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Chemical Composition of Municipal Leaf Waste and Hand-Collected Urban Leaf Litter

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ABSTRACT

Municipal leaf waste delivered to New Jersey farms was sampled to evaluate its chemical composition and suitability for land application. Freshly fallen leaf litter samples were also collected and analyzed from seven different urban landscape tree species. Municipal leaf waste data from 100 samples in this study was summarized using frequency distributions to characterize its variability in composition. The chemical composition of municipal leaf waste was found to be quite variable. The minimum-maximum and median values were as follows: (g kg^{-1}) C, 363 to 516, 480; N, 6.6 to 16.2, 9.4; P, 0.2 to 2.9, 1.0; K, 0.9 to 8.8, 3.6; Ca 1.3 to 30.4, 17.3; Mg, 0.2 to 4.6, 2.4; S, 0.1 to 2.1, 1.1; (mg kg^{-1}) B, 7 to 72, 38; Fe, 46 to 9800, 733; Al, 58 to 10554, 602; Mn, 19 to 1845, 406; Zn, 22 to 392, 67; Na, 36 to 325, 90; Cl, 68 to 3995, 1083; Cu, 2.8 to 31.5, 8.1; Co, 0.9 to 10.9, 2.7; Cd, 0.1 to 6.8, 1.3; Pb, 3 to 400, 18; Ni, 1 to 58, 5; Cr, 0.9 to 35.1, 6.6; Ba, 4.2 to 142.0, 49.4. Although municipal leaf waste contains significant amounts of valuable plant nutrients, the high C/N ratio (range: 26.8–71.8; median: 48.5) suggests that heavy applications are likely to cause immobilization of available soil N. Concentrations of Fe, Al, Pb, and Cd were generally higher and more variable in municipal leaf waste than in hand-collected leaf litter. This suggests that contamination with urban soil during collection contributes to elevated Pb and Cd concentrations in municipal leaf waste. Given careful attention to N-fertilizer practice, municipal leaf waste is a suitable material for application to farm land.

BETWEEN 1960 AND 1990, the waste stream in the USA increased by 122%, with a total of 178 Tg (Tg = 10^{12} g) generated in 1990 (Statistical Abstract of the USA, 1994). During the same period, landfill space continued to decline rapidly. In 1988, there were 7924 landfills remaining in the USA, and by 1994 the number dropped to 3558 (Steuteville, 1995). This combination of events increased the need for recycling and reuse to reduce the waste stream into limited landfill space. In 1990, the waste stream included 32 Tg of leaves plus yard trimmings (Statistical Abstract of the USA, 1994).

Public policies have also affected leaf waste management. Amendments, in 1970, to the Clean Air Act eliminated the open-burning of leaves in densely populated areas, and state laws prohibited municipal leaf disposal in sanitary landfills. These actions created a major challenge for municipalities that needed new strategies to handle this waste. Spurred by such regulations, the composting of yard trimmings and the land application of these materials has increased. In 1988 there were <800 composting facilities in the USA, and only a few states were land applying uncomposted leaves to agricultural land (Glenn and Riggle, 1991). By 1994, there were 3202 yard waste-composting facilities and 24 states allowing direct application on farmland (Steuteville, 1995).

In New Jersey, leaf mulching, the application of municipal leaf waste to farmland, was approved as an emergency disposal/utilization strategy. State regulations (New Jersey Register, NJAC 7:26-1.2. 7 Nov. 1988) require: (i) Leaves shall be delivered unbagged to land deemed actively devoted to agricultural or horticultural use; (ii) within 7 d of delivery, the leaves shall be spread onto the field in a thin layer no higher than 15 cm (equivalent to approximately 45 Mg ha^{-1} of dry matter); (iii) no later than the next tillage season, the layered leaves shall be incorporated into the soil; and (iv) at no time shall leaves delivered to the leaf-mulching operation be stockpiled on-site for more than 7 d.

As residential development has interwoven with farmland, leaf mulching provides an opportunity to use nearby on-farm disposal sites. Farmers now have a new source of organic materials for soil improvement. In addition, many farmers are paid to accept leaves, providing an additional off-farm income source. This particularly interests field crop farmers with large acreage who have seen declines in commodity prices, and who traditionally have low net returns for their crops compared to those of fruit and vegetable farmers (Kluchinski and Derr, 1994).

Measurement of the quantity of plant nutrients in waste materials transferred from cities to agricultural land should be part of the nutrient management process for farms and individual fields (Bacon et al., 1990). Although several studies have characterized the chemical composition of sewage sludges (Berrow and Webber, 1972; Sommers et al., 1976; Doty et al., 1977; Sommers, 1977), there is little information available about the chemical composition of municipal leaf waste.

In addition to the information needed about the content of plant nutrients, there is also concern about the transfer of heavy metals from urban areas to agricultural soil. Leaves collected along urban roads may be contaminated with significant amounts of Pb and other heavy metals (Warren and Birch, 1987; Deroanne-Bauvin et al., 1987; Motto et al., 1970). If municipal leaf waste contains significant amounts of heavy metals, then annual or cumulative loadings of heavy metals would require a limitation on application of municipal leaf waste to agricultural land.

