ARSENIC TOXICITY IN RED PINE AND THE PERSISTENCE OF ARSENIC IN NURSERY SOILS

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Small amounts of arsenic occur in all soils and plants, but use of arsenic-bearing insecticides in earlier years and of arsenical herbicides recently has often increased soil and plant contents. Since arsenic is only slowly lost through leaching or cropping, additions accumulate, occasionally to the point of plant injury (1, 7). Studies of such injury demonstrate that the likelihood and severity of growth reductions are "a function of the kind of soil, the amount of arsenic present, and the kind of plant" (7), making simple generalizations impossible.

New materials have long displaced arsenical insecticides, and the history of their use is often forgotten even where large quantities were applied. Recently we investigated an unexplained tipburn of red pine *(Pinus resionsa* Ait.) at the Lowville, N.Y. State Forest Nursery and found that its cause lay about 35 years in the past, with applications of arsenic to control white grubs.

Visible Symptoms

Generally, 3-0 red pine seedlings from the area of tipburn were almost as tall as uninjured "green" seedlings in the same compartment, and the foliage was only slightly shorter and lighter-10 vs. 12 cm. long; 2.9 vs. 3.4 grams dry weight/100 needles. The tipburn appeared as a brown dead area, about 0.3 to 0.7 cm. long, on every first year needle. To be precise, a medium brown (Munsell color 5YR 5/4-6/5) at the very tip graded into dark brown (5YR 3 3/4) and that through a narrow yellowish or pale green (5GY 7/4-6) transition zone. Below the transition zone, the needle appeared more or less normal; foliage of the upper part of the shoot, however, was distinctly paler than below, or on visibly unaffected seedlings (5GY 5/4 vs. 7.5-10GY 4/4). Tips of the second year foliage were dead and weathered for 1-2 cm. Al these evidences were even more strongly expressed in occasional small patches. Roots of both tipburned seedlings and nearby "green" seedlings in the same compartment were affected. The tipburned seedlings essentially lacked fine roots except for a few mycorrhizal clusters on the upper laterals. The nearby seedlings without top injury had only fair root systems, with an appreciable lower density of fine roots than elsewhere in this nursery.

Tissue Analyses

Our initial spectrographic analyses showed no evidence of nutrient deficiency, no nutritional differences between tipburned and other foliage, and no concentration of micronutrients in the dead tips. Apparant copper content was excessive-around 100 p.p.m.-but this was caused by external coatings of fungicide. We then determined arsenic content by ashing with magnesium nitrate and following the AOAC procedure. This involved separation of arsenic as arsine and colorimetric determination as molybdenum blue.

Table 1 presents the arsenic content characterizing two collections of tipburned seedlings; foliage containing 2 p.p.m. or less was unaffected, whereas at 8 p.p.m. tipburn was marked. The 8 p.p.m. probably is an average value of higher concentrations near the needle tips and in the upper foliage, and lower elsewhere. The second year foliage contained somewhat more arsenic than the first, even though sheltered against high transpiration by the new shoots.

As noted, the finest roots were almost entirely lacking on the tipburned seedlings. Since arsenic accumulation is normally highest in small roots, it is probable that the finest roots had been killed by earlier, and possibly even higher, concentrations than shown. Further, the apparently intact roots of "green" seedlings, almost certainly had been severely damaged also, since such concentrations (50 p.p.m.) are exceptionally high.

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TABLE 1.—*Arsenic content (dry weight) in 3–0 red pine from compartment 5, Lowville Nursery*

Samples	Foliage 1st yr.	Foliage 2d yr.	Stems 1st yr.	Fine roots (< 2 mm.)
	Arsenic			
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
Fall samples—				
Control	< 1			
Mod. tipburned[1]	8			
Severly tipburned[1]	20			
Spring samples—				
Green	2.0	3.0	0.5	52
Tipburned ...	8.5	11.5	1.0	49.5[2]

[1] Bulk sample made up of the outer ½-⅔ of the needle length. This part may have contained somewhat higher concentration than the whole needle.

[2] The comparison of root contents is biased by lack of < 1 mm. roots in the tipburned seedlings; most of this sample between 1 and 2 mm., as compared with a preponderance of < 1 mm. roots in the "green" seedling sample.

In contrast, an oat cover crop sown on the same area immediatetly after lifting the pine grew vigorously and contained only from 1.0 to 2.1 p.p.m. arsenic in the tops, and from < 0.5 to 2.5 p.p.m. in the fine roots, when sampled in mid-June. Comparable samples from low arsenic soils elsewhere in the nursery contained less than 0.5 p.p.m. in both tops and roots. This marked difference between pine and grain may be caused in part by the physiological properties of the oat roots, but also to the large production of dry matter within a relatively short period, allowing limited opportunity for accumulation. It is clear that performance of the cover crop gave no hint of the hazard to conifer seedlings.

