, sugar pine, and ponderosa pine as young-growth of sawlog size from a past logging operation, with a few old-growth residual trees. Timber harvest has occurred three times in the past 16 years and the present residue material is the result of these past operations plus any snags and damaged residual trees left on the site.

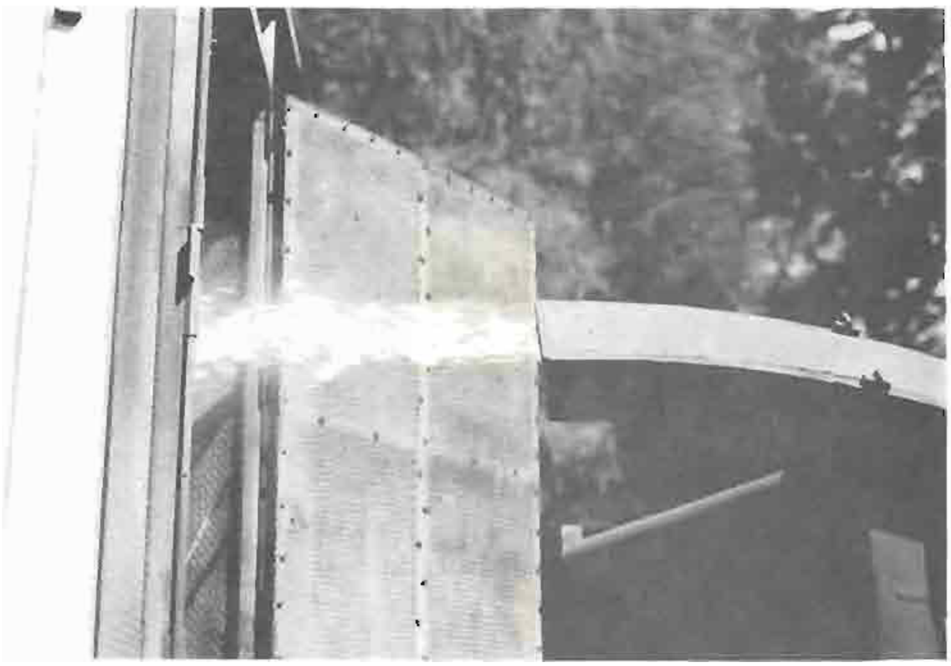
Residue material in ten plots on the area was inventoried for weight by size classes 0-4, 4-8, and greater than 8 inches. Samples of the materials were taken from five points at 20-foot intervals on a 100-foot transect in each plot. The material was chipped for utilization as fuel (except for log-sized debris), and 76 samples from each of the three size classes of the chipped material were analyzed individually to determine the mean elemental composition of debris of each size class.

Careful measurement of logging residue was made along transects.

In all, 227 samples of residue were collected and analyzed for nine elements. The samples were ground in a Wiley mill to pass a 20-mesh sieve. The ground samples were analyzed for nitrogen by the micro-Kjeldahl method, and perchloric acid digestates were prepared by the method of Johnson and Ulrich (1959). The acid digestates were analyzed for phosphorus content by the molybdenum blue method, and for the remaining elements (calcium, magnesium, potassium, sodium, manganese, iron, and zinc) by atomic absorption spectrophotometry. These data were then computer processed to obtain elemental weight per square meter as contained in the various size classes of residue on each plot, and in the wood chip samples.

RESULTS

Wood Chip Composite Data



The residue was chipped and used as hogfuel.

The ultimate fate of the residue material was to be chipped and used as fuel at the nearby Michigan-California Lumber Company mill at Camino, California to produce steam. The aggregated data for the wood chip samples are shown in Table 1. These data were also used for an estimate of removal of fertility elements from the site. A total of 873.3 dry tons of material were removed from 42 acres, or 20.8 dry tons per acre (41,580 pounds per acre). Estimated elemental removal rates, calculated with this assumed value are shown in the last column of Table 1. Thus the data indicate a removal of 54 pounds per acre of nitrogen, 20 pounds per acre of potassium, etc.

Table 1: Mean elemental content of 72 wood chip samples from Blodgett Experimental Forest compartment 500U logging residue and elemental weight per acre assuming 41,580 pounds per acre dry weight.

	N (pct.)	P (ppm)	Ca (pct.)	Mg (pct.)	K (pct.)	Mn (ppm)	Fe (ppm)	Zn (ppm)
Std. Dev.	.13	52.5	.10	.018	.049	54.5	33.6	7.8
Std. Dev.	.02	26.2	.05	.007	.026	43.1	26.0	4.2
Weight (est.) (lb/acre)	54.	2.2	41.6	7.5	20.4	2.3	1.4	0.3

Data by Size Class Breakdown

The composite approach encompassed all the variation on the site. Since the samples were taken from each plot by size classes, it is of interest in each plot to see how size class weight varied as well as how residue weights varied. The data in Table 2 show, in general, a total per acre removal about twice as great as that estimated by the wood chip composite method. For example, according to Table 2, total nitrogen removal is 114 pounds per acre, and phosphorus removal is 4.0 pounds per acre. The major reason for this difference is that the weight of 74937 pounds per acre used in Table 2 is 1.8 times the estimated fuel collection reported for the area in Table 1 (Parker & Stine, 1979). Wood chip estimates were lower due to less intensive utilization by the chipper.