The chemical composition of municipal leaf waste needs to be characterized because it depends on numerous factors, including tree species (Chandler, 1941), exposure of leaves to weather prior to collection (Timmons

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et al., 1970; Cowen and Lee, 1973; Christensen, 1985), methods used for leaf collection, storage practices, and mixing with foreign materials.

Therefore, a study was conducted to determine the chemical composition of urban leaf litter from common shade tree species and also to evaluate the variability of municipal leaf waste as delivered to the farm. This information is needed to develop appropriate agronomic practices and to ensure that excessive amounts of heavy metals are not present in the leaves.

MATERIALS AND METHODS

Farmers in New Jersey who apply municipal leaf waste were asked to collect and submit samples to Rutgers Cooperative Extension. In November 1993 and 1994, participants were mailed sampling instructions and three bags in which to collect the samples. Farmers were instructed to collect the samples of leaf waste from three different truck loads by randomly grabbing small handfuls from 10 locations in a pile shortly after the material had been delivered and dumped at their farm. Participants were asked to label the sample bags with their name and the municipality (if known) the leaf waste originated from. They were also asked to air-dry the samples in open standing bags prior to their being returned in the pre-addressed, postage-paid package provided. A total of 105 samples were returned. They were inspected to identify the predominant tree species comprising the sample. Five of the returned samples contained composted municipal leaf waste and were discarded. The samples originated from 33 municipalities and/or counties spread geographically across the state of New Jersey.

Litter samples of various tree species were collected at maturity in autumn of 1992 and 1993 from recently fallen leaves. The samples were always hand-collected before the leaves were raked and piled. Only the most commonly found landscape tree species (Norway maple, *Acer platanoides* L.; pin oak, *Quercus palustris* Muench; red maple, *Acer rubrum* L.; red oak, *Quercus rubra* L.; sugar maple, *Acer saccharum* Marsh.; sweet gum, *Liquidambar styraciflua* L.; and Sycamore, *Plantanus occidentalis* L.) were sampled. Eight samples of each species were collected from residential lawns from at least eight different New Jersey municipalities.

All samples were oven-dried at 70°C and ground to pass a 0.5-mm sieve. Total C and N were determined with a Carlo Erba CN Analyzer (Fissions Instruments, Beverly, MA)[1]. For P, K, Ca, Mg, S, B, Fe, Mn, Cu, Zn, Al, Na, Ba, Cd, Cr, Co, Pb, and Ni, the samples were digested with perchloric/nitric acid and the concentrations were determined with an inductively coupled plasma emission spectrometer (Thermo Jarrell Ash Corp., Franklin, MA; ICP Model 61E). Chloride was determined using the method of Gilliam (1971) using a Chloridometer (Buchler Instruments Co., Lenexa, KS). Standard reference materials (Tomato Leaves SRM no. 1573, Citrus Leaves SRM no. 1572, and Buffalo River Sediment SRM no. 2704) from the National Institute of Science and Technology were used to assure quality of the chemcial analysis. The detection limit for Cd was 0.15 mg kg^{-1}.

Statistics calculated for all municipal leaf waste and leaf litter constituents included the minimum, maximum, median, mean, standard deviation, and coefficient of variation. Data were analyzed using the Statistical Analysis System (SAS, Cary, NC 27511-8000) program of analysis of variance. Duncans multiple range test was used for comparison of means for the leaf litter of the various tree species.

[1] The use of trade names in the publication does not imply endorsement by the New Jersey Agricultural Experiment Station of the products names or criticisms of similar ones not mentioned.

Table 1. Chemical composition of 100 municipal leaf samples collected in New Jersey.

Component	Minimum	Maximum	Median	Mean	CV† %
C/N ratio	26.8	71.8	48.5	50.0	24
			g kg^{-1}		
C	362.8	516.1	480.1	472.7	6
N	6.6	16.2	9.4	10.0	23
P	0.2	2.9	1.0	1.0	42
K	0.9	8.8	3.6	3.8	44
Ca	1.3	30.4	17.3	16.4	33
Mg	0.2	4.6	2.4	2.4	31
S	0.1	2.1	1.1	1.1	30
			mg kg^{-1}		
B	7	72	38	38	30
Fe	46	9 800	733	1461	138
Al	58	10 554	602	1200	159
Mn	19	1 845	406	550	72
Zn	22	392	67	81	66
Na	36	325	90	110	60
Cl	68	3 995	1083	1264	73
Cu	2.8	31.5	8.1	9.2	44
Co	0.9	10.9	2.7	3.1	62
Cd	0.1	6.8	1.3	1.7	73
Pb	3.1	399.9	18.0	28.4	149
Ni	1.1	57.9	5.3	7.2	105
Cr	0.9	35.1	6.6	7.6	74
Ba	4.2	142.0	49.4	59.6	54

† CV, standard deviation expressed as a percentage of the mean.

RESULTS AND DISCUSSION

Results of the chemical analysis of municipal leaf waste, as delivered to the farm, are summarized in Table 1. To provide a better indication of the distribution of the concentrations of elements in municipal leaf waste, the median values are reported along with the mean. The number of samples of municipal leaf waste falling into different concentration ranges are presented as frequency distributions in Fig. 1. Large differences between median and mean values, as for Fe and Al (Table 1), indicate that the mean value is markedly influenced by unusually high values in a small number of samples.

