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Effects of Different Restoration Practices on Nutrient Loss from Sediments after a Forest Fire in Two Watersheds

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ABTRACT: The loss of nitrogen and phosphorus from sediments in two watersheds, one naturally regenerating and one artificially planted, in Sacheon-myun, Gangneung-si, Gangwon Province, were measured two years after a forest fire in 2000. Sediment losses occurred five times in the course of the year. In the artificially planted watershed, 50~140 times more nitrogen and 54~139 times more phosphorus were lost with sediments during heavy rains, from July to August, than in the naturally regenerating watershed. When the typhoon Rusa struck the country, 1,389 times more nitrogen and 1,647 times more phosphorus were lost from the artificial watershed. In spite of the limited scope of this study, these results suggest that artificially planted watersheds are extremely vulnerable to catastrophic natural disasters such as typhoons. Elevated loss of nutrients in the artificially planted watershed might have resulted from the mechanized silvicultural practices employed immediately after the fire. To maximize soil preservation, the timing and necessity of plantation practices should be reconsidered, and rapidly regenerating vegetation should be protected to promote nutrient uptake and to mitigate nutrient loss from burned forests.

Key words: Forest fire, Nutrient loss, Restoration practice, Runoff, Sediment

INTRODUCTION

A forest fire greatly alters nutrient cycling in the ecosystem by redistributing nutrients during and in the period following the fire (Knoepp et al. 2005). Nutrients are generally stored in form of plant biomass or soil organic matter in a forest ecosystem. However, they are volatilized as a gas or lost in smoke as particles during a fire. After the fire, nutrients left as ashes or accumulated as products of imperfect combustion on the soil surface are easily swept away by runoff or soil and wind erosion.

In Korea, 76% of forest fires occur between February and April, and heavy rains and typhoons strike from July to September (Choung et al. 2005). During this season, forest soils which have become unstable as the result of fires can be damaged by heavy rainfall and the resulting soil erosion.

In forests damaged by fires, damaged vegetation and decreased biomass result in a reduced transpiration rate, and the soil surface is more exposed to the impact of rain drops. Accordingly, the water infiltration rate is reduced and soil erosion energy is increased, which contributes to excessive runoff and sediment loss (Robichaud et al. 2000, Park et al. 2002, Kim et al. 2006).

The rate and nature of soil erosion is influenced by the severity of fire damage, the vegetation cover, the soil type, and the degree of slope as well as the amount and intensity of rainfall (Choung et al. 2005). Large forest fires occurring over the last few decades in Korea have caused enormous damage and loss of vegetation and organic matter, especially in areas where the soil mainly consists of coarse sand (Park et al. 2002, Lee et al. 2000). Yang et al. (2003) report that average annual sediment loss increased from 44.8 ton/ha to 736.4 ton/ha (a nearly 16-fold increase) in Goseung-gun, Gangwon Province after the East Coast Fire in 2000. Similarly, Morris and Todd (1987) found rates of sediment loss in the Colorado Front Range several hundred times higher than those of other regions in the U.S. which were not damaged by the fire.

Plantation of new vegetation in fire-damaged mountain areas has become problematic in that it causes further disturbance in addition to the fire itself. Clear-cutting and replanting of trees using heavy machinery and intensive manpower actually accelerate the loss of topsoil (Vitousek and Matson 1985, Choung 2000, Choung et al. 2000, Duncan 2002). Soils in Korea are generally shallow and unstable as a result of repeated disturbances, and have low organic matter and inorganic nutrient contents (Kim 2002). Therefore, further losses of essential nutrients such as nitrogen and phosphorus may seriously affect the forest and can hinder recovery of the forest after a disturbance. Loss of nutrients increases cation and anion levels in

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nearby creeks and streams, and therefore can also affect water quality and aquatic ecosystems (Leonard et al. 1979, Robichaud et al. 2000).

Comparative studies of nutrient losses in watersheds with histories of different restoration practices can provide crucial information about the restoration of burned forests. However, while several researchers have conducted studies of runoff or sediment production on small runoff plots (Choi and Kim 1999, Park et al. 2002, Choung et al. 2002, 2005), there has been almost no watershed-level research on the loss of nutrients from burned forests in Korea. Watershed-level studies allow us to quantify inflow and outflow as well as considering site heterogeneity (Bormann and Likens 1981), and are important for understanding ecosystem functioning in fire-damaged habitats.

