LONG-TERM LEAF FALL MASS FROM THREE WATERSHEDS ON THE FERNOW EXPERIMENTAL FOREST, WEST VIRGINIA

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Abstract.—Foliar biomass may serve as an indicator of site productivity, and spatial and temporal changes can help us understand effects of important variables affecting productivity. Leaf litterfall mass is one way to estimate foliar biomass, and has been measured on three watersheds on the Fernow Experimental Forest in West Virginia for 19 years. These watersheds all contain Appalachian mixed hardwood stands. The hardwood stand on watershed 4 (W4) has been untreated since around 1910 and serves as the primary reference watershed for the Fernow. The stands on watersheds 3 (WS3) and 7 (WS7) regenerated from clearcuts in 1969-1970. Using 25 litterfall traps per watershed, annual leaf fall mass has been determined since 1989 (WS3, WS4) or 1991 (WS7). Leaf fall mass is greatest on WS4 over time. Despite the addition of 35 kg of nitrogen per ha each year since 1989 to WS3, there is no statistically significant difference in litterfall mass between the two young stands (WS3 and WS7).

INTRODUCTION

Uncertainty about the effects of acidic deposition on forest health and productivity continues to be an issue of concern for forest managers and scientists. There is evidence that acidic deposition may affect soils in some forest types, with implications for health of those forests, most notably red spruce in the northern Appalachians and Adirondacks (Eagar and Adams 1992, DeHayes and others 1999), and sugar maple in some parts of the northeastern U.S. and Canada (Horsley and others 2000, Duchesne and others 2002). Acidic deposition impacts on aboveground productivity have not been well documented in other eastern forest types, however, and ongoing research into effects of acid deposition on forest soil properties and processes continues to be relevant and critical.

The Fernow Watershed Acidification study was begun in 1988, with the objective of determining the impacts of atmospheric deposition on forest ecosystems by determining changes in solution chemistry, particularly soil leachate and stream water chemistry (Adams and others 2006). Since 1989, we have been adding 35 kg N/ha/yr and 40 kg S/ha/yr as ammonium sulfate fertilizer, applied three times per year to the treatment watershed. The scope of the study has expanded over the years, and considerable effort has been made to identify effects on productivity of the forest resulting from soil chemical changes. Measurements of forest productivity, however, are often less sensitive to atmospheric deposition than are soil and water chemistry (Reed and others 1994).

Leaf area is related to the productivity of a forest stand through the mechanism of photosynthesis; leaves are the primary producers of energy for trees. Because of this link, foliar biomass may be one indicator of productivity of forest stands, and it can be easily estimated by determining the amount of leaf shed over the course of a year. Particularly in deciduous stands, this estimate can be easily made with a reasonably high degree of confidence (Lloyd and Olson 1974) by sampling autumn leaf fall. We have been monitoring leaf fall mass since 1988 as part of the Fernow Watershed Acidification Study (Adams and others 2006); here we present the results of this long-term monitoring effort. We hypothesized either an increase in leaf fall

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Table 1.—Some characteristics of the study watersheds. Stand parameters are based on the 1990 inventory for watershed 4, 2004 for watersheds 3 and 7

	Watershed 3			Watershed 7			Watershed 4		
Area (ha)		34			24			39	
Aspect		South			East			Southeast	
Mean elevation (m)		792			792			792	
Stand age in 2007		37			37			97	
Mean stand density (stems ha^{-1})		1883			1473			1206	
Mean stand basal area (m2 ha^{-1})		36.0			28.0			38.6	
Mean stand biomass (mt ha^{-1})		203.4			157.5			310.65	
Dominant tree species (stems ha^{-1}) (% basal area)	Black cherry	442	(51.0)	Sugar maple	334	(4.9)	Sugar maple	336	(11.3)
	Red maple	366	(11.5)	Sweet birch	319	(20.5)	Red maple	188	(8.9)
	Am. beech	245	(2.5)	Red maple	274	(8.2)	Am. beech	183	(6.5)
	Sweet birch	161	(5.1)	Yellow-poplar	143	(26.2)	N. red oak	69	(29.8)
	Sugar maple	119	(1.3)	Black cherry	143	(20.5)	Sweet birch	42	(3.6)

mass, as a result of the increased nitrogen availability resulting from the repeated application of a fertilizer containing nitrogen, or perhaps a decline in leaf mass as the soil acidified and base cation depletion occurred. Our larger objective was to find a simple, reliable signal to detect productivity changes resulting from acidic deposition.

