Retention of Particulate Lead on Foliage and Twigs of a White Pine Windbreak

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ABSTRACT.—The removal of particulate lead from the air by a roadside windbreak of white pine containing 8 rows of 25-year-old trees and 27 m in depth was studied. Knowledge of particulate trapping and retention was gained by atomic absorption spectrophotometry of the lead burden of foliage and twigs of various ages adjacent to and far from the road. The effectiveness of the windbreak was also shown by comparison of the lead content of the soil beneath the windbreak with that of an adjacent open, undisturbed field.

VEGETATION AND SOILS adjacent to heavily-traveled roads incur significant deposits of lead from automobile exhaust *(Cannon and Bowles 1962, Motto et al. 1970, Page et al. 1971)*. The lead is associated with chlorine and bromine in particles on or embedded in plant surfaces *(Heichel and Hankin 1972)*. Observations that the lead burden is frequently retained tenaciously by vegetation *(Smith 1972, Heichel and Hankin 1972)* prompted us to speculate that foliage and twigs of roadside coniferous windbreaks might filter particulate lead from the air and reduce its dispersion from the road. The efficacy of a windbreak in removing particulate lead was evaluated by analyses of the lead burden of foliage and twigs of various ages adjacent to and far from the road. Also, we compared the lead content of the soil beneath the windbreak with that of an adjacent open undisturbed field.

MATERIALS AND METHODS

Site

The windbreak of white pine *(Pinus strobus)* trees growing as a dense roadside screen west of the curb of a heavily-traveled two-lane highway in Hamden CT contained 8 rows of 25-year-old trees and was about 12.2 m tall in the center. The near drip-line of the windbreak commenced 3 m from the curb of the highway, and the far drip-line terminated 30.5 m from the curb. Thus the windbreak was about 27 m in depth.

An open field adjacent to the highway and about 150 m north of the windbreak served as a control site for measuring lead accumulation in soil. The field had not been tilled since establishment of the windbreak and supported a lush growth of perennial forage species that was mowed once a year and allowed to decompose.

Table I.—Daily traffic flow past the windbreak in 1973

Month	Average daily traffic[1]
	No. of vehicles
January	12,960
February	12,960
March	13,680
April	14,500
May	15,600
June	15,800
July	15,000
August	14,700
September	14,800
October	15,100
November	14,400
December	13,200

[1]Source: Connecticut Department of Transportation.

Traffic Flow

Commuter and truck traffic passed the windbreak at 65 to 73 km/hr. A survey station maintained by the Connecticut Department of Transportation 1.6 km north of the windbreak recorded the average daily traffic flow on a monthly basis during 1973 (table 1). Traffic volume during the course of the investigation ranged from 15,800 vehicles/day in June to 13,200 vehicles/day in December, with a mean of 14,800 vehicles/day.

Wind and Precipitation

Records of the prevailing wind patterns in the locality of the windbreak *(Brumbach 1965)* revealed that the trees were downwind of traffic for 3 of the 8 months of the investigation—May, September, and October (table 2).

Precipitation for the 30-day period before each sampling was monitored at the Mt. Carmel weather station located 4.8 km south of the windbreak (table 2).

Sampling and Analysis

Branches were sampled on seven occasions from May to December 1973 from limbs 0.75 to 1.5 m above the soil surface, separated into needles and twigs of various ages, oven-dried, and ground. For measurements of soil lead content, transects were established through the windbreak and across the open field. Samples of the upper 5 mm of needles on the soil beneath the windbreak, and of the upper 20 mm of mineral soil under the windbreak and open field, were oven-dried. Lead analyses were by atomic absorption spectrophotometry *(Fletcher 1971)*.

RESULTS AND DISCUSSION

Knowledge of particulate retention was revealed by the lead burden of needles and twigs adjacent to and far from the road. Needles on the windbreak adjacent to the road persisted 27 months between emergence in late May and senescence 2 years later in September, while needles far from the road persisted 1 month longer.

The lead burden of older needles was consistently greater than that of younger needles (fig. 1 and 2). On 14 June, for example, 1972 needles near the road bore nearly 4-fold and 1971 needles nearly 6-fold the 35 μg/g dry-weight lead burden of 1973 needles. The 1972 needles far from the road bore 3-fold and 1971 needles nearly 6-fold the 5 μg/g lead burden of 1973 needles. Except for the 20 August samples obtained near the road, and the 29 December samples far from the road, older twigs bore a greater lead burden than newer, younger twigs (fig. 1). Clearly, the lead burden of coniferous foliage and twigs was directly related to the duration of exposure to contamination.