Table 2: Nutrient Weights in Blodgett Forest Fuel Study Compartment 500U

Weights in grams per square meter; to convert to pounds per acre, multiply grams by 8.92, or mg. by .00892.

Size (in.)	Weight grams	N gm.	P mg.	Ca gm.	Mg gm.	K gm.	Mn mg.	Fe mg.	Zn mg.
Plot 2									
0-4"	1112	2.0	80.2	1.6	0.18	0.28	61.8	81.6	19.1
4-8"	894	1.3	64.1	0.6	0.09	0.33	29.1	36.5	11.3
8-12"	5482	7.3	419.4	1.8	0.77	3.40	153.5	252.2	71.3
TOTAL	7488	10.6	563.6	4.0	1.04	4.01	245.4	370.3	101.7
Plot 4									
0-4"	2374	4.6	128.2	3.6	0.54	0.54	314.2	163.8	21.4
4-8"	762	1.0	16.8	0.3	0.08	0.26	33.5	46.2	7.4
8-12"	8196	9.8	259.5	5.2	1.10	7.00	568.2	330.6	65.6
TOTAL	11232	15.4	404.5	8.1	1.72	7.80	915.9	540.6	94.4
Plot 8									
0-4"	2038	3.2	84.8	1.9	0.37	0.65	164.2	180.0	17.9
4-8"	919	1.6	70.0	0.6	0.16	0.67	53.1	55.8	12.2
8-12"	4934	6.4	138.2	2.2	0.48	3.03	207.2	238.5	39.5
TOTAL	7891	11.2	293.0	4.7	1.01	4.35	424.5	474.3	69.6
Plot 10									
0-4"	1464	2.8	74.3	2.9	0.41	0.31	141.3	197.2	14.6
4-8"	260	0.5	12.90	0.5	0.05	0.23	30.8	10.3	2.5
8-12"	4923	7.9	195.9	5.2	1.22	2.04	405.6	194.0	37.4
TOTAL	6647	11.3	283.1	8.5	1.69	2.58	577.7	401.6	54.6
Plot 12									
0-4"	2349	3.3	169.6	5.2	0.63	0.34	210.0	59.0	29.6
4-8"	2058	2.8	88.1	1.5	0.28	0.68	21.8	54.8	15.2
8-12"	782	0.9	40.7	0.4	0.10	0.26	10.2	9.1	5.0
TOTAL	5189	7.0	298.4	7.1	1.01	1.28	242.0	122.9	49.8
Plot 13									
0-4"	1092	2.2	57.2	1.8	0.28	0.19	115.0	97.4	9.2
4-8"	1715	2.7	75.5	1.9	0.37	0.97	196.0	66.5	11.7
8-12"	2892	4.2	186.2	5.5	0.84	2.39	492.0	159.0	19.1
TOTAL	5699	9.1	318.9	9.2	1.49	3.55	803.0	322.9	40.0
Plot 14									
0-4"	1036	1.8	75.4	3.2	0.25	0.24	135.0	77.2	14.5
4-8"	1802	2.8	97.0	2.3	0.37	0.92	159.0	35.3	16.6
8-12"	10900	18.4	647.2	12.8	2.59	7.35	1308.0	286.8	98.3
TOTAL	13738	23.0	829.6	18.3	3.21	8.51	1602.0	399.2	129.4
Plot 20									
0-4"	1814	3.1	112.4	2.4	0.45	0.42	163.0	114.0	14.5
4-8"	511	0.7	28.4	0.6	0.08	0.14	15.0	20.0	3.3
8-12"	7003	10.8	472.7	3.9	0.91	3.01	175.0	170.0	59.5
TOTAL	9328	14.6	613.5	6.9	1.44	3.57	353.0	304.0	77.3

Mean Total Weight per square meter

Weight grams	N gm.	P mg.	Ca gm.	Mg gm.	K gm.	Mn mg.	Fe mg.	Zn mg.
8401	12.8	450.6	8.4	1.58	4.4	645	367	77

Mean Total Weight, pounds per acre

Weight	N	P	Ca	Mg	K	Mn	Fe	Zn
74937	114	4.0	75	14	40	5.8	3.3	0.7

Relation to Site Fertility

The relevance of these data depends upon the magnitude of soil storage of the elements on the site. Table 3 shows the range of storage in 485 profiles of wildland soils analyzed by the California Soil-Vegetation Survey. Thus fifty percent of these soils have at most 640 grams of nitrogen per square meter stored to a one meter depth, while ten percent have 250 grams per square meter or less.

