FEASIBLE AND COST EFFECTIVE

FOREST LAND APPLICATION OF MUNICIPAL SLUDGE

Enhanced nutrient cycling and tree growth were among the results of an extensive program in northern Michigan.

Dale G. Brockway

IN Michigan, 199 municipal and numerous industrial wastewater treatment facilities annually generate 222,750 dry tons of sludge, most of which is recycled on farmland. Substantial potential exists, however, to increase application on forest land in the northern two-thirds of the state (Brockway and Nguyen 1986). Although sludge application on agricultural land has received more study, forest land offers numerous unique advantages (Smith and Evans 1977).

The nonedible nature of forest crops generally diminishes the risk of human exposure to elements which may be hazardous in the food chain. While adapted to low ambient nutrient levels in forest soils, native plants respond to sludge application with significant nutrient and biomass increases (Brockway 1983, Zasoski et al. 1983, Wells et al. 1984, Berry 1987). The long-term accumulation of biomass affords substantial storage capacity for certain elements during a crop rotation and harvesting offers a means of removing elements from treated sites. Forest soils are generally porous, resulting in minimal surface runoff of applied nutrients, and often nutritionally impoverished, providing opportunity to substantially increase soil organic matter and nutrient levels with sludge additions. Forest sites are also commonly located away from large population centers and are used for dispersed recreational activities, minimizing the opportunity for human contact with recently applied sludge.

In 1975, USDA Forest Service scientists initiated a series of small plot studies in the forests of northern Michigan to assess the growth and environmental effects of various sludge types applied at widely ranging rates (Urie et al. 1978, Brockway 1979). Results of these studies were used in 1980 to prescribe sludge application rates for an operational scale research-demonstration jointiy initiated by the U.S. Environmental Protection Agency, Michigan Department of Natural Resources and Michigan State University Department of Forestry and Department of Fisheries and Wildlife. The objective of this project was to further examine the environmental effects, sociological dynamics and operational feasibility of large scale forest land application programs and develop regulatory guidance for future use.

MATERIALS AND METHODS

Forest Sites

Sites selected on which to conduct the forest land application project were located in Montmorency County on the Mackinaw State Forest in northeastern lower Michigan. Vegetation on the four sites was representative of the upland forest types of major commercial importance in the northern portion of the state. Permeable glacial drift formed the parent material for soils, which are low in native fertility and allow rapid infiltration of precipitation. Annual precipitation averages 766 mm (30 inches), with 160 mm (6.3 inches) incident as snow from late November to early April (NOAA 1982). The mean annual temperature is 5.8°C (42.4°F) with extremes of -7.4% (18.7°F) in January and 19.6% (67.3°F) in July (NOAA 1981). The sites are underlain by a phreatic aquifer at depths ranging 1 to over 30 m (3 to 97 ft) which is contiguous with the regional groundwater system. Elevation is approximately 300 m (985 ft) above sea level.

The aspen site was occupied by a lo-year-old stand of coppice regeneration which was primarily bigtooth aspen containing a secondary component of quaking aspen, northem pm oak and cherry growing on Grayling and Rubicon soils. The oak site contained a 70-year-old stand (868 trees/ha and 21 m^2/ha) of mixed red oak and white oak with red maple, pines and aspen growing on Graycalm and Rubicon soils. The pine site was occupied by a 50-year-old plantation (680 trees/ha and 23 m^2/ha) of mixed jack pine and red pine growing on Grayling and Montcalm soils. The northern hardwoods site contained a 50-year-old stand (720 trees/ha and 22 m^2/ha) that was predominantly red maple and sugar maple with remnants of American beech, yelow birch, red oak, American basswood, white ash and eastern hemlock growing on Mancelona, Melita, Menominee, Kawkawlin and Sims soils.

Design and Measurements

The experimental design for the demonstration consisted of three treatments—control, application trails only, and sludge application from trails-replicated three times and randomly assigned to individual 1.5 ha (3.8 ac) plots. Study plots covered an area of 64 ha (132 ac), of which 18 ha (44 ac) were treated with nearly 4 million liters (1 million gallons) of wastewater sludge at rates averaging 9 Mg/ha (4 dry tons/ac).

Standard sample collection, measurement and statistical procedures were used to assess treatment effects upon vegetation, forest floor, soil, groundwater and wildlife (Brockway and Nguyen 1986, Burton et al. 1986, Campa et al. 1986, Hart et al. 1986, Merkel et al. 1986, Nguyen et al. 1986, Woodyard et al. 1986). Two food chain studies using sludge-soil-grass-mice-raptors (hawks and owls) and sludge-soil-earthworms-woodcock were also conducted in the laboratory to supplement food chain studies in the field (Haufler and Woodyard 1986). Sociological studies were conducted throughout the state using survey questionnaires to evaluate public opinion and concerns (Gigliotti and Peyton 1986).