We examined how different restoration practices affected rates of loss of nutrients, especially nitrogen and phosphorus, in two watersheds which were treated with different restoration practices following a fire in 2000. We conducted experiments in 2002, two years after the fire, in each watershed. During the study period, the typhoon Rusa, which was accompanied by extremely heavy rains, struck the whole country. This "natural experiment" enabled us to compare the responses of the two study watersheds to catastrophic rainfalls as well as average rainfall events.

METHODS

Experimental Watersheds

Experiments were conducted in two forested watersheds located in Sacheon-myon, Gangneung-si in Gangwon province (Table 1). An area of about 1,302 ha in Gangneung-si was damaged by fire in 2000 (Gangneung-si website 2003). Prior to the fire, the two watersheds primarily consisted of *Pinus densiflora* forests. After both watersheds were severely burned by crown fires, they were treated with different management practices immediately following the fire. In one watershed (hereafter referred to as the "naturally regenerating", or NR watershed), there was no human intervention, allowing natural regeneration processes to occur. Artificial plantation was applied to the other watershed (hereafter referred to as the "artificial plantation", or AP watershed), including logging of the burned trees, artificial plantation, fertilization and periodic removal of regenerating plant species.

Table 1. Characteristics of two experimental watersheds

	Naturally regenerating watershed	Artificially planted watershed
Location	Nodong-ri 176, Sacheon-myun, Gangnung-si	Nodong-ri 142, Sacheon-myun, Gangnung-si
Stream	Yeongok	Sacheon
Area (ha)	1.085	0.852
Altitude (m)	180～215	180～215
Width (m)	70～100	50～90
Length (m)	144	124

The NR watershed covers an area of 1.09 ha, and is a typical hollow with coarse sandy soil weathered from granite. The south- and east-facing slopes have largely recovered from the fire, being dominated by shrubby vegetation from regenerating *Quercus* and *Lespedeza* species. On the ridge top, herb species are dominant. However, on the north-facing slope, where the topography is complicated with many gullies, the recovery of vegetation has been poor (Park et al. 2002). All of the burned trees in the 0.86 ha AP watershed were cut down in 2000. Roughly half of the area was treated for erosion control by grass planting in April, 2001. The other half was planted with pine tree seedlings after the removal of naturally regrowing vegetation in September 2001. The removed burned trees were placed vertically against the slope in an additional attempt to control soil erosion.

A small weir was constructed at each of the two watersheds by the National Fire Prevention Institute and rain gauges, water level meters and turbidimeters were installed to measure rates of water flow (Park et al. 2002).

Soil Sediment Sampling and Nutrient Analysis

Soil was sampled from the two experimental watersheds whenever rainfall events resulted in sediment losses. The collected soil was air-dried and filtered through a 2 mm sieve prior to chemical analysis.

The concentration of nitrogen was analyzed by the micro-Kjeldahl method using a digester (2012 kjeldahl digester, Foss Tecator Co.) and distillation system (1002 Distilling unit, Foss Tecator Co.) (Jackson 1967). The concentration of phosphorus was analyzed using the ascorbic acid method (APHA 1981).

The total losses of nitrogen and phosphorus were calculated from the total sediment yield (Park et al. 2002) and the concentrations of nitrogen and phosphorus in the sediment. The amount of sediment produced was measured from the reservoir of the weir system, which contained only sedimented soil as the colloidal fluid was siphoned out from the reservoir. Five events of sediment loss were recorded, associated with rainfall of 138.0 mm, 84.5 mm, 23.5 mm, 255.0 mm and 892.0 mm in the NR watershed, and 138.0 mm, 84.5 mm, 23.8 mm, 281.0 mm and 959.0 mm in the AP watershed (Park et al. 2002). In the NR watershed, these events resulted in the production of 1.29 kg/ha, 0.28 kg/ha, 0 kg/ha, 1.11 kg/ha, and 72.26

kg/ha of soil sediment, respectively. In AP watershed, the same events resulted in the production of 233.45 kg/ha, 17.96kg/ha, 15.38 kg/ha, 128.17 kg/ha and 146,991.07 kg/ha of soil sediment (Park et al. 2002).

