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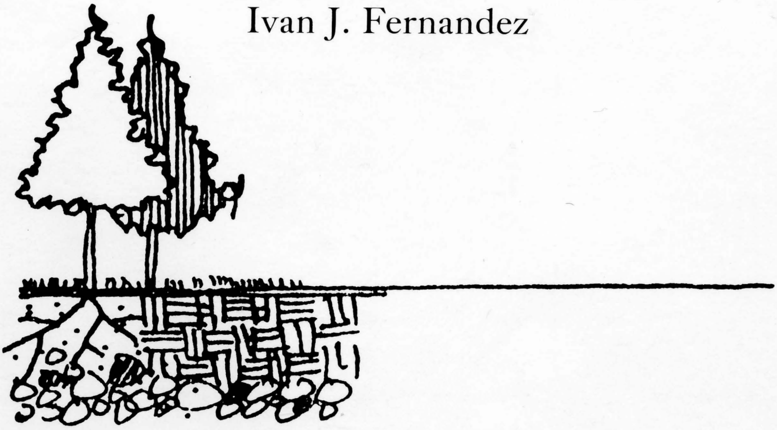

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PRELIMINARY PROTOCOLS FOR SAMPLING AND ANALYSIS OF ASH AND SLUDGE AMENDED FOREST SOILS

by

Ivan J. Fernandez
Associate Professor of Soil Science and
Cooperating Associate Professor of Forest Resources

Department of Plant and Soil Sciences
University of Maine
Orono, Maine 04469

ABSTRACT

Our society has demonstrated a remarkable ability to develop new technologies that promote the production and consumption of goods and services with little forethought for the long-term effects of these developments on our global ecology. The issue of suitable waste management systems that can recover materials of value and dispose of all remaining wastes in an environmentally sound manner is an emerging giant. One example of potentially sound waste management being addressed in Maine is the disposal of selected waste materials that are considered relatively clean (i.e. papermill sludges and wood ash) on suitable forest lands. This approach can have the advantage of being cost effective while avoiding potential concerns that can arise when materials are applied to agricultural systems directly linked with the human food chain. The disadvantage is that we have much less knowledge of forest ecosystem functioning resulting in a limited ability to predict the consequences of sludge and ash amendments to forest soils. This bulletin describes preliminary recommendations for assessing forest soil response to waste applications, and identifies some of the issues that are unique to the forest soil environment when compared to agricultural soil-plant systems.

INTRODUCTION

Over the past decade there has emerged a clear recognition that the escalating production of waste materials by society poses a serious problem, and that significant amounts of many waste materials must be recycled or disposed of by more ecologically integrated means. In Maine, we are fortunate to enjoy the benefits of a rural state rich in natural resources. It is these resources that provide the basis for many of our industries, well demonstrated by our forest resources so vital to the forest products industry and to Maine's economy.

In recent years forests have also been looked to as a source of wood fuel for power generating facilities, and this trend is likely to continue. These and other activities lead to the generation of waste materials that may be considered either effluents, sludges, solid waste, or ash. Some processes can create materials laden with toxic organic compounds or heavy metals that pose serious threats to the environment. Others are relatively "clean" and interest in land applications of these materials has increased due to the high costs of landfilling. While agricultural lands may provide a cost effective receptor site for waste materials, these soils also are a direct conduit to the human food chain and may not be advisable sites when questions remain over potential health risks associated with a particular waste. Thus some of our extensive forest lands in Maine are being considered as sites for waste application and disposal, which holds promise when carefully carried out based on a scientific understanding of forest ecosystem responses.

This bulletin offers some preliminary guidelines to serve as a starting point for the systematic assessment of the effects of ash and sludge application to northern New England forest soils. It must be recognized that our understanding of the nutritional processes in forests is much less sophisticated than our understanding of agricultural systems. Therefore our accuracy and precision in determining appropriate treatment rates and resulting soil effects when it comes to waste applications on forest soils are also deficient, since we are adding additional complexity to an already complex and poorly understood system. Significant research has taken place to allow us to develop meaningful programs in an experimental context for ash and sludge application to forest soils. A number of publications is available dealing with this issue including Bledsoe (1981), Cole et al. (1986), Elliott and Stevenson (1977), Page et al. (1987), Page et al. (1983), PSU (1985), Rock and Alexander (1982), and SSSA (1986).

