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Sediment enrichment ratios after mechanical site preparation for *Pinus radiata* plantation in the Basque Country

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Abstract

The enrichment of organic matter, total nitrogen, phosphorus, and exchangeable calcium, magnesium, sodium, and potassium in runoff sediment was studied by means of sediment traps in two steep slopes (25–34°) for a period of 18 months after site preparation (scalping and down-slope ripping) for *Pinus radiata* plantation. Total nitrogen concentration was significantly higher in the source soils than in their sediments. Phosphorus, and exchangeable calcium, magnesium, and potassium concentrations were higher in the sediments, although not significantly. No relation was found between sediment enrichment ratios and total rainfall and rainfall intensity. Steep slopes and hydraulic soil-surface conditions favourable to runoff production are suggested to govern the high erosive power of runoff, which results in a nonselective displacement of soil particles. In spite of this lack of enrichment of the sediments, surface soil samples taken 18 months after site preparation showed significantly lower concentrations of organic matter, total nitrogen, phosphorus, and exchangeable magnesium, sodium, potassium, and aluminium, and higher aluminium saturation of the exchange complex in relation to samples taken before site

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preparation. Removal of the nutrient-rich organic and mineral surface horizons by scalping, rather than soil water erosion taking place afterwards, is the process responsible for most of the decrease in soil nutrient concentration occurring as a result of site preparation.

Keywords: land degradation; land use system; soil erosion; Spain

1. Introduction

Three land utilization types related to *Pinus radiata* D.Don plantations in the Basque Country (northern Spain) may be defined according to their different site preparation techniques after clearfelling. In the traditional system, slash is burnt and there are no machinery operations. The other two systems involve scalping in one case, or scalping plus down-slope ripping in the other. These mechanical site preparation techniques are becoming increasingly popular as a result of shortages of labour in the farms, and lower monetary cost of such techniques in comparison to the traditional system of slash burning. Materials displaced by scalping operations are accumulated along skid trails and stream banks instead of being redistributed within the site, as is the case in common windrowing operations. The result is the net loss of such material from the site.

Mechanical site preparation techniques that involve surface soil disturbance result in increased water erosion of soil. Pye and Vitousek (1985) and Blackburn et al. (1986) found that sediment losses after windrowing were greater than after chopping and burning of slash. Erosion rates higher than 150 Mg ha^{-1} $year^{-1}$ have been measured in steep plots prepared by scalping plus down-slope ripping in the Basque Country (Edeso et al., 1995). Furthermore, this system of site preparation leaves the soil without sufficient vegetation cover over a period that may exceed 2 years depending on the degree of disturbance (Olarieta et al., 1997). During that period, high erosion rates will still prevail.

Soil water erosion affects two main land qualities, i.e., water and nutrient availability (Biot, 1988). The selective character of the erosion process (Biot, 1988; Marston, 1989) implies that the limited kinetic energy of runoff only allows for the detachment of the finer primary particles (Sharpley, 1985) or the finer aggregates (Wan and El-Swaify, 1998), which are commonly associated with higher concentrations of nutrients. As a result, in agricultural systems, the eroded material has higher concentrations of nutrients and organic matter than the original soil (McDowell et al., 1980; Menzel, 1980; Sharpley, 1985). Degradation of soil water and nutrient availability thus cannot be sufficiently explained through estimates of total loss of soil mass, i.e., through the Universal Soil Loss Equation. We also need to take into account the sediment enrichment ratios (SERs), i.e., the relations between the nutrient, organic matter, and clay contents in the eroded soil and those in the source soil.

In this paper, we present the results of a study on the SERs in organic matter and nutrients as a result of mechanical site preparation techniques for *P. radiata* plantation in the Basque Country (northern Spain).

2. Materials and methods

The two sample plots were located on the same watershed (43°19′ N; 2°32′ W; 270 m altitude) in Amoroto (Bizkaia). The main characteristics of the two slopes are shown in Table 1. Soils have developed from siliceous mudstone, and are classified in both cases as well-drained, clayey, mixed, acid, mesic, shallow Typic Udorthents (Soil Survey Staff, 1992), or as Hyperdystric Regosols (FAO, 1998). The original sequence of soil horizons is O–A–C, rootable depth is 20–25 cm, and the main chemical properties of the A horizons are shown in Table 2. The A horizons have 20%–21% sand, 39%–44% silt, and 36%–41% clay. Climate in the region is humid temperate, with a mean annual rainfall of 1060 mm, and a mean annual air temperature of 12.7°C.