Inspection of municipal leaf waste samples revealed that the material is typically comprised of leaves from several different species. Although the leaves were often difficult to identify by species, at least 70% of the samples contained various species of oak and 35% contained various species of maple. Oak and maple are the most commonly planted trees in New Jersey. Sycamore and sweet gum leaves and pine needles were found in about 5% of the samples. The chemical analysis of leaves of common tree species found in urban landscapes are shown in Table 2. Because the composition of these leaves were unaffected by the processes of leaf collection, it is of interest to compare them to the composition of municipal leaf waste (Table 1).

Nitrogen content and C/N ratio have important agronomic and environmental implications for land application of municipal leaf waste. The mean N concentration in municipal leaf waste was 9.4 g kg^{-1} and the range was from 6.6 to 16.2 g kg^{-1}. Mean C/N ratio for municipal leaf waste was 50 and it ranged from 27 to 72. The mean and median values were essentially the same. In

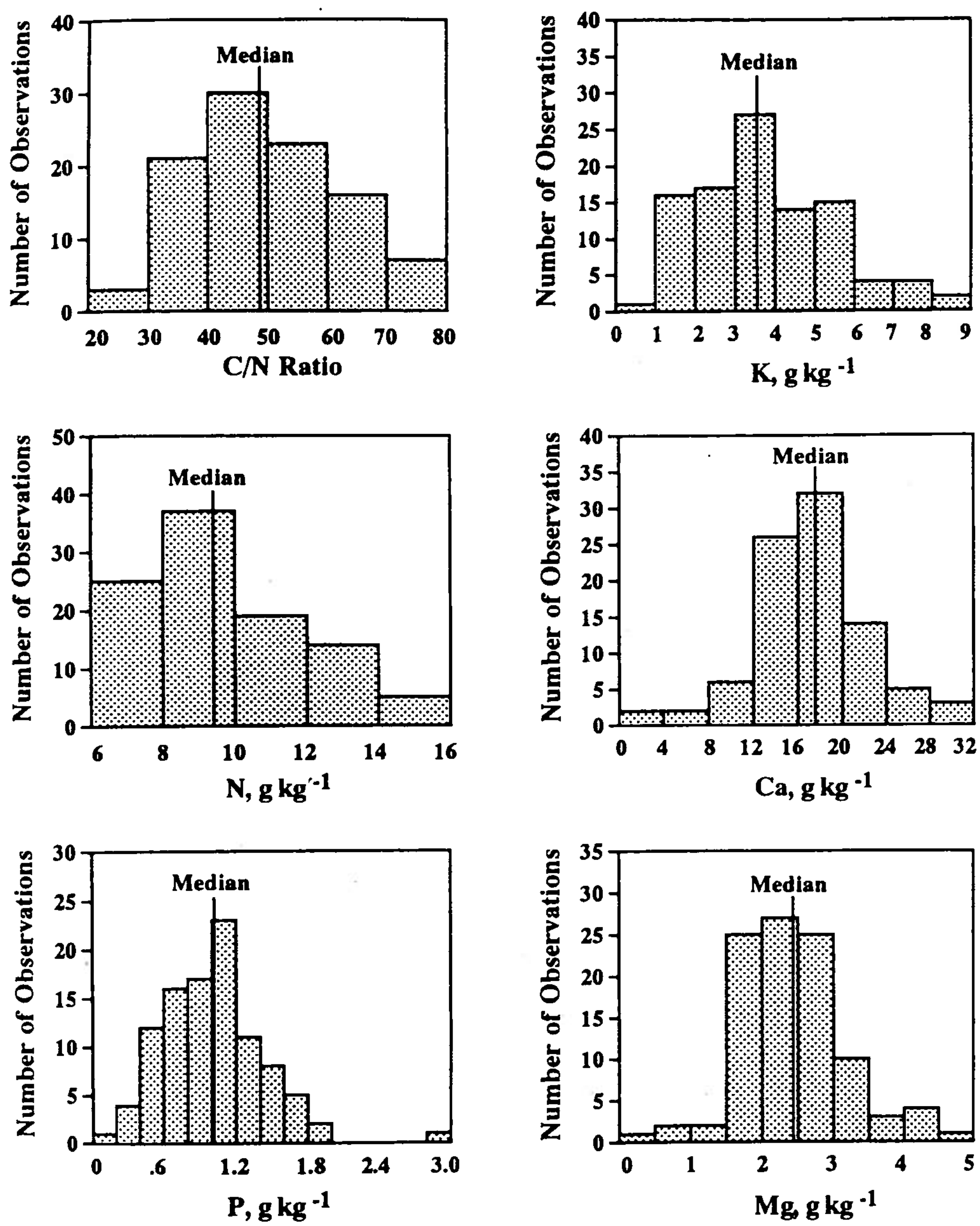

Fig. 1. Frequency distribution diagrams for chemical composition values in municipal leaf waste.

contrast to freshly fallen leaf litter (Table 2), the N concentration is generally higher and the C/N ratio lower in municipal leaf waste. This may be explained by the presence of small amounts of grass clippings that are sometimes collected along with leaf litter. The C/N ratio may also become lower in municipal leaf waste due to loss of C from its partial decomposition prior to delivery to the farm. Some may be at curbside for about a month before collection. Application of 45 Mg ha^{-1} of municipal leaf waste (the maximum permitted rate per year) would add from 297 to 729 kg N ha^{-1}. Although municipal leaf waste adds substantial amounts of N, the high C/N ratio would likely cause immobilization of soil N and an initial N deficit for crop production. This is supported by greenhouse research (Heckman and Kluchinski, 1995) and unpublished field observations. Immobilization of soil N occurs if the C/N ratio is >30/1 (Alexander, 1977). Because increased amounts of N will likely become available to crops as C is lost from the soil, a long-term field study is currently underway to determine the need for adjusting N-fertilizer recommendations when corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] are grown on municipal leaf waste amended soil.