The following represents preliminary protocols for the sampling and analysis of forest soils to both determine permissible loading rates of ash and sludge materials as well as to monitor changes in amended soils over time. Given the limited information available on this subject, specific to forest lands in Maine, current waste application activities should be looked upon as an important source of information to further refine our understanding of ecosystem effects over time. As such, these protocols should be modified as better information becomes available.

Environmental concerns for ash and sludge applications to forest soils include risks for groundwater quality and forest health. The potential effects on forest soils include beneficial effects on tree growth, metal toxicities, as well as negative consequences of drastic pH changes, metal toxicities, salt effects, or nutrient imbalances.

This bulletin draws on forest soil assessment information developed for other environmental issues (Blume 1986a,b, Robarge and Fernandez 1986, Fernandez 1983) as well as the author's experience in forest soils research related to nutrient cycling, atmospheric deposition, and trace metals in forest soils. No attempt is made here to prescribe permissible loading rates of materials, but rather to identify a meaningful approach to forest soil measurements given our current understanding of this issue. A critical factor to consider in these assessments is the variability of forest soils and parameters measured. Recognition of the variability of forest soils as a critical concern is not new (Mader 1963), but deserves some discussion here for perspective on the problems soil variability can pose.

Spatial Variability

Agricultural soils normally consist of a surface Ap horizon that is managed to the depth of 15 cm (i.e. 6 inches) representing a zone that is mechanically mixed by cultivation, that occupies the majority of the effective rooting volume of soil, and that is the target for prescribing fertilizer and lime recommendations. Within any given field a relatively few soil types are usually identified, and the vegetative cover typically consists of a single crop species that lives for only one growing season.

By contrast, undisturbed forest soils in northern New England support plant communities that live for decades and have root systems that occupy much greater depths in the soil; these soils exhibit distinctly different horizons based on both morphological, biological, and chemical characteristics. Thus no single soil horizon can be considered representative of all soil at that point on the landscape. This requires that all of the significant horizons be assessed in describing soil-plant interactions. Undisturbed forest soils typically have an O, E, B, and C horizon, although numerous variations on the model soil profile can be found. Each of these horizons has a unique chemistry that prohibits us from assigning a single value for pH, base saturation, or other chemical property to the soil at a particular location (Table 1). Sampling these soils, and describing changes in soil properties as a result of any perturbation, require consideration be given to the complexity of the differing layers.

When material is added to the soil surface, changes in the soil resulting from this material usually migrate down soil profiles as a front, with the greatest initial effects initially evident near the soil surface. Compounding the complexity of this process is the influence of distinct morphological layers that can react differently to the materials applied. For example, Banin et al. (1987) showed that very thin layers of the surface mineral horizon in forest soils best reflected the accumulation of pollutant derived heavy metals. Similarly, Fernandez (1987) showed that simulated acid deposition treatments had the greatest effect on soil chemical properties in the upper 2 cm of the B horizon in

Table 1 - Means for selected soil chemical properties from soils supporting spruce-fir stands in eastern Maine (Fernandez and Struchtemeyer 1985).

		Horizons			
Property	Units	O	E	B	C
pH_{salt}		3.13	3.20	4.59	4.91
Cation Exchange Capacity	meq/100 g	117.80	8.80	17.50	3.10
Base Saturation	%	14.90	7.70	2.90	12.70

reconstructed soil microcosms. Therefore, very specific zones in forest soils should be sampled if the goal of soil testing is to identify maximum effects, while sampling by major horizons seems appropriate where overall effects on the site are of interest.