Site preparation operations were performed in August 1992. Slash was pushed aside towards branch roads and stream banks with a bulldozer working down-slope, while at the same time, soil was ripped. Ripping brought to the surface many fragments of the underlying mudstone, which occupied 15%–20% of the surface. No vegetation cover was left to protect the soil surface after preparation, and 2 years later, vegetation cover was just 40%–50% and mineral soil was exposed on 50%–60% of the surface. *P. radiata* pine seedlings were planted in the 1992–1993 winter.

Three samples of the mineral soil surface horizons (0–20 cm) were taken from each plot prior to site preparation. Between August 1992 and March 1994, samples were taken periodically (every 2–4 months, making seven sampling dates) from the soil surface (0–3 cm) and from sediments collected in reinforced natural traps at the bottom of the slopes (three traps per plot, each trap acting as a replicate). In March 1994, three samples were taken again from the soil surface horizons (0–20 cm). Soil samples were always drawn from five subsamples. Each sediment trap produced a separate sample, so that for each sampling period, we had three samples of sediments per plot. Chemical analyses performed on the samples were organic carbon content (Walkley–Black method), total nitrogen (Kjeldahl method), available phosphorus (Olsen method), and

Table 1
Slope characteristics

	Morphology	Slope	Length
Plot A	Straight	34°	45 m
Plot B	Straight	25°	30 m

Table 2
Characteristics of the mineral surface horizons before site preparation (means and standard deviation)
$n=3$; OM: organic matter; Nt: total nitrogen; C/N: carbon/nitrogen ratio; P: Olsen phosphorus; Ca, Mg, Na, K, Al: exchangeable calcium, magnesium, sodium, potassium, and aluminium; Al sat: percentage aluminium saturation.

	pH	OM[a]	Nt[a]	C/N	P[b]	Ca[c]	Mg[c]	Na[c]	K[b]	Al[c]	Al sat[a]
Plot A	4.2(0.1)	9.2(1.1)	0.5(0.1)	10.7(0.1)	3.6(0.8)	0.5(0.1)	0.2(0.1)	0.3(0.0)	148(13)	10.7(0.6)	87(1)
Plot B	4.2(0.0)	8.7(0.3)	0.4(0)	11.5(0.4)	2.3(0.3)	0.6(0.3)	0.3(0.0)	0.3(0.0)	138(1)	10.7(0.2)	88(0)

[a] Percentage.
[b] mg kg^{-1}.
[c] cmol(+) kg^{-1}.

exchangeable calcium, magnesium, sodium, and potassium (determination by atomic absorption spectrophotometry after extraction with NH_4OAc 1N pH 7). Organic matter content was estimated assuming it contains 58% organic carbon. Samples from soil surface horizons were also analysed for pH (1:2.5 in water), and exchangeable aluminium by 1.2 M $BaCl_2$ extraction followed by 0.01 N NaOH titration (Mosquera and Mombiela, 1986). Aluminum saturation was estimated as the ratio between exchangeable aluminum and the sum of all exchangeable cations.

SERs in organic matter, total nitrogen, Olsen phosphorus, and exchangeable calcium, magnesium, sodium, and potassium were calculated as the relation between the concentration in the sediments on a given sampling date and the concentration in their source soils (0–3 cm) on the previous sampling date. Thus, SER values higher than 1 represent a selective behaviour of runoff resulting in higher nutrient concentrations in the sediments than in the original soils.

Daily rainfall data for the study period were obtained from a station located less than 1 km away from the plots. Rainfall intensity data were obtained from the Gernika station, 12 km away. Full records for the study period were not available though.

All data were analyzed with either ANOVA or GLM procedures (SAS Institute, 1989). Duncan's multiple-range test was used to separate means.

3. Results

Field observations immediately after site preparation revealed the complete loss of the 1-cm deep organic O horizon present before preparation. Nutrient loss estimates could not be made as no samples of the horizon had been taken prior to site preparation.

Concentrations of organic matter, total nitrogen, and exchangeable elements, except calcium, in the mineral soil surface horizons (0–20 cm) are significantly higher before site preparation than 18 months later (Table 3). Decreases in concentrations after site preparation represent 70% for organic matter, 40%–50% for total nitrogen, 85%–100% for Olsen phosphorus, 30%–50% for magnesium, 30%–70% for sodium, 50%–70% for potassium, and 40%–50% for aluminium. This results in an increase in the percentage aluminium saturation and in a decrease in the sum of exchangeable base cations, which means a decrease in the short-term acid buffering-capacity (Warfvinge et al., 1993). The new surface horizon, with organic matter levels of around 2%, has also a higher risk of degradation by water erosion (Morgan, 1986), and by hardsetting (Mullins et al., 1990) as illite is one of the main components of the clay minerals in these soils.

