IMPACTS OF MULTIPLE APPLICATIONS OF FERTILIZER ON STREAM CHEMISTRY IN THE OUACHITA MOUNTAINS

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Abstract—We have previously reported changes in stream chemistry following a late winter application of urea and diammonium phosphate to a loblolly pine (*Pinus taeda* L.) plantation located in a 176-ha subwatershed in the Ouachita Mountains. This stand was again fertilized with 437 kg/ha of urea in March of 2001. Water chemistry prior to, during, and after fertilization was monitored downstream of the stand at the outlet of the subwatershed. Current Best Management Practices prohibit fertilizer entry in streamside management zones (SMZs) by either direct application or aerial drift. Fertilizer traps were located in a SMZ and within unprotected stream channels to document improper entry of fertilizer into the SMZ and quantify rates of applications in the unprotected stream channels. Nitrogen (N) concentrations at the subwatershed outlet increased immediately during application, and a number of the traps within the SMZ collected significant amounts of fertilizer. Application of urea upstream from the SMZ had only minor immediate impacts on stream chemistry. N concentrations increased dramatically during the first storm following fertilization. This increase indicated that the urea, which fell in unprotected stream channels or surrounding upland areas, was washed downstream to the main channel. In May, almost 3 months after application, NO_3^--N concentrations peaked at 15.4 mg/l during a small storm event. Concentrations of NO_3^--N remained elevated for at least 2 years after application. Concentrations of NO_3^--N were also greater than those observed following the first application of fertilizer, suggesting that repeated application of fertilizer could have a cumulative impact on N levels in water draining from intensively managed forests.

INTRODUCTION

Fertilizer is commonly used to increase production in intensively managed loblolly pine forests. Recent estimates indicate that more than 1.3 million acres of southern pine are fertilized annually (NCSFNC 2002). Frequently multiple applications of fertilizer are made to intensively managed loblolly pine stands. Fertilization can occur at or near the time of planting, canopy closure, following the first thinning, and on a 3- to 5-year interval thereafter (Dickens and others 2003). Generally, the impacts of forest fertilization on water quality are considered to be minimal. Binkley and others (1999) performed a literature review and indicated that even without the use of Best Management Practices (BMPs) there were only short-lived increases of nitrogen (N) and phosphorous in waters draining forests following applications of fertilizer. In addition, increases are not large enough to degrade water or exceed state water quality standards (Binkley and Brown 1993, Binkley and others 1999). We previously reported that N levels in a stream draining a 176-ha subwatershed in the Glazypeau River watershed near Hot Springs Village, AR, were dramatically increased during and following an operational fertilization of a loblolly pine plantation in the subwatershed (Liechty and others 1999). We hypothesized that a portion of the fertilizer may have been applied in a streamside management zone (SMZ) and transported downstream during a severe storm following the urea application, causing increased levels of N in the stream. This manuscript reports the long-term changes in concentrations related to this initial fertilization application as well as the impact of a second operational application of urea to this subwatershed during March of 2001. Our objectives are: (1) to quantify long-term impacts of urea fertilization on NO_3^--N from multiple applications of urea and (2) to quantify inputs of urea to a SMZ and unprotected channels in the treated subwatershed.

METHODS

Study Site

The research site was in the Little Glazypeau watershed located approximately 20 km from Hot Springs, AR (fig. 1). The watershed encompasses 2,273 ha, has an elevation between 209 and 381 m, is located on a southwest aspect, and contains 32 km of perennial or intermittent streams. A 176-ha subwatershed (FSW) in the larger watershed (fig. 1) was instrumented, and a portion of this subwatershed received multiple fertilization applications. This FSW is dominated by the Bismark-Carnasaw soil complex on slopes of 8 to 20 percent and 20 to 40 percent. These soils are well- to excessively well-drained. The soils are also relatively shallow with depth to bedrock of 25 to 50 cm in the Bismark soils and 100 to 150 cm in the Carnasaw series. A 138-ha mid-rotation pine plantation in the FSW was the targeted area for fertilizer application (fig. 2). This stand had previously been fertilized with 437 kg ha^{-1} of urea on February 9, 1998, and 140 kg ha^{-1} of diammonium phosphate on April 27, 1998, prior to the second application of fertilizer. A total of 8.7 ha in the FSW bordering the stand was delineated as a SMZ and was not to be included in the area to be fertilized. A reference subwatershed (RSW) is located in the northwestern portion of the basin (fig. 1). The RSW contains 104 ha of loblolly pine plantations. Mixed hardwoods, natural pine stands, and shrub/bush vegetation dominate the remaining 221 ha. A total of 76 ha of pine plantations in the RSW had been fertilized in 1997. No other fertilization has occurred in this subwatershed since 1997. Monitoring stations were established at the outlet of each subwatershed as well as the outlet of the Little Glazypeau Watershed (LGW). The monitoring station on LGW is approximately 6.5 km below the FSW station.