Soil spatial variability on the horizontal axis has received more attention in the scientific literature to date than vertical variability, but little quantitative information exists that would allow accurate estimates of soil variability in Maine. For intact forest stands with undisturbed soils, significant horizontal variability exists in soil properties due to natural processes. A highly visible example of this natural variation is the pit and mound surface conditions typical of our forest soils reflecting tree throw over the many years of soil development. Where plantation culture is practiced and upper soil horizons have been cultivated, soil variability for many properties is reduced since the soil-plant system begins to take on the character of agricultural cropland. However, very few intensively managed plantations exist in northern New England when compared to the extensive land base that supports commercial forests. Therefore, ash and sludge amendments more likely will occur on forest soils that have not been cultivated, and have developed under natural stands.

Most ash and sludge applications occur on recently harvested sites where harvesting operations can add to the diversity of forest soil conditions. Harvesting operations leave site conditions that include (a) intact soil profiles, (b) scarified areas where the forest floor (i.e. O horizon) has been scraped away, sometimes with mineral soil, (c) disturbed soil conditions that resemble cultivation where surface organic materials are mixed with underlying mineral soil horizons, and (d) rutted areas where subsoil horizons are exposed often promoting the accumulation of water or erosion. All of these conditions compound the problem of adequately assessing soil conditions on the site, and soil response to ash or sludge amendments.

As with agricultural land, areas supporting forest cover will also have a diversity of soil types that require separate identification and assessment. In addition, the species composition of a forest stand affects the chemical, physical, and biological characteristics of the underlying soil. Coniferous species are known to create more acidic and infertile soil conditions when compared to deciduous species where all other environmental conditions, including the original soil properties, are the same. Therefore on a harvested site, soils from the same soil series but under different stands may require separate evaluations. In addition, soil properties systematically vary with distance from the trunk of a tree. A recent study by Riha et al. (1986) showed that soil pH is usually lowest near the tree and increases with distance from the trunk. Studies on the effect of individual trees on soil properties generally attribute these soil chemical trends to the influence of the tree canopy and bole on throughfall, stemflow, and organic matter distribution.

Wilding and Drees (1983) provided an excellent discussion of the variability of soil properties in the context of soil mapping and sampling for pedological objectives. In their paper they present information on the importance of defining meaningful confidence intervals and limits of accuracy based on a knowledge of the variability of soil properties being evaluated. Examples from their study show that the relative variability of certain soil properties follows the trend:

Least Variable	Moderately Variable	Most Variable
Soil pH	Total sand	B horizon thickness
A horizon thickness	Total clay	Depth to mottling
Total silt	C.E.C.	Exchangeable H, Ca, Mg, and K
	Base saturation	
	Soil structure	Organic matter

As the variability of a soil property increases, so does the need to collect greater numbers of samples in order to achieve the same level of precision and accuracy in assessing average or mean soil conditions. While traditional statistical analyses require a 95 or 99% confidence level in a mean value within a range of +/- 5 to 10% of that mean, practical limitations, given the variability of soils, may require less stringent criteria.

The key is to quantify variability before developing sampling and statistical criteria. Haines and Cleveland (1981) studied forest soil variability under old field conditions in southwest Georgia. In order to maintain a 95% confidence level +/- 10% of the mean, their calculations on spatial variability of soil properties for a pine and hardwood site showed that 97, 52, and 1 sample would be required in the 0 to 10 cm soil layer for exchangeable calcium, organic matter, and pH, respectively. Sample sizes increased to 387, 205, and 2 for the same properties when +/- 5% of the mean is required. While not specific to Maine, these calculations indicate the magnitude of the soil variability problem and should emphasize the importance of its recognition in ash and sludge disposal questions regarding forest soil effects. Similar sample size requirements have been calculated based on forest floor trace metal data for selected study sites in Maine by Fernandez and Czapowskyj (1986), and ongoing investigations at the University of Maine are beginning to assemble this type of information for forest soil nutrient levels.

