The role of herbicides in protecting long-term sustainability and water quality in forest ecosystems

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Abstract.-The use of herbicides for controlling competing vegetation during stand establishment can be beneficial to forest ecosystem sustainability and water quality by minimizing off-site soil loss. In addition, the organic residues of forestry herbicides do not adversely impair water quality.

INTRODUCTION

A critical component of inter-rotation forest management is the manipulation of successional vegetation to ensure adequate survival and growth of the next forest crop. Techniques such as mechanical site preparation, fire, and herbicides have been used to reduce competition from undesired vegetation. Herbicides have been incorporated into vegetation management programs on intensively managed forests more frequently in the past two decades. Despite considerable controversy about their environmental impacts, particularly on water quality, herbicides actually can have a positive effect on maintaining the sustainability of tree crops and protecting water quality within forest ecosystems. This paper addresses both ecosystem sustainability and water quality issues, focusing on the role of herbicides in keeping soil resources on-site.

METHODS AND MATERIALS

Standard hydrological, soil erosion, and herbicide residue methodologies were used in the conduct of this research. A detailed discussion of the specific Methods and Materials can be found in the references used for this synthesis, as well as in the full manuscript of this paper.

RESULTS AND DISCUSSION

The concept of sustainability addresses whether a site can supply sufficient water and nutrients to support successive rotations of trees. The keys to long-term sustainability are organic matter, nutrient supply, soil hydrologic function, and soil physical conditions. Tree seedlings require adequate supplies of nutrients and water to grow, and roots need a well-structured soil to develop large enough systems to support that growth (1). Vegetation management after harvesting may produce adverse effects on site characteristics which control productivity. Fire can consume much of the organic matter in slash, litter, and the mineral soil, volatilizing nitrogen and leaving nutrient-rich ash susceptible to water or wind transport off-site. Soils left bare by hot fires increase surface runoff and often develop water repellent horizons, thereby making sites erosion-prone and drier. Mechanical site preparation can redistribute organic matter, effectively removing from seedlings up to 5 times the amount of nutrients as whole-tree harvesting. Soils are often left bare and susceptible to surface runoff

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and erosion. Additional machinery passes can increase bulk density in fine textured soils, significantly reducing both rooting volume and available moisture holding capacity. Herbicides do not produce these adverse effects associated with fire and mechanical site preparation, and therefore work to minimize impacts on site productivity.

The main impact on water quality from inter-rotation vegetation management is sediment (2). Next to roads and logging skid trails, the major source of sediment comes from any ground-disturbing activity. Off-site movement of sediment from mechanical, burning, and herbicide site preparation techniques reported in the literature has ranged from 97,000 to 170 kg/ha/yr, respectively. Natural rates of sediment loss from undisturbed forest watersheds are usually <100 kg/ha/yr but in some locations can range up to 540 kg/ha/yr (2). Sediment yields during site preparation are affected by geology, soil, slopes, vegetation and litter cover, and climate. They typically are at a maximum during the first year after site preparation, and decline as vegetation recovers on the treated area (up to 4 years). The highest losses have been documented in China. Under intensive high-yield forest management in the USA, the highest documented losses (14,250 kg/ha/yr) have occurred on silt-textured soils in the upper coastal plain of Mississippi after cutting and bedding. On clay-textured soils in the Piedmont of North Carolina, sediment losses of 9730 kg/ha/yr have been reported after mechanical site preparation (blading and windrowing) to control competing vegetation. In New Zealand, maximum sediment yields the first year after clearfelling and site preparation were 6,432 kg/ha with skidder logging and burning with a 20 m riparian buffer, but were much less (611 kg/ha) with cable logging and burning with no buffer strip.

As part of a regional vegetation management environmental impact analysis, 27 watersheds in different National Forests of the Southern United States, covering all physiographic regions, were evaluated to determine the effect of vegetation management on sediment yields. Modeling of sediment yields over a 10 year period indicated that all land management activities (forestry, agriculture, grazing, etc.) would elevate natural sediment yields 5 - 487%. Forest harvesting could increase sediment production 1 - 13% above natural rates. Current post-harvest vegetation management operations on National Forest lands could increase sediment loss by another <1 - 7%. By comparison, roads on both National Forest and private lands account for sediment yield increases from 2 - 156% of the natural erosion rate.

Sediment losses resulting from inter-rotation vegetation management affect both on- and off-site environmental quality. Mechanical site preparation, which produces the largest mass of sediment loss, can result in nitrogen and phosphorus losses 21 to 30 times the normal annual rate of undisturbed forest watersheds. While these losses are low compared to agriculture-related nutrient losses, they do represent a concern for long-term forest management. For example, some forests in the southern USA now under intensive forest management were highly eroded during abusive agriculture in the late 19th and early 20th century. Due to loss of nutrient-rich A horizons, these forests remain sensitive to potential productivity declines unless augmented with fertilizers or vegetation control. Sediments transported into streams as a result of vegetation management destroy aquatic invertebrate and fish habitat, damage municipal water supplies, increase flood peaks, and detract from recreation values. Unlike organic chemicals and plant nutrients originating from fire or chemical vegetation control techniques, sediment added to stream systems does not degrade and becomes part of normal fluvial sediment transport and storage processes. The residence time of this sediment in fluvial geomorphic systems can range from decades to hundreds of years.

Research over the past two decades has documented low concentrations and short persistence of forestry herbicides in surface waters (3,4). In the Southern USA, applications of hexazinone, imazapyr, metsulfuron methyl, picloram, sulfometuron methyl, and triclopyr at rates of 0.3 to 5.6 kg/ha produced peak stream concentrations <130 mg/m^3 when buffer strips were maintained. Aerial applications to entire watersheds in both the USA and Canada have resulted in peak streamflow concentrations in the 442 680 mg/m^3 range. Higher concentrations (2,400 mg/m^3) have been reported in short sections of streams after accidental overflights. These peak concentrations do not persist and rapidly attenuate. Although water quality standards do not exist for all forestry herbicides, monitoring experience clearly indicates that the rates and use patterns of these chemicals do not pose any problem for surface water quality. For instance, the suggested water quality standard for hexazinone has only been exceeded for a short time where ephemeral or perennial channels were treated. Where forestry herbicides have been detected in streamflow, the residues usually dissipate within 6-12 months, and persist in only low concentrations ($<25\ mg/m^3$).

Forestry herbicides have been detected in shallow, surficial ground water (unconfined aquifer of soil, colluvium, or saprolite) only from broadcast applications and then only in about half the studies that monitored for them. In none of these situations were the herbicide residue concentrations of any toxicological significance. No cases exist of a bedrock aquifer being contaminated on localized or landscape scales by operational use of forestry herbicides. Transport and storage of concentrated herbicide products are the only activities with any risk for localized contamination of major aquifers.

CONCLUSIONS

From both the water quality and sustainability perspectives, herbicides have a real advantage for stand establishment and inter-rotation vegetation management. By keeping soil on site and not in streams, long-term forest sustainability is protected and water quality is not adversely affected. Considerable research and monitoring studies have shown that operational use of forestry herbicides for inter-rotation vegetation management does not create a significant risk to water quality as far as herbicide residues are concerned.

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