RESULTS

Soil sediment was collected five times from July 2002 to September 2002 in the two experimental watersheds (Park et al. 2002). The first four events of sediment loss were caused by heavy rains during the monsoon season, while the fifth event of soil loss was caused by rains associated with the typhoon Rusa. The concentration of nitrogen in the sediment varied among samples (Table 2), and may be correlated with the amount of rainfall. The concentration of nitrogen was generally high when the rainfall was lower, and lower when the rainfall was high. The concentrations of nitrogen and phosphorus extracted from the soil of the NR watershed were generally higher than those of soil from the AP watershed, (Table 2).

We calculated the total amount of nitrogen lost from the watersheds for 2002 (Table 3). The total loss of nitrogen from the NR watershed over the course of the five events was 0.0745 kg/ha, whereas the total loss of nitrogen from the AP watershed was 103.5 kg/ha, indicating a 1,389 times greater nutrient loss. The total loss of phosphorus showed a similar pattern; while a total of 0.0245 kg/ha of phosphorus was lost from the NR watershed, 40.3 kg/ha of phosphorus was lost from the AP watershed, indicating a 1,647 times greater nutrient loss (Table 3). More than 90% of the total loss of nitrogen and phosphorus in both watersheds was associated with typhoon Rusa. The maximum rainfall intensity was very high in both watersheds when the typhoon Rusa hit the region, but the rates of soil loss associated with this event differed between the watersheds. This single event resulted in a loss of 147 ton/ha of soil from the AP watershed, as compared with only 72 kg/ha from the NP watershed, a greater than two thousand-fold difference in soil loss (Park et al. 2002). In other events of heavy rain, 50~140 times more nitrogen and 54~139 times more phosphorus were lost in the AP watershed than the NR watershed (Table 3).

Table 2. Total nitrogen and phosphorus concentrations (mg/g) of the soil sediments produced from NR and AP watersheds in 2002

Events	Nitrogen (mg/g)		Phosphorus (mg/g)	
	Naturally regenerating	Artificially planted	Naturally regenerating	Artificially planted
Jul. 5~6	2.36	1.40	0.54	0.35
Jul. 13~19	1.99	1.55	0.47	0.40
Jul. 22~23	nd[1]	1.61	nd[1]	0.40
Aug. 5~11	1.23	0.96	0.34	0.41
Aug. 30~Sep. 1	1.49	0.70	0.32	0.27

[1] not determined due to no sediment loss.

Table 3. Total nitrogen and phosphorus loss through the soil sediment produced from two differently managed watersheds in 2002

Events	Nitrogen (kg/ha)		Phosphorus (kg/ha)	
	Naturally regenerating	Artificially planted	Naturally regenerating	Artificially planted
Jul. 5~6	0.003	0.327	0.007	0.082
Jul. 13~19	0.001	0.278	0.000	0.007
Jul. 22~23	-[1]	0.248	-[1]	0.006
Aug. 5~11	0.001	0.191	0.000	0.053
Aug. 30~Sep. 1	0.070	102.894	0.023	40.152

[1]no sediment loss.

DISCUSSION

Choung (2000) and Choung et al. (2002) compared and analyzed long-term restoration processes in several regions of different ages on the east coast of Gangwon Province which had been treated with different restoration practices involving either natural regeneration or artificial plantation following fires. Their results suggest that soil fertility in artificially replanted regions was lower than that of areas allowed to regenerate naturally even after thirty years. They propose that additional disturbances resulting from mechanized plantation practices immediately after a fire resulted in reduced soil fertility and slower recovery. Therefore, we compared the effects of different restoration practices on nutrient loss from sediments at the watershed level in NR and AR watersheds during the monsoon season, and were also able to compare the responses of the two watersheds to extreme levels of rainfall resulting from typhoon Rusa, which struck Korea in 2002.

In the year of the study, a total of five events of sediment loss associated with rainfall were recorded. The concentration of nitrogen and phosphorus was higher in soils from the NR watershed than in soils removed from the AP watershed. The AP watershed was fertilized after trees and grasses were planted in 2001(Hwang 2004). There are at least two possible reasons why nitrogen and phosphorus concentrations in the soil were lower in the AP watershed than the NR watershed. More inorganic matter, included the topsoil, may have washed away in 2000~2001 in the AP watershed, shortly after logging and fertilization, which could resulted in lower concentrations of nitrogen and phosphorus in the soil in 2002, relative to the NR watershed. Alternatively, the concentration of nutrients may have been diluted by the heavy rainfall and large soil losses from the AP watershed.