Temporal Variability

Soils are dynamic with changes taking place on temporal scales from seconds, seasons, and years to geologic time scales. Significant changes take place in forest soil properties on seasonal, annual, and forest rotation length time frames. Essentially all of the soil chemical properties considered important in assessing sludge and ash amendment effects on forest ecosystems vary within the time frames mentioned. The study by Haines and Cleveland (1981) also characterized seasonal variations in soil properties for the forest types they studied showing major changes should be expected. Seasonal trends in both biological and meteorological processes point to the need for recognition of the seasonality factor of soil chemical properties. The easiest way to address this concern is to maintain consistency in the time of sampling soils relative to season. This would not overcome the possible influence of differing patterns of temperature and precipitation from year to year, which may be a source of variability that only long-term investigations can overcome. Complicating the issue is the fact that each soil parameter reveals different seasonal patterns, and no single sampling scheme will be best for all parameters of interest, requiring a compromise in sampling schedule.

Temporal variability of soil properties is greater where vegetative communities are young (i.e. aggrading forest stands) and where the site has been disturbed. Forest ecosystems are closest to steady-state conditions in mature forests. Of importance for sludge and ash amended sites is the fact that perturbations resulting from soil amendments usually occur shortly after major disturbance in ecosystem processes resulting from harvesting operations. Figure 1 shows the dynamic changes in selected nitrogen fluxes that occur as a result of harvesting (Hornbeck 1986). This figure demonstrates that ash and sludge amendments on harvested sites will usually occur when many soil properties are already undergoing dynamic changes. Without adequate soil sampling prior to waste applications, as well as the maintenance of control sites within the treated areas, it is difficult to imagine how meaningful conclusions

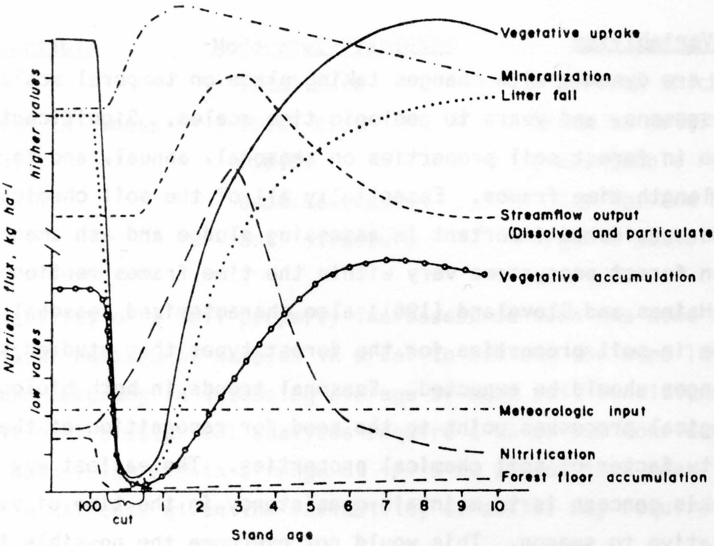

Figure 1. Hypothetical curves of changes in fluxes of nitrogen (from Hornbeck 1986)

will be drawn from soil assessments over time regarding the effects of sludge or ash applications as distinct from soil changes brought about by harvesting. As the young forest stand begins to aggrade on the site, ecosystem processes can be expected to stabilize, but remain relatively dynamic, during the juvenile growth period of the stand.

Amendment Characteristics

No attempt is made here to prescribe desirable rates of sludge and ash amendments to forest soils. Neither do these proposed protocols depend on the schedule of amendments, although single and multiple application schedules should be expected to influence the interpretation of the results of soil analyses. It is important to adequately characterize the physical and chemical characteristics of a sludge or ash material in order to ensure meaningful treatment prescriptions. Included in that characterization should be the variability of the material being applied, as well as an assessment of how evenly material was applied to the landscape. The focus of this document is on the influence of waste applications to forest soils relative to pH, carbon, and the major nutrient composition of treated sites. Where trace metals (e.g. Cd, Pb, Zn, Cu, Ni) are a significant component of the waste materials employed, additional soil measurements should be considered to determine the fate and chemical form of these metals resident in the soil. In addition, potentially toxic organic compounds known to exist in a waste material should be included in soil evaluations requiring special analytical procedures.