SITE DESCRIPTION

The three watersheds that have been monitored as part of the Fernow Watershed Acidification study are located on the Fernow Experimental Forest (FEF) in north central West Virginia (39.03° N, 79.67° W), in the Allegheny Mountain section of the mixed mesophytic forest (Braun 1950). The growing season of the FEF extends from May through October and the average length of the frost-free season is 145 days. Annual precipitation is evenly distributed between growing and dormant seasons, averaging 145.8 cm. The average annual air temperature is 9.2 °C. Soils are acidic, derived from acid sandstone and shale, and about a meter in depth (Kochenderfer 2006).

Forests on the FEF are predominantly deciduous hardwoods, with a high diversity of tree species. Dominant tree species include black cherry (*Prunus serotina*), yellow-poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), and northern red oak (*Quercus rubra*), among others (Table 1). The stands on these three watersheds have different treatment histories as part of long-term research on the FEF. Watershed 4 (WS4), which serves as the main long-term reference watershed on the FEF, has been undisturbed since around 1910, when much of eastern West Virginia was logged for the first time (Kochenderfer 2006). Watershed 3 (WS3) originally received an intensive selection cut in 1958-1959, and then was harvested in a series of patch clearcuts in 1968-1969. Watershed 7 (WS7) was clearcut and maintained barren with herbicides between 1963 and 1969. Both WS3 and WS7 regenerated from natural regeneration sources beginning in the winter of 1969/1970. WS3 was then selected in 1988 to serve as a treatment watershed for the Fernow Watershed Acidification Study. Since 1989, WS3 has received approximately 35 kg N/ha/yr and 40 kg S/ha/yr as ammonium sulfate fertilizer, applied 3 times per year. For water chemistry and hydrologic purposes, WS4 is the reference watershed in the Fernow Watershed Acidification Study. However, because of the differences in stand age between WS3 and WS4, we decided that information should also be collected from WS7, where the trees are the same age as in WS3. Further information about the three watersheds is shown in Table 1, and can be found in Kochenderfer (2006).

METHODS

Twenty-five litterfall traps (91 cm x 91 cm x 10 cm deep) were randomly located on each of the three forested watersheds. Each autumn, beginning in 1988, the leaves from these traps are collected in plastic bags and returned to the lab for drying and weighing. Approximately weekly collections are made throughout the autumn (generally three to five collections per year), until all of the leaves appear to have fallen. The leaves in each litter trap are dried to a constant mass in a 60 ºC oven, and the mass recorded. Litter traps are cleaned before leaf fall each year, and only leaf fall into the traps is collected (i.e., no large or small woody debris; seeds are not excluded). Total leaf dry mass is determined for each litterfall trap, and then a total value estimated for each stand. Because of the high species diversity and the large effort involved in separating leaf litter by species, the total leaf fall mass was determined across all tree species. Also, Lloyd and Olson (1974) reported that while this method provides precise estimates of annual leaf fall mass for mixed hardwood stands, it does not appear to be particularly good for estimating annual leaf fall mass of individual tree species.

Means and standard deviations were calculated for each watershed for each year, and means were compared between each pair of watersheds using t-tests (WS3 vs. WS4, WS3 vs. WS7, WS7 vs. WS4), with comparisons made at the 0.05 level of significance. Data were analyzed using linear regression techniques to examine trends within watersheds over time, and to evaluate relationships with growing season precipitation amount.

RESULTS AND DISCUSSION

Annual leaf fall mass ranged from 1.92 Mg/ha (WS7, 2000) to 5.57 Mg/ha (WS4, 2004), with considerable year-to-year variability (Table 2). Leaf mass on WS7 (coefficient of variation of 14 percent)was slightly more variable from year to year than WS4 (11.6 percent) and WS3 (910.6 percent). These values approximate the range described by Jenkins (2002) of 2.5 to 5.4 Mg/ha/yr for Central Hardwood forests. Kochenderfer and Wendel (1983) reported a much narrower range, from 3.94 to 4.68 Mg/ha/yr over a 4-year period for stands on north- and south-facing slopes on the FEF. In general, the stands evaluated by Kochenderfer and Wendel (1983) were second-growth stands, comparable in age to the stand on WS4. Leaf fall mass was consistently greatest on WS4, the oldest of the three stands. WS4 was also the stand with the highest aboveground biomass, suggesting an age or biomass effect. Stands with greater aboveground biomass are likely to produce more leaf area than those with less biomass. Muller and Martin (1983) compared old-growth and second-growth (approximately 45 yrs old) forests in eastern Kentucky and found no significant difference in total leaf fall between the two stands, averaging 2.91 Mg/ha. Note, however, in that study the basal area did not differ between the two stands, and was equal to that of the WS7 stand in our study (~29 m^2/ha). Thus stand biomass may not have varied greatly between the two Kentucky stands. The authors reported the two stands were similar in species composition as well.