Table 3: Cumulative probability table of nutrient storage to one meter depth for wildland soil profiles analyzed by the California Soil-Vegetation Survey. (Example: 40% of wildland soils probably have 9 or less kilograms of Carbon per square meter to a meter depth.)

			Phosphorus mg/sq.m		Exchange Cations (equivalents per sq.m.)				
Percentile	Carbon kg/sq.m	Nitrogen g/sq.m	water sol.	bicarb. sol.	C.E.C.	Ca++	Mg++	K+	Na+
5	3	189	3	58	57	8	1	0.7	0.2
10	4	250	4	136	76	13	3	1.0	0.3
20	6	353	8	338	108	24	7	1.6	0.6
30	8	447	13	600	136	36	11	2.0	0.9
40	9	541	19	933	165	48	17	3.0	1.0
50	12	640	27	1360	195	63	25	4.0	1.6
60	14	750	38	1919	228	81	35	5.0	2.0
70	16	877	52	2689	266	102	48	6.0	2.6
80	19	1040	73	3849	315	133	69	7.0	3.4
90	23	1288	111	5993	388	184	106	9.0	5.0
95	27	1511	152	8297	454	233	146	12.0	6.0

Prepared from data of the Cooperative Soil-Vegetation Survey, California Division of Forestry (Zinke and Stangenberger, 1975).

To convert to pounds per acre, multiply tabled values as follows:

Nitrogen x 8.92

Phosphorus x .00892

Basic metallic cations x 8.92 x equivalent weight:

Calcium = 20, Magnesium = 12, Potassium = 39

Table 4 shows the estimated storage of fertility elements in the residues on the sample site. For comparison, the fiftieth percentile depth storage values on all sampled California wildland soils are shown, as well as the nutrient storage level in a Holland soil similar to the of the soil on the study site.

Table 4: Pounds per acre nutrient drain represented by various residue removal estimates in comparison with the 50th-percentile value of soil nutrient storage and with a typical Holland soil more than five feet deep.

	N	P	Ca	Mg	K	Mn	Fe	Zn
Nutrient drain:								
Wood Chip Estimate	54.0	2.2	41.6	7.5	20.4	2.3	1.4	0.3
Sample plot data	114.0	4.0	75.8	14.0	40.0	5.8	3.3	0.7
50th-percentile wildland soil:								
Storage	5710.0	12.1	11255.0	2663.0	1273.0			
Pct. drain	2.0	33.0	0.6	0.5	3.1			
Holland soil five feet deep:								
Storage	4664.0	16.3	8920.0	417.5	1454.0			
Pct. drain	2.4	25.0	0.8	3.3	2.7			

The results indicate that the worst potential drain is in the removal of phosphorus. For a typical Holland soil, the estimated phosphorus drain represents about one quarter of that found to be available as bicarbonate soluble phosphorus on the site. For the fiftieth-percentile wildland soil in California, the estimated phosphorus drain is about one-third of the total stored in the soil. Nitrogen, magnesium, and potassium are 2.4, 3.3, and 2.7%, respectively of the storage of these elements in the soil. Other elements are probably much less, although soil analyses are not available to substantiate this hypothesis. Thus if any fertility drain is potentially serious on this site it would be that due to phosphorus removal, and this could be especially serious on the 25% of California wildland soils which have less than four pounds (461 mg. x .00892) pounds per acre (as bicarbonate soluble) phosphorus. This may underestimate the ultimate amount available since the reserve phosphorus storage not measured by the bicarbonate soluble method may be considerable.

Carbon

There still remains the question of the organic matter drain. Fifty percent of California wildland soils have a carbon storage of 11.7 kg. or less per square meter, according to the distribution in Table 3. A Holland soil similar to that found on the sample site would have 15.7 kg. of carbon per square meter (Zinke and Stangenberger, 1975). From Table 2 we see that the average weight of detritus is 8.4 kg. per square meter. Assuming that this is 48% elemental carbon, the detritus on the site contains about 4 kilograms of carbon per square meter. This is equivalent to 25% of the carbon content of a soil similar to that of the study area. This carbon drain could be equivalent to more than the carbon contents of 10% of California wildland soils as seen in Table 3. But these sites may also be unattractive for intensive forest fuel harvesting.

Removal of logging slash reduces the fuel loading and reduces the threat of wildfire.

DISCUSSION

Results of this study show that for the study site, the phosphorus removal represented a possible serious drain of fertility on the site. As in other forms of agricultural harvest, this could be replenished with 4 pounds per acre phosphorus addition as fertilizer. However, it could also be ameliorated by favoring phosphorus-cycling species such as incense cedar, or altering pH to make phosphorus available from insoluble forms of soil phosphorus. Continuous removal of the organic matter may eventually result in a serious drain on soils already low in organic carbon.

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