PROPOSED PROTOCOLS

The following recommendations should be considered preliminary due to the limited data available to date on forest soil amended with sludge and ash in Maine. Essentially all forest soil applications should be considered within an experimental context for the near future and should be viewed as opportunities to address current information needs on this subject.

Site Characterization

Landscapes are composed of a heterogeneous mosaic of vegetative, soil, and geologic units that can be defined at scales from experimental plots to continents. Each site considered for waste application will include a variety of soil types that have supported, or currently support, a range in forest types with variable species, age, and stocking characteristics. The first priority in characterizing soils on a potential site should be to obtain soil maps and supporting information that may be available. Where no soil maps are available, a qualified soil scientist should develop soil maps for the site. For the purpose of soil evaluations in regard to waste application effects, the site should be divided into meaningful LANDSCAPE UNITS that contain similar soil types that have developed under similar stand conditions. No firm scientific data exist that define the optimum size of a Landscape Unit in this context. However, an initial guideline is offered here defining Landscape Units as being areas of similar soil and forest characteristics not to exceed a maximum of four hectares (9.88 acres). Landscape Units should not be identified solely on the basis of identical or similar soil series, but should include obvious differences that may exist among areas on the site such as O horizon thicknesses or scarification and rutting that may have resulted from the harvest. The following comments assume this approach to "mapping" a potential waste application site is employed.

Harvesting initiates a period of rapid and complex changes in the various pools and fluxes of materials in forest soils. Therefore, it is recommended that a "control" plot be delineated that does not receive sludge or ash amendments within each of the major Landscape Units on a site. The purpose of these plots will be to provide sites that can be sampled after waste materials have been applied to the rest of the site. These untreated plots can be used to determine changes in soil properties that may be occurring as a result of harvesting or natural variations. This approach then allows us to better determine what proportion of possible soil changes may be the result of the waste application itself by comparing data from untreated plots to analyses from waste amended soils. Using soil analysis data from before the harvest or from before the application of waste materials as a reference point ignores the rapid changes that take place in soil properties following major cutting operations on the site. Control plots should be a minimum of approximately 0.04 hectares and located in the most upslope position within Landscape Units. Square plots 20 x 20 meters, or circular plots with a 23 meter diameter are suggested. A two meter buffer strip along the perimeter within these control plots should be excluded from sampling to avoid potential effects of surrounding treatments on control plot soil analyses.

Soil Sampling

The rooting environment in forests encompasses numerous morphologically and chemically distinct horizons, and sampling only a surface layer of material to a constant depth as in agricultural fields is inappropriate. Two questions arise with regard to sampling as follows.

(1) How many locations on the landscape should be sampled per unit area?

A truly informed prescription for the number of samples per unit area is not possible without information on the spatial variability of soil properties and the required precision is estimating "average" soil conditions. This question is perhaps the most difficult to answer at this time. A preliminary recommendation is to sample on the basis of Landscape Units, and that a minimum of three points be sampled within each Landscape Unit identified for the site. This is clearly a MINIMUM given the practical limitations of sampling extensive treatment areas. More desirable would be sampling 10 points per Landscape Unit with subsequent sampling using the initial data to better estimate the number of samples needed for future evaluations.