The interannual variability (annual cv range = 9.3 percent to 28.6 percent) was not significantly related to growing season precipitation amount (for WS4 r^2=0.1172 p=0.2117) to total annual precipitation (WS4: r^2=0.0728, p=0.3308), nor did it appear to be related to specific large disturbances such as windstorms

Table 2.—Annual leaf fall dry mass from three watersheds on the Fernow Experimental Forest

year	WS3	WS3 std.dev	WS7	WS7 std.dev.	WS4	WS4 std. dev.
	----------Mg/ha----------					
1988	3.33	0.31			4.2	0.69
1989	3.19	0.50			3.89	0.69
1990	3.02	0.57			3.56	0.53
1991	3.31	0.57	3.31	0.47	4.21	0.53
1992	3.41	0.40	3.08	0.52	4.19	0.99
1993	3.19	0.37	3.01	0.56	3.82	0.76
1994	3.21	0.47	3.09	0.61	3.60	0.60
1995	3.11	0.39	3.32	0.57	4.35	0.68
1996	3.05	0.54	3.00	0.49	4.38	1.12
1997	2.15	0.37	2.35	0.45	3.61	0.67
1998	2.67	0.51	2.98	0.65	3.92	0.82
1999	2.84	0.34	2.89	0.42	3.96	0.50
2000	2.86	0.41	1.92	0.40	3.68	0.51
2001	3.22	0.40	3.71	0.55	4.59	1.21
2002	2.92	0.30	3.10	0.44	4.04	0.48
2003	3.35	0.43	3.44	0.40	4.50	0.60
2004	2.91	0.57	3.25	0.49	5.57	1.43
2005	3.63	0.43	3.49	0.46	4.35	0.86
2006	2.89	0.41	3.36	0.96	3.70	0.68
mean	3.06		3.08		4.11	
std.dev.	0.32		0.43		0.47	
coefficient of variation	10.6%		14.1%		11.6%	

and ice storms which significantly affected the canopy (Adams and others 2003; Fig. 1). Burton and others (1991) reported that they could not attribute changes in litter production to an acid deposition gradient because of year-to-year variability resulting from insect defoliation and seed production.

Leaf fall mass was significantly greater on WS4 than on WS3 or WS7, but the differences between WS3 and WS7 were generally not statistically significant. This result suggests that the acidification treatment has not significantly increased leaf production on WS3 as a result of increased nitrogen availability. We might have expected an increase in foliar biomass over time on WS3 and WS7 as younger trees are generally more capable of utilizing available N. Significant increases in foliar nitrogen concentrations were observed for some tree species in the early years of the fertilization treatment (Adams and others 2006), which provides support for this hypothesis. In addition, there was an initial positive volume growth response to the fertilizer additions (DeWalle and others 2006), providing support for the idea of a short-term increase in productivity due to increased nitrogen availability. This fertilizer effect was not sustained, however, either in terms of nutrient concentrations or aboveground growth (Adams and others 2006, DeWalle and others 2006). Therefore, we conclude that an apparent effect of the fertilizer on leaf fall biomass was not detected, either as a difference between WS3 and WS7, or as an increase or change in litter fall mass over time for WS3. None of the watershed regression lines shows a statistically significant trend over time (Fig. 2). The