There are no statistically significant differences between nutrient and organic matter concentrations of the source soils (0–3 cm) and their sediments (means

Table 3
Mean and standard deviation values for some characteristics of the mineral soil surface horizons (0–20 cm) before site preparation (Original) and 18 months later (Final) (means for the two plots)
$n = 6$; Signific.: level of significance. ***$P < 0.01$; **$P < 0.05$; *$P < 0.10$; n.s.: not significant at the 0.10 level.

	pH	OM[a]	Nt[a]	Al[b]	Al sat[a]	P[c]	Ca[b]	Mg[b]	Na[b]	K[c]
Signific.	***	***	***	***	***	***	n.s.	**	***	***
Original	4.2(0.1)	9.0(0.7)	0.5(0.1)	10.7(0.4)	87(1)	2.9(0.9)	0.5(0.2)	0.3(0.1)	0.3(0.0)	143(9)
Final	4.3(0.1)	2.0(0.7)	0.1(0.0)	6.4(0.8)	91(1)	0.2(0.2)	0.3(0.2)	0.1(0.1)	0.1(0.1)	58(12)

[a] Percentage.
[b] cmol(+) kg^{-1}.
[c] mg kg^{-1}.

Table 4
Mean and standard deviation values for some characteristics of the surface—3 cm source soils (Soil) and their sediments (Sediment) (means for the two plots and seven sampling dates)
$n = 42$; Signific.: level of significance. ***$P < 0.01$; **$P < 0.05$; *$P < 0.10$; n.s.: not significant at the 0.10 level.

	OM[a]	Nt[a]	P[b]	Ca[c]	Mg[c]	Na[c]	K[b]
Signific.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.
Soil	2.3(0.5)	0.2(0.0)	0.1(0.3)	0.4(0.9)	0.1(0.1)	0.1(0.0)	52(8)
Sediment	2.1(0.7)	0.1(0.0)	0.2(0.5)	1.1(1.6)	0.1(0.1)	0.1(0.0)	56(19)

[a]Percentage.
[b]mg kg^{-1}.
[c]cmol(+) kg^{-1}.

for both plots and seven sampling dates), except for total nitrogen (Table 4) which is in higher concentrations in the source soils. Organic matter shows a similar trend, but phosphorus, calcium, magnesium and potassium tend to appear in higher concentrations in the sediments.

All variables behave in the same way in both plots: higher concentrations in the sediments for phosphorus, calcium, magnesium, and potassium, and higher concentrations in the source soils for nitrogen and sodium. Organic matter, on the other hand, is in higher concentrations in the sediments than in the source soils in plot B, but in higher concentrations in the source soils in plot A. These differences in concentrations are statistically significant only in the case of organic matter and nitrogen in plot A, and for calcium and sodium in plot B (Tables 5 and 6).

Mean SER values and standard deviations for the two plots and seven sampling dates show that there is not a significant enrichment of sediments in any of the variables studied, although there is a tendency towards an enrichment in phosphorus and exchangeable calcium, magnesium, and potassium (Table 7). In fact, there is a statistically significant negative enrichment of the sediments

Table 5
Mean and standard deviation values for some characteristics of the surface—3 cm source soils (Soil A) and their sediments (Sed A) in plot A (means for seven sampling dates)
$n = 21$; Signific.: level of significance. ***$P < 0.01$; **$P < 0.05$; *$P < 0.10$; n.s.: not significant at the 0.10 level.

	OM[a]	Nt[a]	P[b]	Ca[c]	Mg[c]	Na[c]	K[b]
Signific.	*	**	n.s.	n.s.	n.s.	n.s.	n.s.
Sed A	2.1(0.5)	0.1(0.0)	0.3(0.6)	1.7(1.9)	0.1(0.1)	0.1(0.0)	56(16)
Soil A	2.4(0.5)	0.2(0.0)	0.1(0.4)	0.6(1.2)	0.1(0.0)	0.1(0.0)	52(7)

[a]Percentage.
[b]mg kg^{-1}.
[c]cmol(+) kg^{-1}.

Table 6
Mean and standard deviation values for some characteristics of the surface—3 cm source soils (Soil B) and their sediments (Sed b) in plot B (means for seven sampling dates)
$n = 21$; Signific.: level of significance. $^{***}P < 0.01$; $^{**}P < 0.05$; $^{*}P < 0.10$; n.s.: not significant at the 0.10 level.