Compositing samples is not recommended until adequate quantitative information on the variability of soil properties is obtained. Without individual soil sample analyses, no estimation of variability can be determined, prohibiting the calculation of (a) precision and accuracy for means calculated from the data, as well as (b) sample numbers required to achieve a given level of confidence in soil characteristics. Where analytical costs may be prohibitive, compositing samples within a Landscape Unit could be employed as long as at least one occurrence of each Landscape Unit type is reserved for individual soil sample analyses. Where composite samples are used, a minimum of 20 samples per Landscape Unit should be composited resulting in only one homogenized sample for laboratory analysis. Again, it is critical to sample at least one occurrence of each Landscape Unit type on the site as individual samples, and a minimum of three samples is required in this case although more are strongly recommended. As discussed below, each point on the landscape where samples are collected should include separate samples from at least the O and B horizon. In no case should composite samples be created by mixing soil from different horizon types (i.e. O and B horizons). As an example, when composite samples are created for a Landscape Unit they should be the result of mixing all of the B horizon samples together. A separate composite sample should be created for the O horizon, or any other morphologically distinct soil layer sampled on the site.

(2) What soil horizons or layers should be sampled?

Undisturbed forest soils in the Northeast typically consist of the major horizons O, B, and C with ranges in the presence of an E horizon from none at all to well expressed eluvial layers. Research scientists like to sample many distinct layers individually, but practical limitations for operational sludge and ash spreading require minimizing the number of samples necessary while still allowing meaningful information to be collected. Therefore only two of the major soil horizons seem critical for treatment effect assessments on a routine basis. These are the O and B horizons. The B horizon is critical since it is the only mineral soil horizon consistently present in the upper part of the soil profile, and since it is used by pedologists as a diagnostic layer in the soil best representing soil weathering processes active at the site. Mechanical disturbance at the soil surface is rarely expected to alter much, if any, of the B horizon. If changes are observed in B horizon chemistry as a result of waste amendments, this would seem to indicate significant long term changes to the site have occurred (i.e. changes expected to persist longer than a single growing season). From a broader environmental perspective relative to groundwater quality and soil productivity, changes in B horizon properties appear to provide the most useful "index" of overall site effects.

The second critical soil horizon to sample is the O horizon. This soil layer composed of a high percentage of organic materials is critical to the productivity of a site due to its role in nutrient cycling. Through decomposition and cation exchange processes, the O horizon is thought to play a major role in the supply of nutrients to the growing stand on an annual basis. Much of the fine root biomass (or feeder roots) of trees is often concentrated in the O horizon, as is microbial activity responsible for decomposition and mineral transformation processes. In addition this surface layer is generally the first to chemically interact with materials applied to the soil surface, and the O horizon can buffer the site to changes in subsurface mineral soils. Where trace metals are involved, it is well documented that organic matter tenaciously complexes these metals and the O horizon is viewed as a sink for trace metal absorption. Therefore the O horizon can be viewed as the soil layer that shows both the greatest changes as a result of sludge and ash applications, and the soil layer that has the most immediate and dramatic influence on the development of a new forest ecosystem.

With these comments, it is recommended that soil sampling follow the guidelines below.

MODEL SOIL PROFILE		SAMPLING REQUIREMENTS
O Horizon	<----------------	Required
E Horizon	<----------------	Optional
B Horizon	<----------------	Required (upper 10 cm)
C Horizon	<----------------	Optional

Many variations exist on this model soil profile. In almost all situations a B horizon will be present. Sampling from the B horizon should be confined to the upper 10 cm of the horizon to insure consistency in material collected. In most cases the upper boundary of a B horizon is relatively abrupt providing a useful guideline for sampling. This seems to hold true whether the E or O horizon is present, as well as on sites that were mechanically disturbed at the surface. Even where a portion of the upper B horizon has been incorporated into a surface layer of disturbed material, the upper boundary of the intact B horizon usually remains distinct. The lower boundary of the B horizon is typically gradual and difficult to distinguish consistently except where soils may be shallow to bedrock or well defined basal till (i.e. hardpan). Therefore using a set depth interval of 10 cm within the B horizon is recommended, confining that interval to the uppermost material.

The O horizon should be sampled as a block of material after having removed loose litter from the surface. Cutting out a block of material is recommended to avoid artificial separations of the various O horizon subdivisions (Oa, Oe, Oi) from being collected as a "representative" sample. Where sites are from old agricultural fields, or have been significantly disturbed by mechanical operations, the surface Ap type mineral soil horizon should be sampled to a standard depth of 15 cm representing the traditional "plow layer" concept in agriculture.