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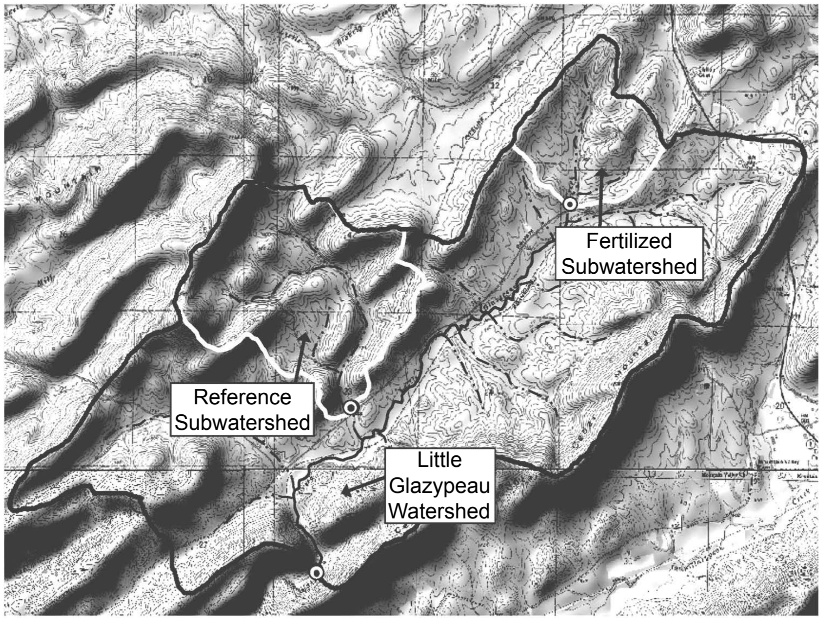

Figure 1—Study watersheds and outlet monitoring stations.

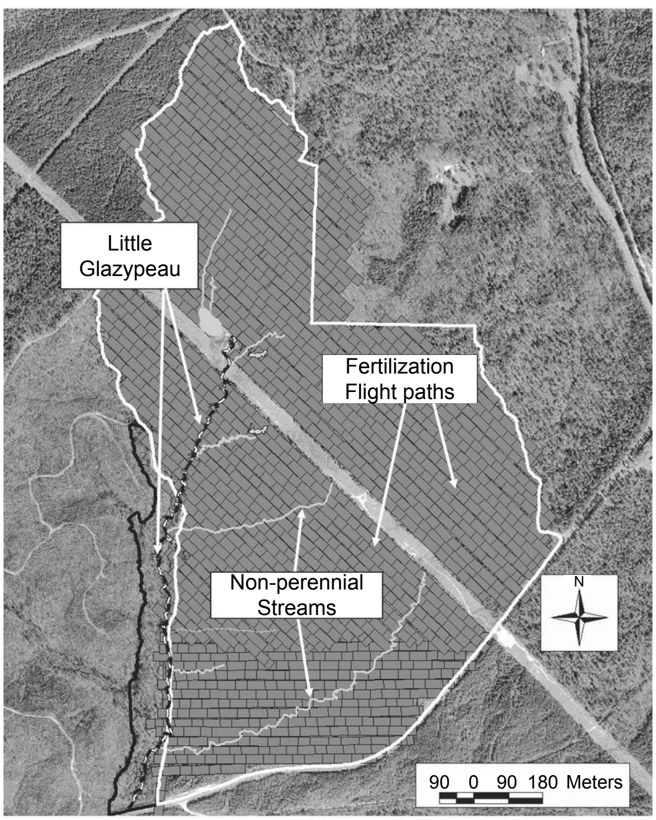

Figure 2—Fertilizer application area in the FSW.