The loss of nutrients from the AP watershed was 50~140 times greater for nitrogen, and 54~139 times greater for phosphorus than those from the NR watershed during the four rainfall events associated with the seasonal monsoon. Nutrient losses in the experimental watersheds were generally proportional to the rainfall amount and rainfall intensity. When the typhoon Rusa struck Korea, 892 mm of rain fell on the NR watershed and 959 mm of rain fell on the AP watershed (Park et al. 2002). Maximum rainfall intensities at that time were 92.0 mm/hr in the NR watershed and 113.5 mm/hr in the AP watershed. During this extreme event, 1,389 times more nitrogen and 1,647 times more phosphorus were lost in the AP watershed than the NR watershed.

Even if we consider the slightly higher rainfall and higher rainfall intensity in the AP watershed, it is clear that AP watersheds are particularly vulnerable at natural disasters such as typhoons. The typhoon Rusa damaged only 0.6% of unburned forests in Gangneung-si, while 6.4% of burned forests experienced landslides (Park 2002), which suggests that burned forests are more vulnerable than unburned forests to landslide damage during extreme weather events.

In *Pinus pinaster* forest of Portugal, 600 times more nitrogen and nearly 2,000 times more phosphorus were leached out from burned forests than unburned forests during the rainy season (Thomas et al, 1999). Though a large amount of nitrogen and phosphorus is volatilized during fires (Raison 1980), soil levels of inorganic nutrients such as nitrogen, phosphorus, calcium and magnesium actually increase following fires, because the ashes and products of imperfect combustion accumulate on the soil (Mun and Choung 1996, Lee et al. 2000). In naturally regenerating areas, the vegetation rapidly regenerates and the available nutrients are fixed into plant biomass. In addition, the soil is rapidly stabilized by rapid regrowth of vegetation (Choung and Kim 1987, Mun and Choung 1997, Choung 2000, Choung et al. 2004). Coats et al. (1976) and Vitousek and Matson (1985) also suggested that nitrogen uptake by plants is an important factor preventing loss of nitrogen in unstable soils.

Mechanized practices such as logging of burned trees, site preparation for planting, and the introduction of temporary forest roads and heavy duty machinery cause additional disturbances in artificially planted watersheds (Vitousek and Matson 1985). Roots of vegetation and litter provide natural erosion control, and the canopies of shrubs and trees reduce the impact of raindrops (Park et al. 2002). Therefore, AP watersheds, which have poor vegetation cover and unstable soils, are exposed to greater danger of damage in the event of a natural disaster compared to NR watersheds.

Choung (2006) and Kim (2003) found that the extent of vegetation cover is highly correlated with rates of soil erosion and nutrient loss in runoff plots, which means that artificial restoration after a forest fire does not promote restoration, but rather actually hinders recovery of the disturbed ecosystem. Beschta et al. (2004) argues that artificial restoration after fires has hindered restoration of forests in the Northwestern U.S. for decades.

We conducted this study two years after our study area was damaged by forest fire. Considering that both runoff and sediment loss are highest in the first year after a fire (Knoepp et al. 2005), our results suggest that the restoration work conducted in the artificially forested land might have caused enormous loss of nutrients during the first year after the fire, because soils are typically more impermeable and nutrients more easily washed away in the period immediately after a fire.

In general, forest soils in Korea contain low levels of nutrients due to topsoil erosion and poor soil management (Kim 2002). If large amounts of nutrients, particularly nitrogen, an essential element, are lost due to volatilization during a fire, blown away as particles, or washed away with the rain after a fire, these losses may cause a serious imbalance in the nutrient cycling of the ecosystem (Knoepp et al. 2005).

It is important to reduce the loss of nutrients in a watershed after a fire by promoting rapid absorption of nutrients into biomass and reducing sediment loss to preserve the shallow and unstable topsoil in Korean forests. Thus, we recommend that fire-damaged forests be allowed to regenerate naturally for a period of time to allow vegetation to regrow, to prevent loss of nutrients and to stabilize damaged soils after forest fires.

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