Mean P, K, Ca, Mg, and S concentrations found in municipal leaf waste were 1.0, 3.8, 16.4, 2.4, and 1.1 g kg^{-1}, respectively. The mean and median values for these nutrients were similar but the ranges in concentrations were wide. Municipal leaf waste applied at the 45 Mg ha^{-1} rate, for example, would add per hectare from 9 to 131 kg P, 40 to 396 kg K, 58 to 1368 kg Ca, 9 to 207 kg Mg, and 5 to 95 kg S. It is evident that municipal

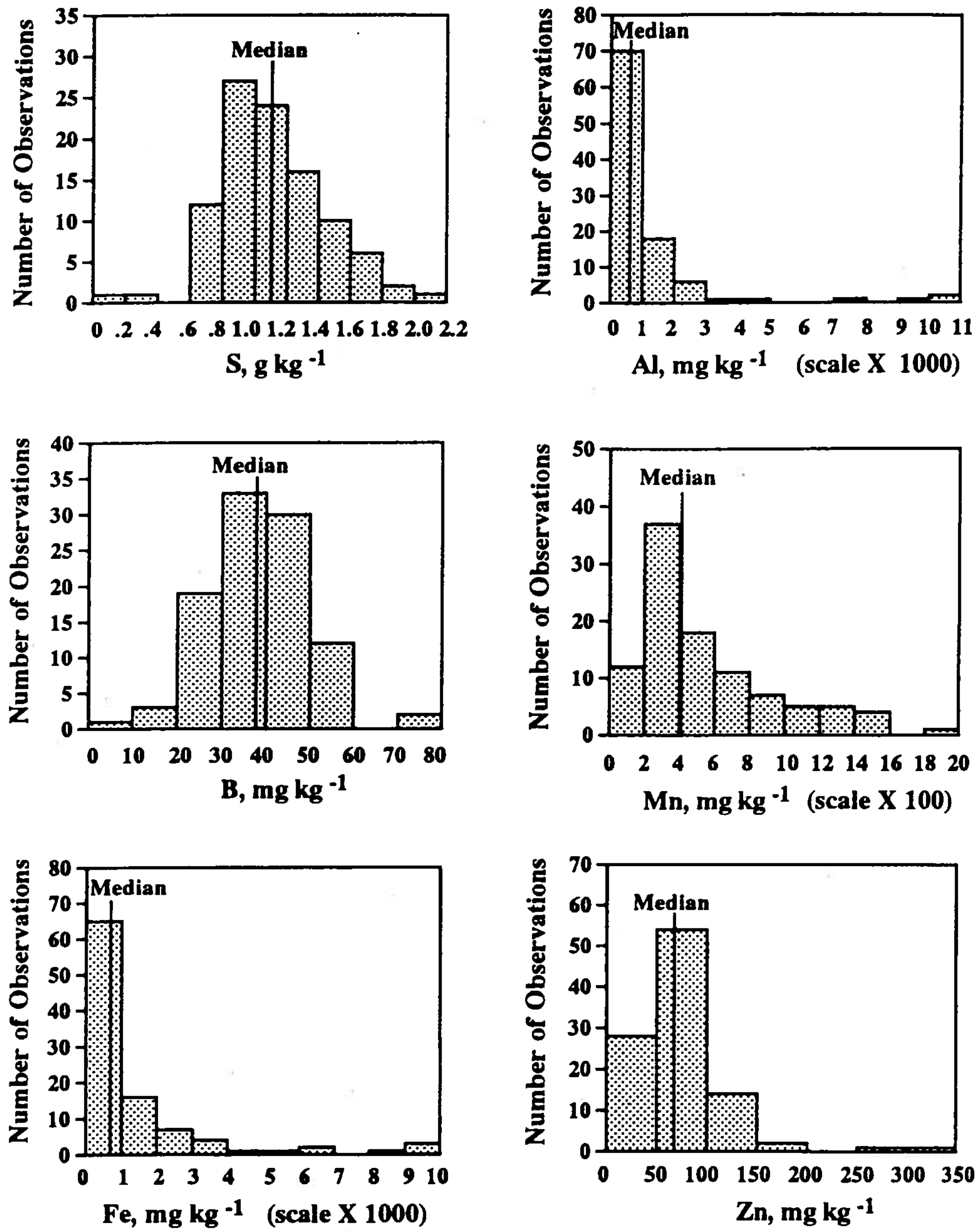

Fig. 1. (*continued.*)

leaf waste has significant nutrient value but it is not a material that has a uniform composition. From the frequency distributions (Table 1 and Fig. 1) however, it can be seen that for the primary and secondary nutrients, the majority of the samples fall within one or two standard deviations of the mean.