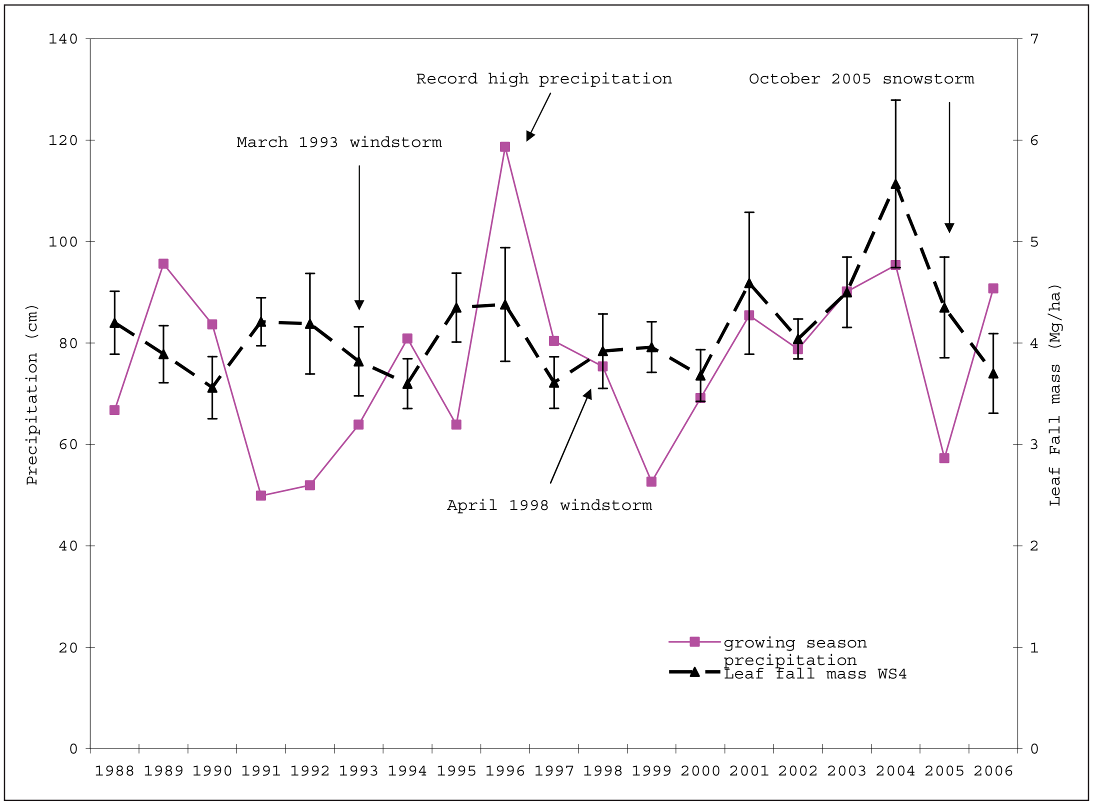

Figure 1.—Leaf fall mass (Mg/ha/yr) and growing season precipitation (May 1-October 31) from watershed 4 on the Fernow Experimental Forest. Significant climatic events which could affect leaf fall mass are indicated (Adams and others 2003.)

effect may have been short-lived, perhaps due to increasing competition among the young trees because of high stand density, or perhaps due to another nutrient limitation (phosphorus or possibly calcium). We have some evidence to suggest that phosphorus may be limiting the volume growth of black cherry on WS3 (Adams and others 2006).

Similarly, a decline in leaf biomass which might be attributed to the cumulative acidification effects of the treatment was not demonstrated. Such a decline might occur if soil acidification processes adversely affected productivity. There is some evidence from soil solution chemistry of mobilization and decline of calcium (Edwards and others 2006), although exchangeable soil calcium levels did not significantly change (Adams and others 2006). The mobilization and depletion of calcium is reflected in a relatively limited sample of tree rings, both in radial growth and dendrochemistry (DeWalle and others 2006), but does not show up as a statistically significant effect in leaf fall mass. Although the slope of the regression line for WS3 is negative (Fig. 2), the trend is not statistically significant.

Other studies of fertilizer effects on hardwood forests have shown relatively few effects on foliar mass or leaf fall. Kochenderfer and Wendel (1983) reported no statistically significant effects of a single addition of 336 kg N/ha on leaf fall biomass on either north- or south-facing watersheds containing second-growth hardwood forests. Other researchers working in similar central Appalachian hardwood stands (Auchmoody and Smith 1977), reported slight increases in foliar mass of yellow-poplar and northern red oak as a result of fertilization, but these differences were not statistically significant, although foliar chemistry was significantly altered by the treatment.