Information on the composition of the E or C horizon is of secondary importance in assessing site effects and does not appear essential except from a research perspective. Should composite samples be created, sampling should be carried out as described above and then composited in a large container with thorough mixing.

It may be useful to point out that certain materials should be collected when the "maximum" effect of sludge and ash amendments is to be identified for the site. Since these materials are applied to the soil surface, the upper portion of the O horizon, the upper 2 cm of an Ap type horizon, and the upper 2 cm of the B horizon are likely to demonstrate maximum responses to treatments where no mechanical disturbance of the soil has occurred. While not meaningful for standard protocols, these sampling approaches could be useful for special interest concerns.

Soil Preparation

Soils collected in the field will have varying moisture contents and, when stored in this state in warm environments, provide excellent conditions for microbial activity that can alter soil characteristics. This is a particular concern for O horizon materials. Therefore soils should be dried as soon as possible after collection. Recommended procedures include:

1 - Soil samples should be air-dried on open benches or in greenhouses. These air-dried samples are the material used for subsequent chemical analyses. Subsamples of the air-dried samples should be taken to determine oven-dry moisture contents. This information is used in the calculation of analytical data on a mass basis since nearly all data in the scientific literature are expressed on an oven-dry basis.

2 - Organic soil materials (i.e. O horizons) should be oven-dried at 70°C and mineral soil materials should be oven-dried at 105°C for the determination of oven-dry moisture content.

3 - The standard for sieving mineral soils is to use a 2 mm mesh sieve. For some organic soil materials, there is a concern that chemically reactive material is excluded from the sample when sieved through such a small mesh size. Also there is the question of whether too much artificial surface area of organic materials is created when it is dried and crushed to pass through this size sieve. As a result of these concerns, many researchers in the forest soils community have begun to use a 6.35 mm mesh screen (1/4 inch hardware cloth) for sieving organic soil materials and this approach is recommended here for O horizon preparation.

Soil Analysis

Many of the analytical techniques used for agricultural soil testing can be applied to forest soils, but important differences exist in forest soils requiring special consideration in some instances. Table 2 lists the soil parameters likely to be important in assessing the effects of sludge and ash amendments. These parameters are not listed in order of priority, and recommended methods are not necessarily standards used by all forest soil scientists. The methods do represent this author's best judgement at this time.

The parameters listed in Table 2 include most of the elements added to the ecosystem in sludge and ash treatments. Any direct or indirect effect on the influence of nutrients such as N, P, and Ca are important to identify since these nutrients can often be a limiting factor for plant growth on the site. One important difference in the recommended methods when compared to standard agricultural tests is the use of unbuffered extracting solutions for exchangeable cations (including the basic and acidic cations). Most soil testing laboratories use buffered extracting solutions such as NH4OAc, often at a pH of 7.0. Since most agricultural soils have pH values near 7.0, the buffered nature of the extracting solution is not a concern. However, in forest soils the natural pH of the soil is typically much more acidic, and buffered extracting solutions can result in data poorly representative of field conditions. Using unbuffered extracting solutions means that the extraction takes place at nearly the field pH of the soil, and the terms "effective exchangeable cations" and "effective cation exchange capacity" are often employed to indicate unbuffered extractants were used. An example of this effect is well illustrated by O horizon materials, where a cation exchange capacity measured at a buffered pH of 7.0 can easily be two or three times the effective cation exchange capacity measured at ambient soil pH with unbuffered extractants. Total elemental analysis can be useful when comparing the amount of a nutrient or metal added in a waste application to the total amount of that element found naturally in the soil. This could be particularly important for trace metal accumulation concerns.

Table 2 - Recommended parameters and methods for forest soils.