The chemical characteristics of leaves from the various tree species contributing to municipal leaf waste are probably important in determining its composition. Table 3 documents that sycamore has the highest N and S concentrations and lowest C/N ratio. Sweet gum has the lowest N concentration and the highest C/N ratio. Norway maple and sugar maple were highest in P and red maple the lowest. Norway maple was highest in K and sweet gum the lowest. Norway maple and sugar maple were about twofold higher in Ca than the other species. Magnesium concentrations were highest in sweet gum and lowest in red oak and pin oak.

Chandler (1941) examined the N, P, K, Ca, and Mg concentrations in leaf litter deposited by tree species in hardwood forest in central New York growing on soils of various levels of productivity. It was concluded that "if the proportion of the various tree species is known, then with knowledge of the nutrient content of the litter of the individual trees, reliable estimates of the average nutrient content of the litter can be made." Chandler (1941) also reported that the predictive value of tree species was strongest for Ca and least predictive for K. Of the few species (sugar maple, red maple, and red oak) that this study has in common with Chandler's survey of forest species, there is general agreement. The one exception was that the Ca concentration was found

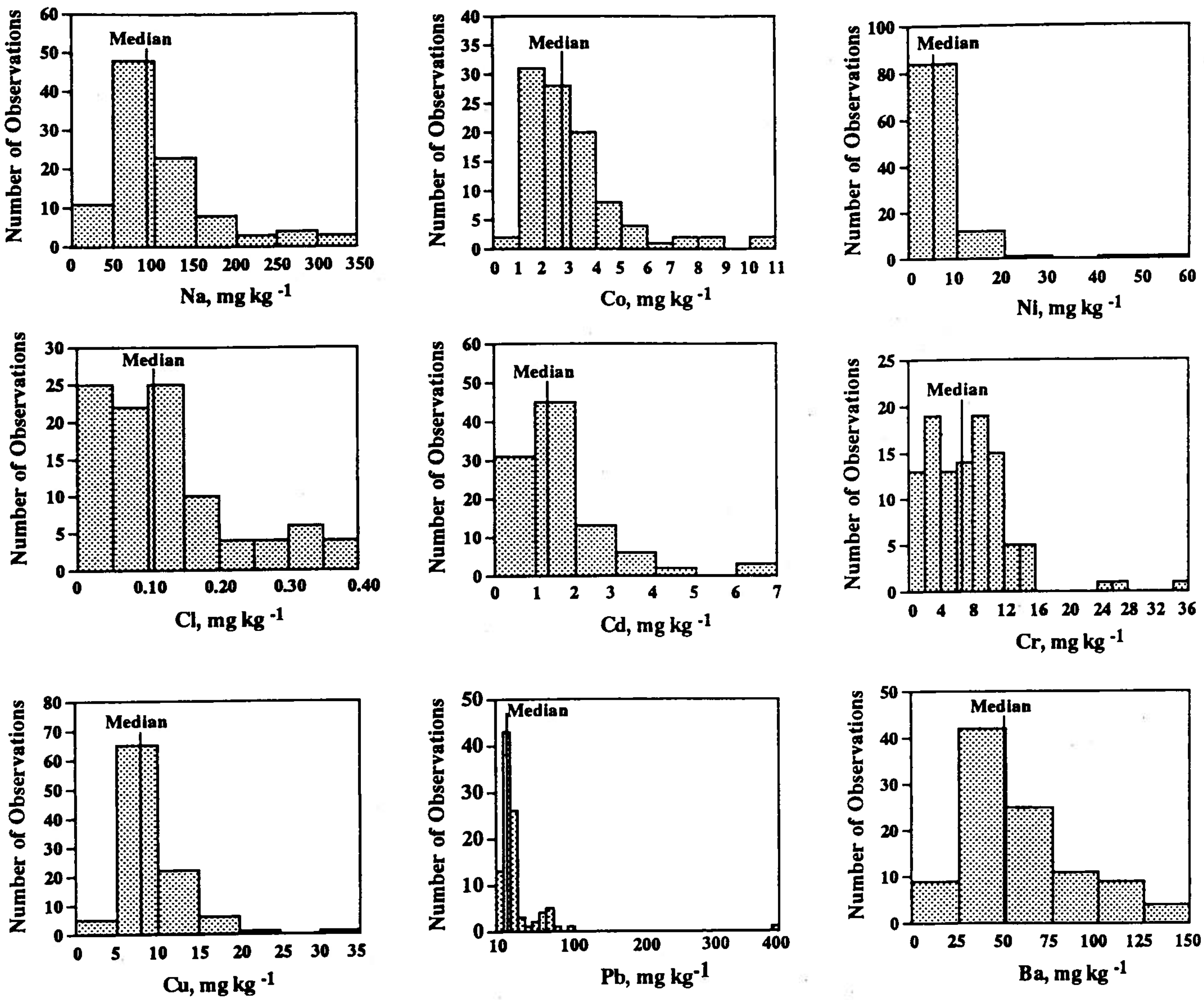

Fig. 1. (*continued.*)

to be considerably higher in New Jersey urban sugar maple leaf litter. Lime and fertilizer applications to urban soils and the use of deicing salts on sidewalks and streets may be responsible for concentration differences. Knowing the tree species along with the chemical composition data in Table 3 may have some predictive value for the nutrient content of municipal leaf waste. Several other factors, however, should be considered. These include the possible presence of the other landscape debris, the loss of nutrients such as P, K, Ca, and Mg by leaching rains (Timmons et al., 1970; Cowen and Lee, 1973; Christensen, 1985), and loss of C due to microbial decomposition.