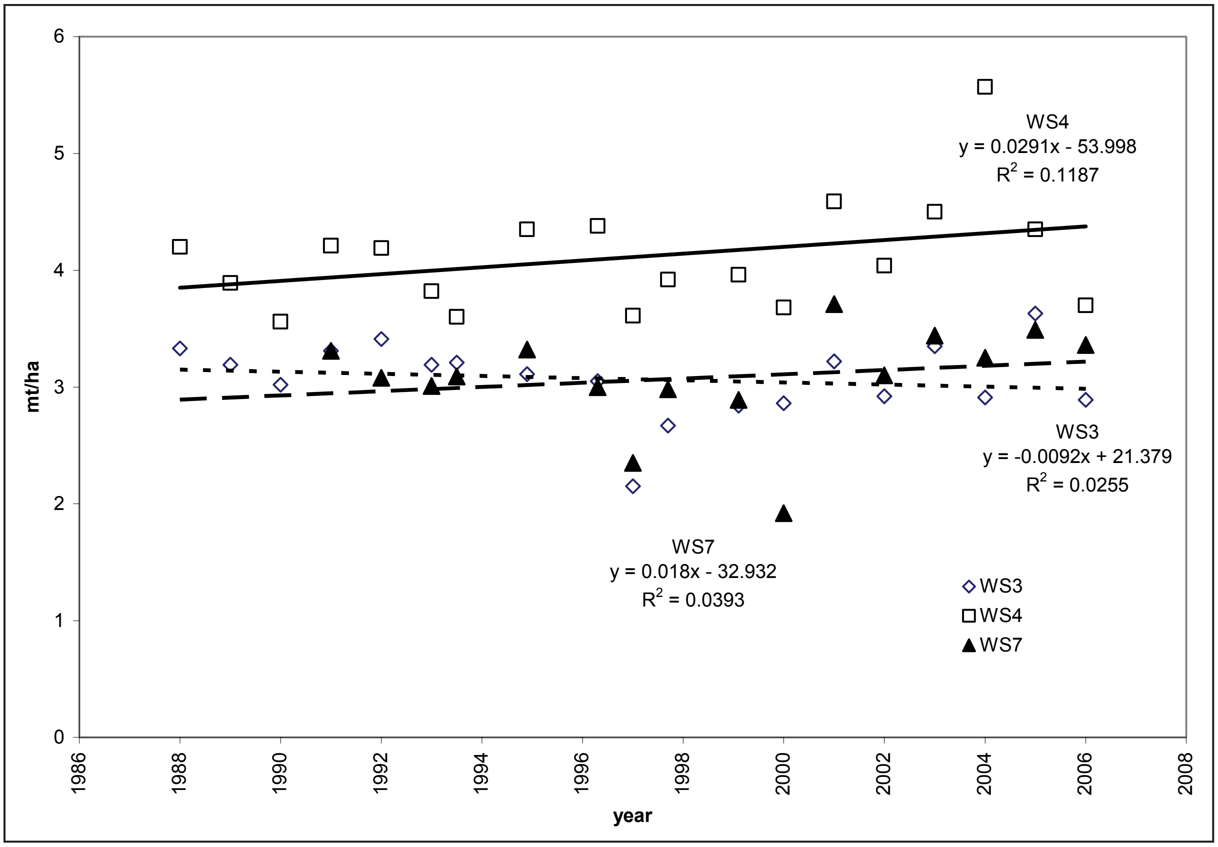

Figure 2.—Leaf fall mass (Mg/ha/yr) from three forested watersheds on the Fernow Experimental Forest, with linear regression trend lines and statistics.

In general, our results suggest that leaf fall biomass is relatively nonresponsive to site quality, except perhaps as mediated through effects on overall biomass, as neither fertilization treatments nor differences in precipitation amount significantly altered the annual leaf fall mass in these stands. It is possible that the fertilization treatment, while having other ecosystem effects, may not have been a sufficiently large amount of nitrogen to create the hypothesized response. Conversely, the significant interannual variability in leaf fall mass may have masked any treatment effects. Finally, the response of leaf area and mass to fertilization is complex, and any initial effect may have diminished over time. The Fernow Watershed Acidification Study is on-going, and fertilization treatments and monitoring are continuing. Further assessments of productivity, including continuing measures of leaf fall mass, will provide us with additional insights into the relationship between acidic deposition, soil fertility and forest productivity.

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