Fertilization Application

A total of 437 kg/ha urea was applied to the FSW during the second application of fertilizer, a 3-day period from March 9 to 11, 2001. Application of the fertilizer was by a fixed-winged aircraft and occurred during a 3-day period due to aircraft mechanical problems and adverse visual conditions. Fertilizer was applied to approximately 33 percent of the pine plantation during a 2-hour period on March 9 (fig. 2). On March 10, approximately 50 percent of the plantation was fertilized over a 3-hour time period. Finally on March 11, the remaining portion of the plantation in the FSW was fertilized during an approximate 1-hour time period. Perennial stream channels and the SMZ surrounding this portion of the stream channel were avoided during application. However, non-perennial channels and the associated surrounding riparian areas did receive the same application rate as the upland portions of the watershed. Prior to fertilizer application, we deployed 38 1-m^2 traps along 5 transects that traversed the boundary of the SMZ, within unprotected ephemeral or intermittent drainages, and along sensitive water bodies such as ponds. A total of 10 traps were installed in the SMZ. A total of 20 traps were installed within unprotected ephemeral or intermittent drains in the stand. The traps were retrieved, the fertilizer collected from a trap, and then estimates of the amount of fertilizer collected on an area basis were determined.

Sample Collection and Stream Measurements

Stream stage was measured in stilling wells using FW1 10-turn potentiometers at each station. Rainfall amounts were measured using tipping bucket rain gages, and stream water samples were collected using ISCO 3700 wastewater samplers. A Campbell CR10X Datalogger recorded the potentiometer stage and precipitation at 10-minute intervals. These measurements were then used to initiate, control, and record water sample collection by the ISCO 3700 samplers. A critical stage initiated hourly sampling, and incremental changes between consecutive 10-minute stage readings initiated additional sampling during rain events. Samples were collected on an hourly basis just prior, during, and following urea application in 2001. Baseflow sampling continued on a daily basis for several weeks after fertilization and then sporadically thereafter. Samples from storm events were taken for a 24 month period after urea application.

Sample Analysis

Concentrations of NO_3^--N and NH_4^+-N were determined for each water sample, but Total Kjeldahl N (TKN) concentrations were only determined for every other sample. Concentrations of NO_3^--N were determined using ion chromatography. Concentrations of NH_4^+-N were determined colormetrically using a Latchat 2000 flow injection system. TKN was determined in the same manner after digestion with sulfuric acid. All concentrations were determined after filtration using a 2.0μ filter.

RESULTS AND DISCUSSION

Concentrations of TKN began to increase almost immediately after urea application (fig. 3) and reached their highest levels during the first day of application (when application was nearest to the outlet of the FSW; fig. 2). TKN concentration, which includes N as $CO(NH_2)_2$, reached 60.3 mg/l at 13:00 EST on March 9. The maximum TKN concentration on March 10 was 18.1 mg/l, just following the second day of urea application. TKN concentrations then decreased and did not increase during the application on March 11. The flight lines on March 11 were in the upper northeastern section of the subwatershed, away from the SMZ. The lack of changes in stream N concentrations on March 11 further suggests the increased concentrations of N in the 2 previous days were related to the application of urea within or near the SMZ where water was flowing in the primary stream channel.

In addition to the increase in N concentrations, flight lines were found to frequently cross the eastern SMZ boundary, and 9 of the 10 traps within the SMZ received some amount of urea. A total of 7 of the traps within the SMZ had collected significant amounts of urea ranging between 93 and 833 kg/ha. Although amounts of urea collected in the traps near the eastern SMZ boundary were greater than those located nearest the stream channels in the interior of the SMZ, it seems likely that urea was applied directly to portions of the stream channel, which was as near as 5 to 10 m of the eastern boundary.

As in the first application of urea in 1998 (Liechty and others 1999), there was a dramatic increase of NH_4^+-N concentration in the first rainstorm following the 2001 application of urea (fig. 4). The maximum NH_4^+-N concentration at the FSW station was 3.36 mg/l. This concentration occurred during the peak discharge of a storm event that took place approximately 24 hours after the last urea application. During the storm event, concentrations in the RSW were < 0.04 mg/l. We attributed the high concentration of NH_4^+-N during the 1998 application of urea to runoff generated by a 60 to 80 year storm that occurred a few hours following the urea application. However, the storm that occurred in 2001 following the second application was much less intense than the 1998 storm (peak stage was 0.25 compared to 1.04 m) and occurred at least 24 hours following urea application. It seems likely that, given the relatively low amounts of surface runoff generated by the 2001