The enrichment of soils with heavy metals is a major concern in the application of waste materials to agricultural land. The heavy metals found in municipal leaf waste may be compared with the background soil metal concentrations recently published by Holmgren et al. (1993). For the agricultural soils of the USA they reported mean Cd, Zn, Cu, Ni, and Pb concentrations of 0.265, 56.5, 29.6, 23.9, and 12.6 mg kg^{-1} dry soil, respectively. Mean concentrations of these elements found in municipal leaf waste are higher than reported in soils for Cd, Zn, and Pb and lower than reported in soils for Cu and Ni (Table 1).

The frequently higher concentrations of Al and Fe in municipal leaf waste (Table 1) compared with freshly fallen leaf litter (Table 2) suggests that municipal leaf waste often becomes contaminated with urban soil or dust from the road surface through various processes (raking, lawnmower pickup, and vacuum) used for litter collection in the yard and at curbside. Concentrations of Pb and Cd are also often higher in municipal leaf waste than in freshly fallen leaf litter. Urban soils, which are often contaminated with Pb and Cd, apparently contribute to the concentrations of these pollutants in municipal leaf waste. Aluminum, which is a major constituent of soil minerals, can serve as a marker to indicate the level of contamination of municipal leaf waste with urban soil. The stronger correlations of Pb and Cd concentra-

Table 2. Chemical composition of leaf litter samples hand collected from New Jersey urban shade trees. Species samples include Norway maple, pin oak, red maple, red oak, sugar maple, sweet gum, and sycamore.

Component	Minimum	Maximum	Median	Mean	CV† %
C/N ratio	30.8	124.5	60.9	66.2	29
			$g\ kg^{-1}$		
C	407.8	510.9	478.2	479.9	4
N	3.8	14.9	7.7	7.8	27
P	0.3	2.8	1.0	1.1	50
K	1.7	11.4	4.1	4.8	49
Ca	7.2	42.0	15.8	18.0	48
Mg	1.1	4.3	2.2	2.5	32
S	0.4	3.4	0.9	1.2	57
			$mg\ kg^{-1}$		
B	12	101	40	44	42
Fe	39	383	117	140	53
Al	37	728	95	171	112
Mn	46	3843	480	820	101
Zn	9	130	44	56	63
Na	29	877	73	103	108
Cl	569	9249	2419	2813	78
Cu	1.1	11.2	4.8	5.0	39
Co	0.3	4.1	1.9	2.0	46
Cd	0.02	4.6	0.8	1.1	81
Pb	0.3	35.7	11.4	12.8	82
Ni	0.7	13.7	3.1	4.1	74
Cr	0.1	6.6	1.1	1.2	84
Ba	16.3	136.2	41.0	52.1	61

† CV, standard deviation expressed as a percentage of the mean.

tions with Al in municipal leaf waste than in hand-collected leaf litter (Fig. 2 and 3) therefore indicate that contamination with urban soil is a significant source of heavy metals in municipal leaf waste. Thus, the problems with heavy metals may be partially alleviated by using collection practices that would minimize contamination with urban soil. Collection of leaves over well-maintained residential turfgrass stands will likely provide an effective barrier to soil contamination (Beard and Green, 1994).

The current Pb burden of leaves is apparently less than it was before the removal of Pb additives from vehicle fuels. A survey (Smith, 1972) of Pb in leaves hand-collected during the fall of 1970 from pin oak, sugar maple, and Norway maple trees growing in the city of New Haven, CT, found the mean Pb concentrations about 10 times greater than those observed in the urban leaf litter collected for this study in 1992 and 1993 from New Jersey.

The maximum concentrations of Cd, Cr, Cu, Pb, Ni, and Zn found in municipal leaf waste generally do not exceed, and in most cases are well below, the limiting concentrations of these pollutants in the USEPA 503 rules and regulations (USEPA, 1993) for sewage sludge. Because the application rate of municipal leaf waste is not limited by its N content, as is often the case for sewage sludge, application rates may be much greater. When applied at 45 Mg/ha, municipal leaf waste generally does not exceed the USEPA 503 rules and regulations for annual pollutant loading rate. One highly contaminated municipal leaf waste sample, however, had a concentration of 400 $mg\ kg^{-1}$ of Pb. Using this most contaminated municipal leaf waste as an example, 16 yr of annual applications at 45 Mg/ha would be needed to reach the cumulative pollutant loading rate for Pb. When this same calculation is performed on the mean Pb and Cd concentrations 235 and 509 yr, respectively, of annual applications would be needed. In practice, however, municipal leaf waste is not likely to be applied continuously to the same land area.

Micronutrients present in municipal leaf waste may be of value to crop production, but the concentration ranges are wide. Even though extremely wide ranges were obtained, it is obvious from the frequency distributions that a high percentage of the samples contain concentrations of B, Cl, Cu, Mn, and Zn characteristic of the median value. Municipal leaf waste applied at the 45 Mg/ha rate would on average add per hectare 1.7 kg B, 57 kg Cl, 0.4 kg Cu, 25 kg Mn, and 3.6 kg Zn.