Soil Parameter	Method	Reference
(A) pH	H_2O 0.01 M $CaCl_2$	Page (1982)
(B) organic matter	Loss-on-Ignition	Robarge and Fernandez (1986)
(C) exchangeable cations (Ca, Mg, K, Na, Mn)	1 N NH_4Cl	Robarge and Fernandez (1986)
(D) exchangeable acidity (H, Al)	1 N KCl	Page (1982)
(E) cation exchange capacity	summation (C + D)	Fernandez (1983)
(F) extractable phosphorus	Bray #1	Page (1982)
(G) total nitrogen	Kjeldahl or N Analyzer	Page (1982) or Robarge and Fernandez (1986)
(H) extractable metals	0.1 N HCl	Robarge and Fernandez (1986)
(I) total elemental analysis	$HF/H_2SO_4/HClO_4$	Page (1982)

Frequently the Lime Requirement test has been used to estimate waste application rates for agricultural soils. This test is not recommended for testing forest soils due to (a) the wide range of soil characteristics encountered in forest soils, (b) the arbitrarily high target pH used for Lime Requirement determinations, and (c) results of studies we have conducted showing a poor correlation exists between Lime Requirement and forest soil pH changes following ash amendments.

Soil Solution Assessments

It is not likely that waste application sites will routinely be monitored for soil solution and groundwater effects given the complexity and costs of these assessments. This type of site monitoring is best reserved for research sites. Where soil solution chemical composition is of interest, quantifying solution variability becomes even more difficult than noted for soil evaluations. In addition, numerous types of lysimeters can be employed to sample soil solutions with each having an effect on the chemistry of the resulting samples. The generic approaches to consider would be the use of tension lysimeters, zero tension lysimeters, or centrifugation techniques to extract solutions from soils. Groundwater sampling can be accomplished via piezometer wells. Although soil solution and groundwater quality assessments may not be routine components of waste application practices, often ephemeral or perennial brooks and streams exist on sites. If present, these natural drainages should be sampled before and after applications of waste to the landscape as they offer easy access to water samples that can be useful additional evidence of effects on the landscape. It should be noted, however, that changes in streamwater quality following treatments may not reflect changes in soil and groundwater quality on sites with significant surface runoff.

Vegetation Composition

Additional information regarding waste application effects on the site can be gained through measurements of foliar chemistry and growth of the vegetation. In most settings assessing effects on forest health and growth for mature stands will be impossible since materials are typically applied to recently cut sites. However, when natural or artificial regeneration exists, tree growth (i.e. height and root collar diameter) and foliar chemistry would be useful information. Young trees have root systems confined to soil layers most likely to be affected by sludge and ash amendments and should show the greatest response from soil changes. Also, young trees respond differently to environmental stress than older trees, and questions may still remain regarding future stand development. Nevertheless, changes in tree growth and foliar chemistry provide a unique opportunity, since they reflect the integration of all biologically reserved for research sites. Where soil solution chemical composition is of interest, quantifying solution variability becomes even more difficult than noted for soil evaluations. In addition, numerous types of lysimeters can be employed to sample soil solutions with each having an effect on the chemistry of the resulting samples. The generic approaches to consider would be the use of tension lysimeters, zero tension lysimeters, or centrifugation techniques to extract solutions from soils. Groundwater sampling can be accomplished via piezometer wells. Although soil solution and groundwater quality assessments may not be routine components of waste application practices, often ephemeral or perennial brooks and streams exist on sites. If present, these natural drainages should be sampled before and after applications of waste to the landscape as they offer easy access to water samples that can be useful additional evidence of effects on the landscape. It should be noted, however, that changes in streamwater quality following treatments may not reflect changes in soil and groundwater quality on sites with significant surface runoff.

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CONCLUSIONS

Further development of protocols for the sampling and analysis of forest soils amended with sludge and ash materials will rely on the results of research and experience from operational sites. A significant amount of work has been done in the forest soils research community to identify appropriate laboratory methodologies at this time, with the major unknowns dealing with suitable sampling schemes to meet the intended objectives. Each new site provides opportunities for additional data to address the sampling question, which is an information need important to meeting sound management goals.

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