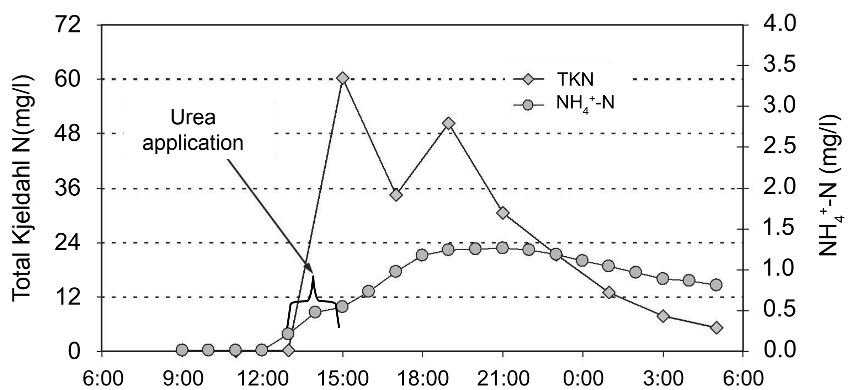

Figure 3—TKN and NH_4^+-N concentrations of water draining the FSB just prior, during, and for 15 hours following urea application on March 9, 2001.

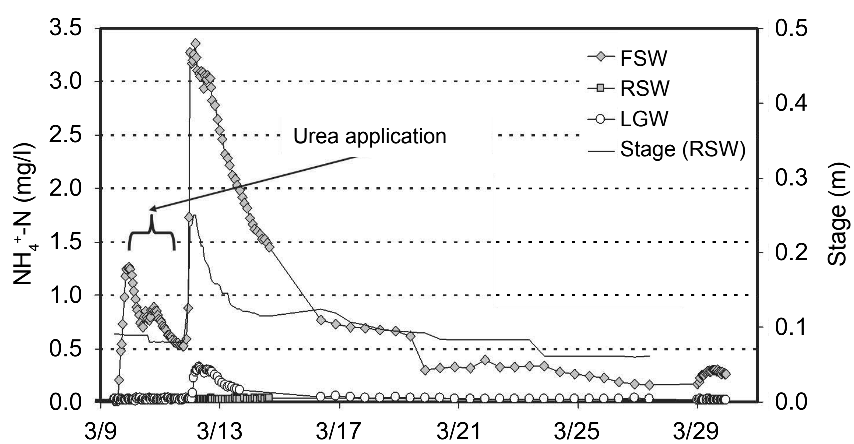

Figure 4—NH_4^+-N concentrations at the three monitoring stations and the stream stage at the FSW during the first rainstorm following urea application.

storm, the source of much of the NH_4^+-N was the urea applied to unprotected ephemeral and intermittent channels. Similar to the first application of urea in 1998, increases in NH_4^+-N concentrations were observed at the outlet of the LGW during peak concentrations in the FSW (fig. 4).

To evaluate the amount of urea that was applied to these unprotected channels, we placed 22 traps within ephemeral and intermittent channels outside the SMZ prior to application. The average amount of urea collected in a trap was 545 ± 129 kg/ha. This amount was approximately 117 kg more than the application rate. This may suggest that these channels receive higher loads of urea than a typical upland area. This increase would potentially be due to differences in structure and vegetation composition within these riparian areas compared to other portions of the pine plantation. Although differences between the amounts of urea collected in the traps located within the channels were not significantly different ($p=0.125$) than the 437 kg/ha application rate, further quantification of delivery rates and loadings to unprotected channels appears warranted.

NO_3^--N concentrations in the FSB slowly increased following urea application (fig. 5). Maximum concentrations occurred 2 to 3 months following application. The maximum NO_3^--N concentration following the second fertilization was 15.4 mg/l and occurred on May 31, 2001. When sampling following the last of these two rainfall events had ended, concentrations were still above 15.0 mg/l. Although our primary concern related to the increased concentrations of N in the stream is its impact on aquatic life, the NO_3^--N concentrations did exceed the EPA drinking water standards of 10 mg/l NO_3^--N. Similar elevated levels of NO_3^--N were reported by Helvey and others (1989) and Edwards and others (1991) following fertilizer application to hardwoods in West Virginia.

NO_3^--N concentrations following the second fertilizations were much greater than those following the initial application of urea in 1998. There were a greater number and intensity of storms following the first application of urea then the second (fig. 5). The greater number of storms and storm water may have diluted concentrations during this time period and contributed to the lower concentrations in 1998. However, long-term monitoring of the FSB indicated that concentrations of NO_3^--N continued to be elevated as much as 1 to 2 years after application (fig. 6). Again, the long-term elevation of NO_3^--N concentrations were similar in duration to those observed during a 3-year time period by Edwards and others (1991) and Helvey and others (1989).