In summary, the chemical composition of municipal leaf waste is quite variable. Heavy applications of municipal leaf waste will likely cause immobilization of available soil N because of its high C/N ratio. This suggests that fertilizer N application rates may need to be increased to avoid a N deficit for crop production the first season after application. The large amount of organic N that is added to soil from high rates of municipal leaf waste suggests that N fertilizer requirements of crops may be reduced in subsequent years as leaf N mineralizes. Although additions of plant nutrients from municipal leaf waste application are often agronomically significant, it is difficult to generalize about its fertilizer value without a chemical analysis of the specific material being applied. Identifying the major tree species represented in municipal leaf waste may help to predict its nutrient composition. Leaves from sweet gum trees have a low concentration of N and a high C/N ratio whereas leaves of sycamore, Norway maple, and pin oak are relatively high in N and have lower C/N ratios. Lead concentrations in municipal leaf waste are generally not high but occasionally

Table 3. Concentration of selected elements in hand-collected leaf litter of various tree species in New Jersey.

Tree species	C/N ratio	N	P	K	Ca	Mg	S
					$g\ kg^{-1}$		
Norway maple	54.5 c*	8.6 ab	1.8 a	6.8 a	31.8 a	2.5 bc	1.4 bc
Pin oak	52.6 c	9.1 ab	0.1 bc	4.0 bc	9.7 d	1.8 d	0.9 c
Red maple	65.4 b	7.8 abc	0.6 c	5.4 ab	14.8 cd	2.9 ab	0.8 c
Red oak	65.3 b	7.4 bc	0.9 bc	4.9 ab	13.7 cd	2.0 cd	0.7 c
Sugar maple	72.3 b	6.6 cd	1.7 a	5.3 ab	25.0 b	2.5 bc	1.0 bc
Sweet gum	96.0 a	5.2 d	1.2 b	2.3 c	15.3 c	3.3 a	0.9 c
Sycamore	52.1 c	9.4 a	0.9 bc	4.8 ab	16.7 c	2.6 abc	2.7 a
Species	0.0001	0.0001	0.0001	0.0046	0.0001	0.0008	0.0001
CV %	21.1	21.2	36.3	43.6	28.7	27.4	27.9

* Means within the columns followed by the same letter are not significantly different ($P < 0.05$).