The lead burden of needles and twigs varied with time of year (fig. 1 and 2). The burden of 1971 needles sampled

Table 2.—Wind and precipitation in the vicinity of the windbreak

Sampling date (1973)	Mean monthly wind direction	30-day cumulative precipitation at sampling
		(cm)
15 May	East	13.31
14 June	Southwest	9.73
July	Southwest	—
20 August	Southwest	11.71
17 September	Northeast	4.60
30 October	Northeast	8.38
26 November	Northwest	7.34
29 December	Northwest	30.33

Figure 1.—Patterns of retention of lead on needles and twigs located on the near side of a white pine windbreak adjacent to a road.

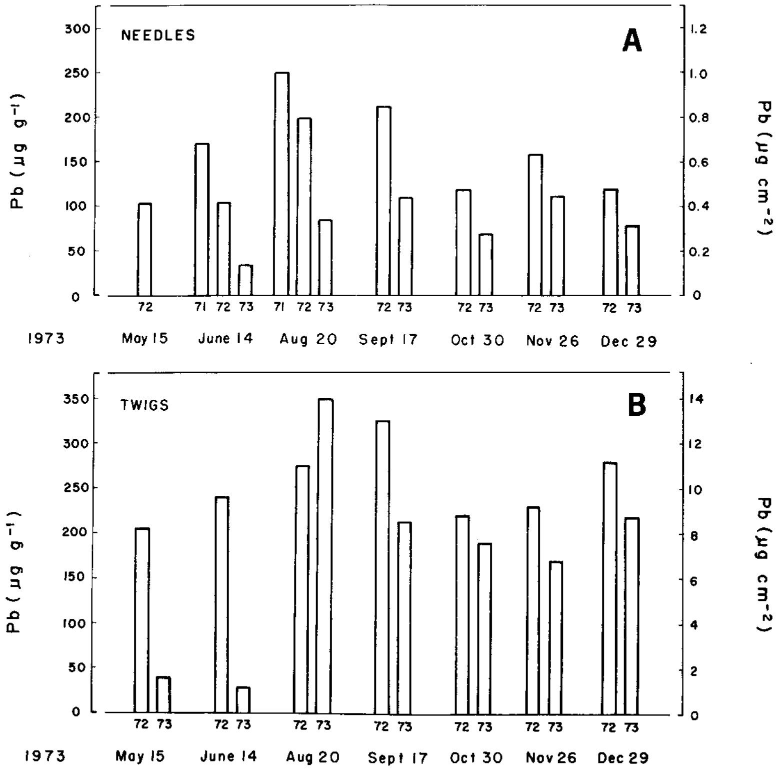
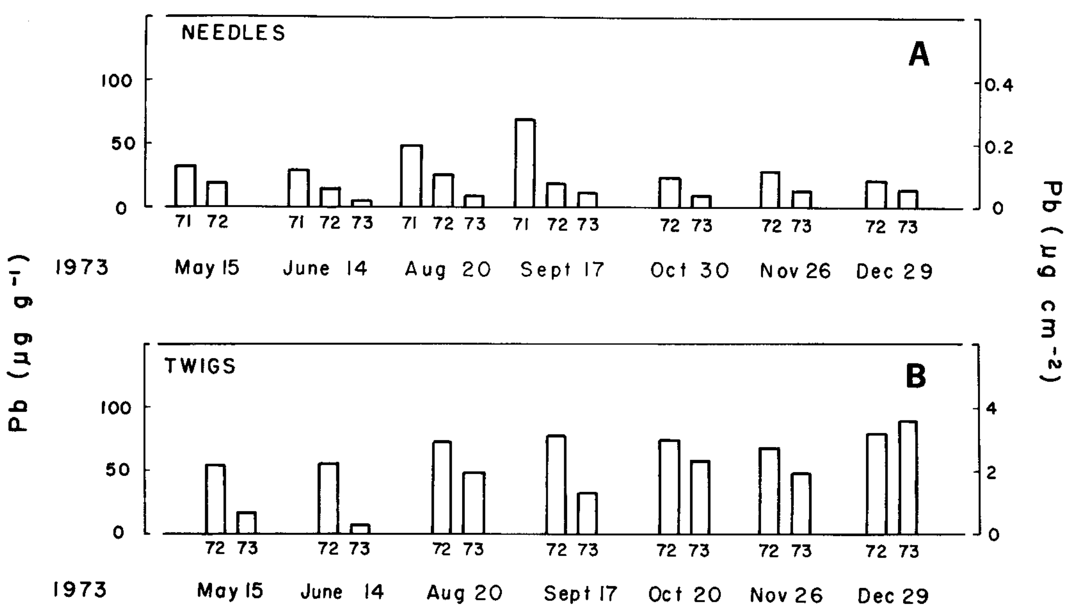


Figure 2.—Patterns of retention of lead on needles and twigs located on the far side of a white pine windbreak adjacent to a road.



near and far from the road increased from May until they were shed in September. The lead content of 1972 and 1973 needles obtained adjacent to the road peaked in September and then declined during the remainder of 1973. In contrast, the lead burden of 1972 and 1973 needles sampled far from the road remained relatively invariant throughout the year (fig. 2A).