	OM[a]	Nt[a]	P[b]	Ca[c]	Mg[c]	Na[c]	K[b]
Signific.	n.s.	n.s.	n.s.	*	n.s.	***	n.s.
Sed B	2.2(1.0)	0.1(0.0)	0.1(0.2)	0.3(0.2)	0.2(0.1)	0.1(0.0)	56(23)
Soil B	2.2(0.4)	0.2(0.0)	0.1(0.2)	0.2(0.1)	0.2(0.0)	0.2(0.0)	53(9)

[a] Percentage.
[b] mg kg^{-1}.
[c] cmol(+) kg^{-1}.

Table 7
Mean and standard deviation values for sediment enrichment ratios in the two study plots during the study period
$n = 7$; Signific.: level of significance; n.s.: no significant differences at the 0.10 level.

	OM	Nt	P	Ca	Mg	Na	K
Signific.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Plot A	0.9(0.2)	0.8(0.1)	31.3(67.5)	14.2(23.3)	1.6(1.1)	0.7(0.3)	1.2(0.3)
Plot B	1.0(0.3)	0.9(0.1)	9.4(19.7)	1.6(0.7)	1.1(0.2)	0.7(0.2)	1.0(0.2)
Mean	0.9(0.2)	0.9(0.1)	20.3(48.3)	7.9(16.9)	1.3(0.8)	0.7(0.2)	1.1(0.2)

(lower concentrations than in the source soil) in total nitrogen, as could be expected from the results shown in Table 4. Phosphorus and calcium behave erratically, so their mean SER values should be taken with caution. In the case of phosphorus, such behaviour may result from the extremely low concentrations of this element, which make any small differential to produce very high or very low SER values.

Table 8
Sediment enrichment ratios in relation to total rainfall (RF, mm) between samplings (means for both plots)
Signific.: level of significance; n.s.: no significant differences at the 0.10 level. Within columns, figures followed by the same letter are not significantly different at the 0.10 level.

RF	OM	Nt	P	Ca	Mg	Na	K
Signific.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.
209	0.8	0.8	0.5	1.4	1.0	0.7a	1.0
278	1.1	1.0	22.8	6.5	1.5	0.8a	1.1
398	0.7	0.9	1.0	2.2	1.0	0.4b	1.1
626	1.0	0.9	76.5	28.2	2.2	1.0a	1.0

Table 9
Sediment enrichment ratios for different values of maximum rainfall intensity in 1 h (RFIN, mm h^{-1}) between samplings (means for both plots)
Signific.: level of significance; n.s.: no significant differences at the 0.10 level. Within columns, figures followed by the same letter are not significantly different at the 0.10 level.

RFIN	OM	Nt	P	Ca	Mg	Na	K
Signific.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.
9.6	1.0	0.9	76.5	28.2	2.2	1.0a	1.0
13.8	1.0	0.9	11.7	3.4	1.2	0.7b	1.1
16.8	0.7	0.9	1.0	2.2	1.0	0.4c	1.1

SER values are not significantly different between the two plots (Table 7), although they tend to be higher in plot B for organic matter and nitrogen, and in plot A for the other variables.

Total rainfall in the period between two sampling dates, i.e., total rainfall originating the sediments of a particular period, does not result in statistically significant differences in SER values except for sodium (Table 8). Even in this case, there is no clear pattern in the distribution of SER values, with the highest rainfall producing SER values not significantly different from those of the lowest rainfall.

SER values are not significantly different in relation to maximum rainfall intensity in 1 h between two sampling dates, except for sodium (Table 9). In this case, higher rainfall intensities result in lower SER values. This tendency holds for the other variables, except for total nitrogen and potassium, which show very little difference in their SER values anyway.

4. Discussion

A decrease in the concentration of organic matter and nutrients in the mineral surface horizon is common after mechanical site preparation techniques involving soil disturbance (Tuttle et al., 1985; Reynolds, 1990). Three processes may be related to such decrease in our study: soil removal by scalping, particulate losses due to soil water erosion, and dissolved losses.