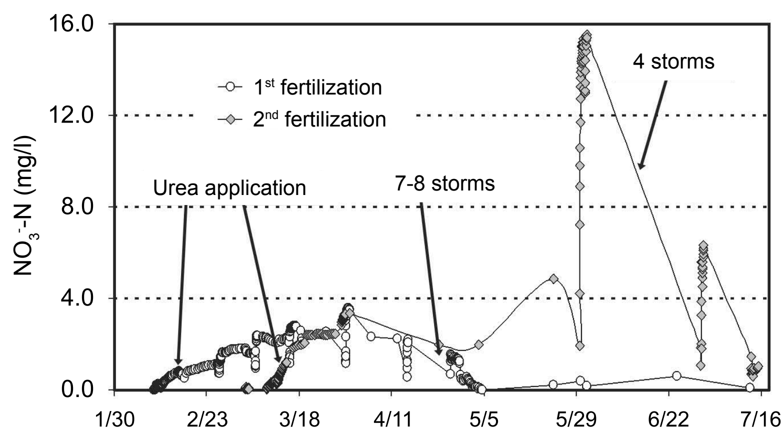

Figure 5—Stream NO_3^--N concentrations in the FSB shortly following the initial (1998) and second (2001) application of urea.

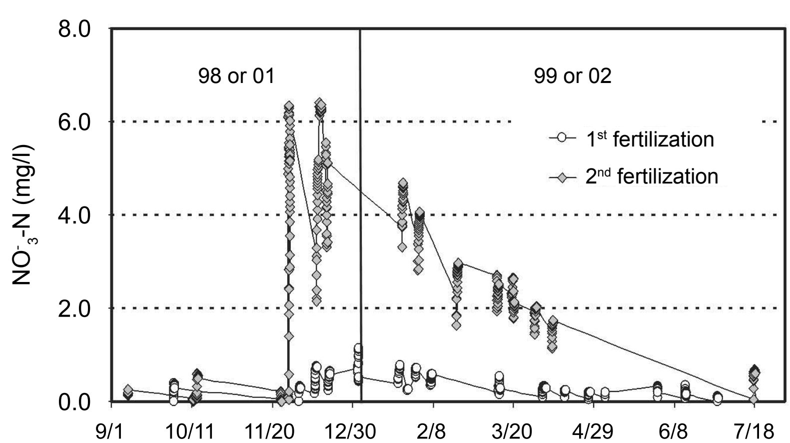

Figure 6—Stream NO_3^--N concentrations in the FSB 6 to 18 months following the initial (1998) and second (2001) application of urea.

Average maximum storm event NO_3^--N concentrations 8 to 18 months after application (September to August) were significantly ($p<0.001$) higher following the second urea application (3.14 mg/l from 9/01 to 8/02) than they were following the first application (0.45 mg/l from 9/98 to 8/99). Average maximum concentrations were also still significantly greater ($p=0.01$) 18 to 30 months following the second application (0.45 mg/l) than the first application (0.17 mg/l). Increased levels of NO_3^--N in the soils or soil nitrification rates of the FSW following the second fertilization would likely contribute to these long-term increases in N concentrations. Soils in this watershed are shallow, and accordingly, discharge from the FSW responds rapidly to precipitation events. Thus, repeated application of fertilizer may have less long-term impacts on water quality in watersheds with deeper soils or that are hydrologically less responsive than the FSW.

SUMMARY

We have documented increased levels of N following two separate applications of urea in a subwatershed located in the Ouachita Mountains. An increase in N during application of the urea was in part attributed to direct application of fertilizer in a SMZ. Initial storm events following application elevated levels of NH_4^+-N. We hypothesize that application of fertilizer over unprotected ephemeral or intermittent stream channels may have contributed to the amounts of N in stream water during these events. NO_3^--N concentrations exceeded drinking water standards during two storm events following the second application of urea. Concentrations of NO_3^--N in stream water during storm events following the second application of urea were consistently greater than those following the first application of urea. It seems likely that repeated application of urea to the subwatershed has increased nitrification rates and/or the levels of N within the soils of the subwatershed.

Based on these results, the Weyerhaeuser Company in this region has modified their fertilization practices to prevent aerial drift of fertilizer into SMZs. New Arkansas BMPs instituted after this study also require more intermittent stream protection. While these changes will greatly reduce fertilizer delivery to the streams, upstream ephemeral areas may continue to contribute nutrients to protected reaches of stream systems. These contributions need to be further quantified.

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