The increase in the lead burden of 1972 and 1973 twigs near the road continued until August, commenced to decline about 1 month before that of needles, and then increased slightly in December (fig. 1B). The lead content of 1972 and 1973 twigs far from the road slowly increased throughout the year, in contrast to the pattern of lead accumulation on twigs adjacent to the road (fig. 2B). Adjacent to the road, therefore, the pattern of lead accumulation throughout the year on twigs was similar to that of needles except for a slight shift in phase.

The pattern of lead accumulation on fully expanded needles varied with precipitation in the interval preceding sampling (table 2, fig. 1A). About 4.6 cm of precipitation, 61 percent less than in the previous sampling period, occurred between 20 August and 17 September. Concurrently the lead burden of 1972 foliage increased 2 percent and that of 1973 foliage 29 percent by 17 September compared with 20 August. In contrast, 8.4 cm, or 82 percent more rain fell in the 30 days ending on 30 October, and the lead burden of 1972 and 1973 foliage was diminished about 45 percent compared with that of the 17 September sample. About 7.4 cm of precipitation, or 13 percent less than in the September-October interval, fell in the 30 days ending 26 November. This decrease in precipitation was accompanied by a 32-percent increase in the lead burden of 1972 foliage and 60 percent increase in that of the 1973 foliage on 26 November compared with 30 October.

As a final illustration, 30.3 cm of water fell as rain, sleet, and snow in the 30 days before the 29 December sampling. This abrupt increase in precipitation was accompanied by a decline of 24 percent in the lead burden of 1972 foliage and 30 percent in that of 1973 foliage compared with 26 November. In contrast, the pattern of lead accumulation on twigs was unrelated to the pattern and quantity of precipitation, presumably because particles are less easily dislodged from the rugged topography of twigs than from the waxy, even surfaces of needles.

The seasonality of traffic flow apparently had no effect on the pattern of lead accumulation on foliage and twigs adjacent to the road (table 1, fig. 1A and 2A). Peak traffic flow occurred in May and June, but maximum lead accumulation occurred in September. Traffic flow increased between August and October, but the lead burden of twigs and needles declined. Compared with the changes in lead burden related to precipitation, seasonal traffic-volume changes of 3 to 8 percent were clearly insufficient to be reflected in lead deposition on needles and twigs. Finally, the expected dilution of the lead burden by rapid foliage and twig growth from May through July did not occur. Indeed, lead accumulated rapidly on foliage and twigs at this time of year.

Retention of lead by needles and twigs was evaluated on mass and area bases (fig. 1 and 2). Twigs of various ages near and far from the road retained about 115 percent more lead/g than similarly located needles. We observed, however, that needles displayed about 10-fold more area/g than twigs. Thus, twigs retained about 2,050 percent of the lead burden/cm of similarly located needles. Clearly, the surfaces of twigs retain particles more effectively than the surfaces of needles.

With these retention patterns, the lead burden of a single tree in the windbreak can be illustrated. Unpublished data of our colleague George Stephens reveals that a 12-m-tall white pine growing in a dense planting would have about 15 x 10^4/cm^2 of woody surface and about 15 x 10^5/cm^2 of foliage surface. Although the tree exposed about 10 fold more foliage than woody surface, the woody surfaces retained about 20-fold the lead burden of foliage (fig. 1 and 2). Thus, about two-thirds of the lead on a tree in the windbreak would be retained on the wood, and the remaining third on the needles.

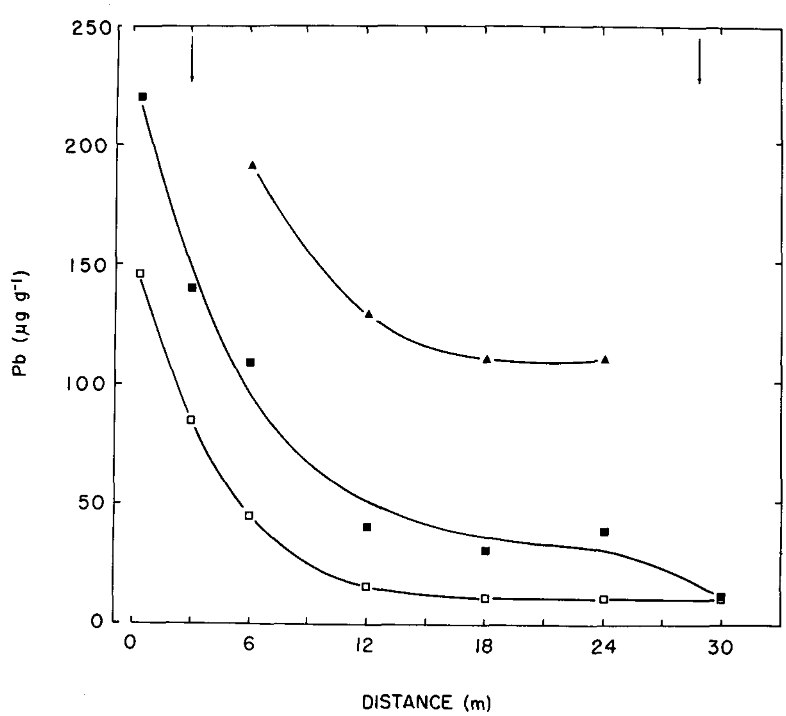
Comparing the soil lead burden beneath the windbreak with that of the open field demonstrated the increased accumulation resulting from the presence of the windbreak (fig. 3).