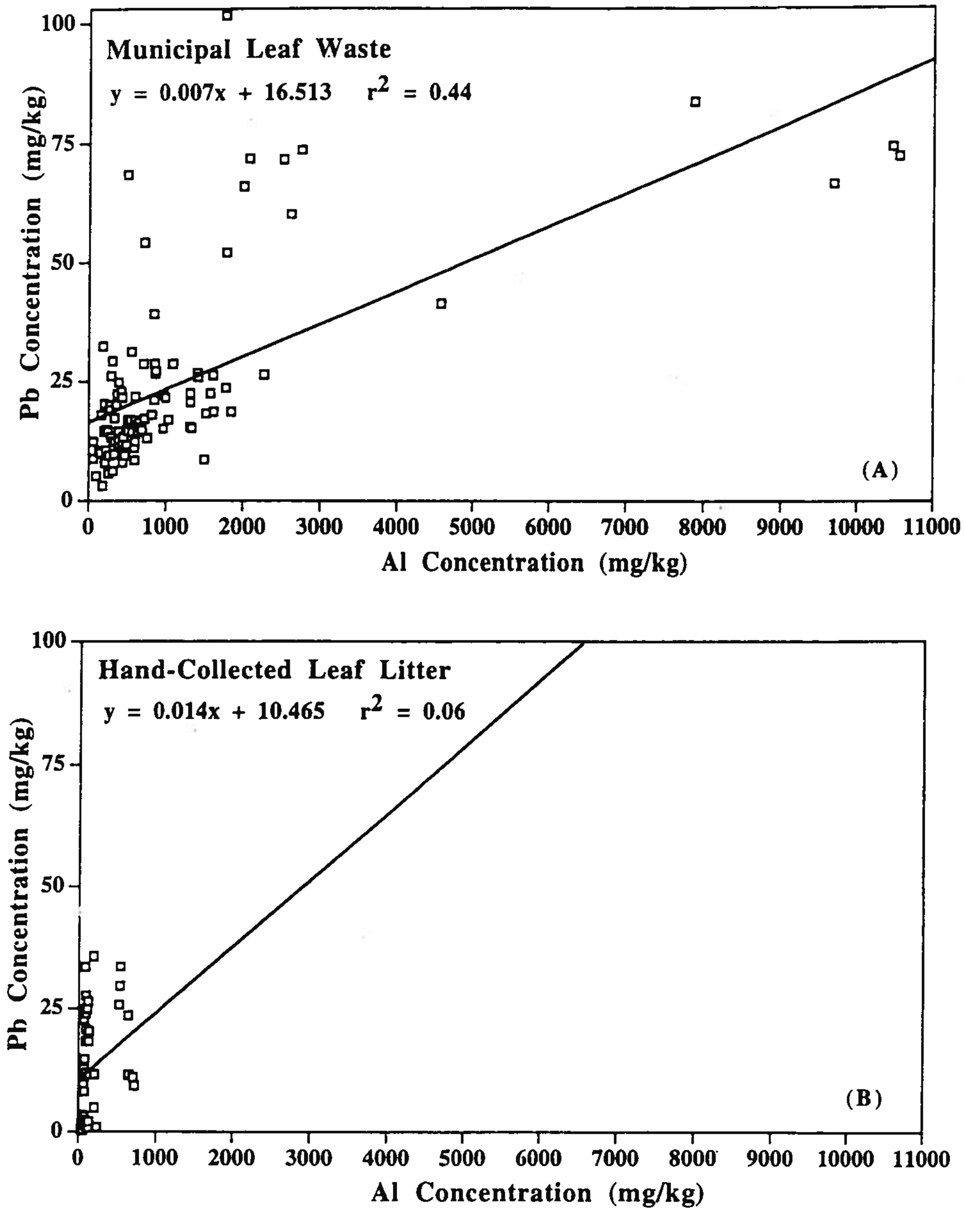

Fig. 2. Lead concentration in relation to Al concentration in (*A*) municipal leaf waste and (*B*) hand-collected leaf litter.

rather high Pb concentrations occur when it becomes contaminated with urban soil. Land application of leaf waste would contribute to increased concentrations of heavy metals in soil but would not be a major source of contamination.

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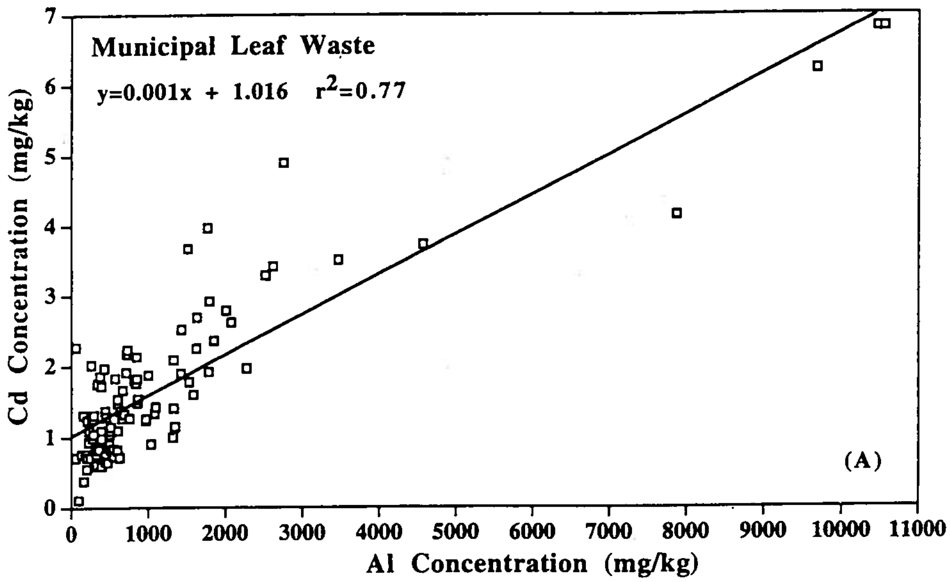

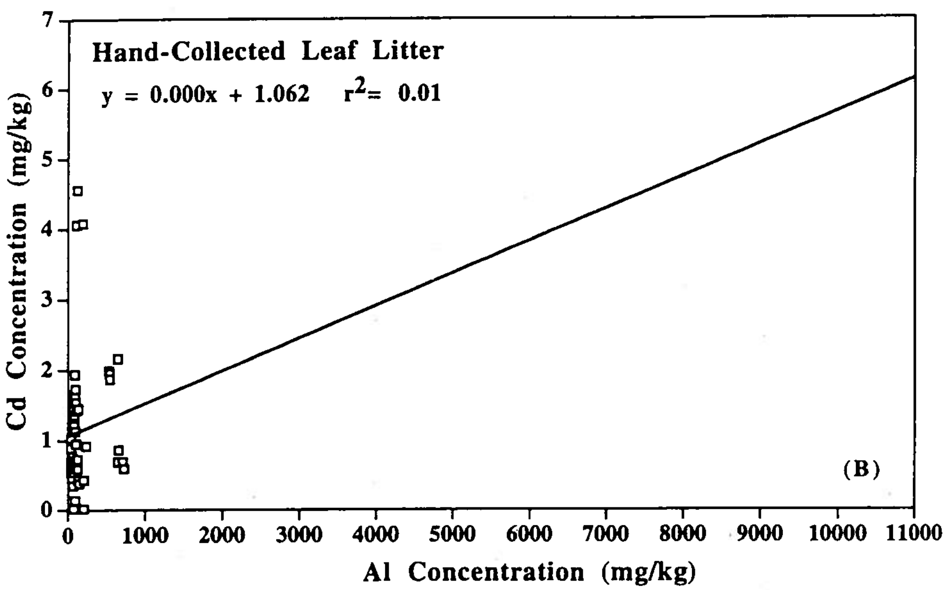

Fig. 3. Cadmium concentration in relation to Al concentration in (*A*) municipal leaf waste and (*B*) hand-collected leaf litter.

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