Soil Analyses

Soil of the nursery area is predominantly a Duane loamy fine sand. Soil reaction in the tipburn area varried from pH 5.6-5.7. No mechanical analyses were made, but texture estimates by "feel" indicated that the areas with visible tipburn probably contained somewhat less fine sand, silt, and clay than the surrounding areas.

Estimates of total soil arsenic in the affected compartment and those nearby were made according to the 1955 AOAC methods. Results are given in table 2. Other samples from newer blocks of this nursery contained only about 2 p.p.m.

It is instructive to compare these amounts with the probable history of arsenic use in the N.Y. State Nurseries, as indicated by references in the Annual Reports of the Conservation Department (4). Almost certainly the original recommendation of material and amount was through H. B. Peirson's 1927 bulletin (2), which reported favorably an Australian finding that crude white arsenic (arsenic trioxide) at the rate of 80 lbs. per acre controlled white grubs in nurseries. The New York report for 1931 stated that "this past year" use of crude arsenic at the 80 lb. rate materially reduced damage, but experiments indicated that 150 lbs. should be used for complete eradication. The report of the following year went further: ". . . since damage this year was not materially reduced by using eighty pounds of crude white arsenic to the acre, one hundred fifty pounds will be used in 1933." The 1934 and 1935 reports indicate that damage to trees had occurred, and use of arsenic was discontinued.

Assuming 2.5 million lbs. soil per acre furrow slice and a 76-percent As content in crude white arsenic, then 25 p.p.m. As in soil (the approximate mean for the moderate group (table 2)) is equivalent to 75 lbs. of white arsenic per acre, or essentially the recommended 80 lbs. The weight is perhaps too conservative with present plowing depths, and the arsenic content is too liberal. Similarly, values around 50 p.p.m. (table 2) would correspond to the 150 lb. application of the above reports, whereas the 83 p.p.m. value suggests repeated application. Arsenic is strongly fixed in soil so that leaching losses are slight, although plant availability is high in soils low in clay. Even when plant contents are injuriously high, the removal by cropping is negligible-10 p.p.m. in a 5-ton crop is only 1 lb. As per acre. Thus the values (table 2) reflect, probably accurately, the original levels of arsenic application some 35 years previously.

Discussion and Conclusions

It was soon recognized in New York (4) and elsewhere (3, 5) that arsenic at the rates employed often injured young conifers, and especially in sandy soils. The third edition of Toumey and Korstian (5) acknowledged this conclusion without specific reference, as well as noting that the toxicity persisted "for several years." Somewhat similarly, Wilde has illustrated the toxicity of lead arsenate in nursery

TABLE 2.—*Approximate total arsenic content in the plowed horizon of older compartments, Lowville Nursery*

Compartment Nos.	Total arsenic	Arsenic class
	P.p.m.	*Air dry sort*
		(Low)
#2, 6[1]	2, 3	
16, 17	1, 1	
		(Moderate)
#13, 14, 15	28, 25, 20	
		(High)
1A, B	10, 36	
5A, B	66, 45	
5 [area of "green" spring samples, table 1]	67	
[area of "tipburn" spring samples, table 1]	83	

[1] Compartments #2 and 6 were adjacent to #1 and 5, respectively, but were still undeveloped in 1934.

soils; as little as 50 lbs. per acre added to an acid sand low in clay and organic matter produced mild tipburn in newly germinated seedlings. This insecticide contains much less arsenic than "white arsenic," but its lead content may contribute to its phytotoxicity.

Red pine is likely to be more susceptible to arsenic injury-or at least to visible foliage symptoms-than other northern conifers. Other conifers have been grown on the tipburn areas at Lowville in years past without top injury sufficient to attract attention. Similarly, K. A. Armson of the University of Toronto, has observed that red pine was the only visible topinjured species in an Ontario nursery where lead arsenate had accumulated during nearly 50 years previous use as an apple orchard (personal communication). Nevertheless, these evidences of greater top injury may merely indicate that arsenic is more readily transported from roots to top in red pine. Some other species, such as peach, are severely damaged by high accumulations in the roots, even though foliar concentrations remain low. Hence, a better index of arsenic injury is root concentration and root injury; this is also a significant though easily overlooked measure of arsenic effects on planting stock quality. Thus the seedlings indicated as "green" (table 1) had healthy tops but root density was reduced, and the capacity for rapid regeneration almost certainly was seriously impaired by the 52 p.p.m. concentration.

Accordingly, the possibility of arsenic toxicity should not be ignored where poor stock survival or unexplained root injury are encountered, especially in nurseries founded before 1935 and on sandy soils. Arsenic is known to have been used in some New England nurseries at the same time and at the same approximate rates as in New York, and it may have been used elsewhere as well. Again, accumulation of lead arsenate spray residues is a common and troublesome featutre of many soils formerly used as orchards. Various treatments to reduce arsenic injury are known (1).

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