In the open field, the lead content of the upper 2 cm of soil declined from about 150 μg/g 0.3 m from the curb to 12 μg/g at 18.3 m from the curb, and remained at 12 μg/g to 30.5 m from the curb. However, the soil between the curb and the near drip-line of the windbreak contained 140 to 220 μg/g lead, or about 50 percent more than that of the open field at a similar distance from the road.

Within the windbreak, the soil contained 110 μg/g lead 6 m from the curb to 38 μg/g 24 m from the curb, or about double the lead burden of the field soil at similar distances from the curb. Beyond the far drip-line, the lead burden of the soil near the windbreak, 12 μg/g, was similar to that of the field soil at the same distance from the curb (fig. 3).

Compared with that of the open field, the lead burden of the soil beneath the windbreak might be enhanced by incorporation into soil of needles, twigs, and bark that fall from the trees, by re-

Figure 3.—The lead burden of the needle litter (▲) and soil (■) beneath a windbreak, and of soil in an open field (□) at various distances from a road. The curves are drawn by hand. Distance=0 is the curb, and the arrows indicate the canopy drip-lines.



moval of impacted lead from the surfaces by precipitation, and by increased sedimentation of particles from the air.

That needlefall would enrich the soil with lead was shown by sampling the litter layer beneath the windbreak. The uppermost 5 mm of needles beneath the windbreak was enriched 76 to 300 percent compared with the upper 2 cm of underlying soil. The lead content of the needle litter on the roadward side of the windbreak was about 190 μg/g, similar to that of the 1971 needles that were sampled prior to senescence in early September. The lead burden of the needle litter mirrored that of the underlying soil and diminished with distance into the windbreak (fig. 3). The rates of deposition of lead from twigs and bark in the litter layer remain to be evaluated.

There have been numerous reports that, in the laboratory, washing with water removes lead from leaf surfaces rather easily *(Page et al. 1971, Smith 1972, Little 1972)*. Our field results further illustrate this by revealing that the lead burden of needles, but not of twigs, varies with patterns of precipitation.

Compared with needles, the invariance of lead removal from twigs by precipitation is probably due to the characteristics of woody surfaces. Lead particulates are undoubtedly less easily eroded from the fissures, cracks, and seams of woody surfaces than from comparatively smooth needle surfaces.

The pattern of wind movement into and through windbreaks might be of substantial significance in the deposition of lead-bearing particulates. For a windbreak having a composition and dimensions similar to ours, Caborn *(1957)* showed that the wind velocity on the leading edge was reduced to about 70 percent of the free wind velocity. That sedimentation of particles from moving aerosols increases with diminishing wind speed is well established *(Davies 1966)*. Moreover, 30 to 50 percent of the particulate lead in automobile exhaust is larger than 5 μm diameter *(Hirshler and Gilbert 1964)*, has settling velocities greater than 0.3 cm/sec, and likely settles more rapidly within the windbreak than without.

Compared with the open field, therefore, reduction of wind velocity at the roadward edge of the windbreak might account for a significant proportion of the increased lead burden in the soil adjacent to the road. Additionally, eddy circulation on the leading edge of a relatively impenetrable windbreak is groundward *(Caborn 1957)*, and this pattern of air movement might enhance deposition of particulates on the soil surface.

Within a windbreak having a structure similar to ours, Caborn *(1957)* observed that the windspeed was only 50 to 60 percent of the free wind velocity. A halving of windspeed might be expected to double the rate of particulate sedimentation from moving aerosols *(Davies 1966)* like automobile exhaust dispersing from roadways. Our observations that the soil within the windbreak bore about double the lead burden of that of the open field therefore conform to expectation.

Windbreaks have long been used to shelter plants from the desiccation of brisk and persistent winds. Our results, however, suggest another role for windbreaks in the urban environment: to act as a sink for particulate pollutants and thereby beneficially modify their dispersion from roadways.

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