For those elements, except phosphorus, we studied, dissolved losses are widely prevalent in undisturbed forests (Likens and Bormann, 1995). In the case of phosphorus particulate losses account for 60%–80% of total losses even in undisturbed conditions (Vaithiyanathan and Correll, 1992; Likens and Bormann, 1995). After disturbance, dissolved losses may increase, but the quantities involved are clearly exceeded by particulate losses (Clayton and Kennedy, 1985; Binkley, 1986; Soto et al., 1995). Two factors should be expected to increase particulate losses in our case in relation to other cases in the literature. On the one hand, the complete loss of soil surface cover due to site preparation operations. And on the other, the favourable surface conditions for increased overland flow of water resulting from the system of down-slope ridge-furrows created by ripping operations. We could therefore expect particulate losses to represent a very high proportion of nutrient losses in relation to dissolved losses.

SERs, which represent the relative speed in the decrease in nutrient concentration as a result of particulate losses in surface water erosion, have been studied in agricultural soils or in slightly sloping areas. In most cases, they range from 2 to 4 for organic carbon, 1.1 to 10 for organic matter, 1.1 to 5 for nitrogen, from 1 to 6 for phosphorus, and from 1.3 to 13 for potassium (Stocking, 1984; Sharpley, 1985; Biot, 1988; Marston, 1989; Francis, 1990, Usón, 1998). Only Usón (1998) has obtained values lower than 1 in agricultural conditions, and as low as 0.60 for Olsen phosphorus and 0.85 for organic matter and nitrogen. In this study, enrichment ratios were measured in vineyards with very low vegetative cover, high-intensity rainfall, and high soil-loss rate. Otherwise, SER values in the literature are higher than in our plots. But these differences can be explained because SERs decrease as the total mass of soil eroded increases (Menzel, 1980; Sharpley, 1985; Francis, 1990; Sharpley and Smith, 1990; Usón, 1998), as the erosive power of runoff increases due to increased steepness of slope (Biot, 1988), and as the original concentration of nutrients in the soil decreases (Lal, 1976, cited in Stocking, 1984). All these factors meet in our case.

We have a situation, then, where particulate losses represent most of the total mass of nutrient losses, but the concentration in this particulate mass is too low to contribute significantly to the decrease in the nutrient concentration after site preparation. We may therefore conclude that of the three above mentioned processes, soil removal by windrowing is responsible for most of that decrease in concentration. Although scalping may only remove a few soil-top centimeters, these usually have higher concentrations of carbon and nutrients than the underlying horizons.

The increase in the proportion of particulate nutrient losses in relation to dissolved losses after clearfelling is mainly related to the inorganic rather than the organic fraction (Likens et al., 1970). Fullen (1991), working on gently sloping agricultural soils, also found lower organic matter concentrations in eroded material than in the original soil. He suggests a process in which much surface organic matter inwashes to filtration pavements beneath the soil surface. In our field observations, we found that soil material around fine roots was more resistant to surface runoff than loose soil, which is in agreement with the proposals of Dissmeyer and Foster (1981). All these factors would help to explain the low SER values for organic matter and nitrogen in comparison to the rest of nutrients other than sodium.

The lack of differences in SER values between the two plots suggests that on these steep slopes and with favourable surface hydraulic conditions, small differences in slope do not change the nonselective behaviour of runoff. The lack of response to changes in total rainfall and rainfall intensity point in the same direction, although the tendency towards lower SER with increasing rainfall intensity agrees with the literature mentioned.

5. Conclusions

The land utilization type defined by the use of scalping and down-slope ripping for site preparation for *P. radiata* pine plantation in the Basque Country results in a strong soil disturbance during and after these operations.

This disturbance is associated with the degradation of various land qualities, i.e., nutrient and water availability, acid-buffer capacity, resistance to erosion, and hardsetting behaviour, as a result of a strong decrease in the concentration of organic matter and nutrients in the mineral soil surface horizon, and the complete loss of vegetation cover and litter horizons.

Sediments produced by surface water erosion after site preparation are not significantly enriched in organic matter or nutrients, although there is a tendency in that direction for Olsen phosphorus, and exchangeable calcium, magnesium, and potassium. This nonselective behaviour of water erosion seeems to be produced by the high erosive power of runoff as a result of the steep slopes and the soil surface hydraulic conditions favourable to erosion, which also make changes in rainfall and rainfall intensity to have no significant effects on that behaviour.

Total nitrogen, on the other hand, is in significantly higher concentrations in the source soils than in the sediments due probably to a specific resistance to erosion of materials rich in organic matter.

In any case, the decrease in the concentrations of organic matter and nutrients as a result of site preparation cannot be explained, but in a small fraction by particulate losses in surface erosion. Dissolved losses probably contribute in a smaller fraction. Removal of surface organic and mineral horizons by scalping is thus mostly responsible for this process of land degradation.

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