OPERATIONAL FACTORS

Application

Sludge application was conducted in October and November 1981 on oak and aspen and in June and July 1982 on pine and northern hardwoods. Anaerobically digested sludge from the municipal wastewater treatment facilities in Alpena and Rogers City, Michigan was transported 80 km (50 mi) as liquid (3 to 8% solids) in tank trucks from generator facilities to forest sites where it is directly transferred to the application vehicle, an Ag-Gator 2004 (Ag Chem Equipment Company of Minneapolis, Minnesota) equipped with high-flotation tires to minimize soil compaction and a pressure-vacuum pump to fill and empty its 8,300 *liter (2,200 gal)* tank. Liquid sludge was laterally discharged up to 10 m (33 ft) from the vehicle through three spray nozzles arranged to cover near, intermediate and distant bands of forest floor (Brockway and Nguyen).

Sludge Quality

Sludges from Alpena and Rogers City were both rich sources of nitrogen, phosphorus and calcium, with moderate to low levels of micronutrients and heavy metals (Table 1). Because of the relatively low levels of potentially toxic metals in these *two* sludges, sludge from the City of Detroit wastewater treatment facility was used in the laboratory food chain studies in hopes of testing the biomagnification potential of heavy metals in sludge from a heavily industrialized municipality, However, a comparison revealed that heavy metal concentrations were not very different from those in the Alpena sludge (Table 2).

Substantial sludge solids, nutrients and trace elements were applied on a unit area basis to treated plots (Table 3). Overall loading rates of trace elements and heavy metals were quite low. In the laboratory raptor food chain study, applications provided 584 kg N/ha (522 lbs N/ac) with Alpena sludge, 739 kg N/ha (660 lbs N/ac) with Detroit sludge and 600 kg N/ha (536 lbs N/ac) with commercial fertilizer. In the woodcock study a 7:10 sludge to soil mixture resulted in soil metal levels significantly greater than soils receiving commercial fertilizer (Table 4).

Forest Access

Best operational results were achieved with all-terrain tank vehicles traveling on prepared access trails and spraying liquid sludge upon the forest floor. To *allow access* of these vehicles, parallel trails at intervals of 20 m (66 ft) were cleared by felling and removal of mature whole trees with a rubber tired skidder or shearing aspen coppice at the groundline with a bulldozer. Study access trails were 5 to 6 m (16 to 20 ft) wide; spaced at intervals of 20 m (66 ft) and oriented parallel in a north-south direction to minimize sun-scald on bark of newly exposed residual trees (Hart et al. 1986). Although these dimensions resulted in removal of 20 percent of the stand area for access trails, use of spray equipment capable of discharging greater distances or use of existing access would require removal of little or no area from production (Henry and Cole 1983).

Costs

Major costs for sludge application in forests are associated with stand preparation, which is typically borne by the land-owner, and sludge transport and application, normally borne by the sludge generator (Brockway and Nguyen 1986). The cost of bulldozing trails through aspen sprouts averaged $164 per ha ($66 per ac). If trees are of sufficient size and quality, a net income may be realized by harvest of timber growing in proposed access trails, as was the case on northern hardwoods, oak and pine sites, where return ranged from $15 to $38 per ha ($6 to $15 per ac). The cost for transport of 3.7 million liters (1 million gal) of sludge a distance of 80 km (50 mi) and application to 18 ha (44 ac) of forest land was $48,576 (in 1981), or $303.52 per Mg ($275.94 per dry ton). This compares favorably with sludge application on agricultural land, where shorter transportation distances (24 km or 15 mi) are typical in operational programs.

Baaed upon the median nutrient and trace element content of sludges and current commercial fertilizer prices, the value of the sludge is estimated at $26.31 per Mg ($23.76 per ton). At recommended application rates (Urie and Brockway 1986). the value added to these forest sites ranged from $184 to $395 per ha ($75 to $160 per ac).

> At recommended application rates, value added to forest sites ranged from $75 to $160 per acre.

ENVIRONMENTAL EFFECTS

Forest Vegetation

Sludge applied nitrogen and phosphorus were rapidly *taken* up by trees, increasing foliar nutrient concentrations. Nutrient in-

Table 1. **Average** chemical concentrations in **sludges** appiied on forest sites **(Brockway and Nguyen 1986).**

Element	Aspen'	Oad	Oak[3]	Pine"	Northern Hardwood?
		mglkg (dry basis)			
Nitrogen	53.040	32.490	71,840	45,840	85,140
Phosphorus	28,080	32,490	35,920	30,560	41,580
Potassium	2,733	2,389	3,040	2,685	1,295
Calcium	41.902	86.321	64,521	45,534	55,064
Magnesium	4,452	5,763	7,150	4,053	5,445
Sodium	3,151	2,334	4,263	3,648	2,028
Boron	44	4	122	86	30
Aluminum	30,514	19,733	16,164	16,808	8,732
Iron	55,942	58,379	68,113	61,044	50,846
Manganese	706	1,073	431	417	182
Zinc	1,234	1,119	1,201	932	942
Copper	571	434	1,221	516	597
Chromium	182	109	102	106	64
Nickel	43	42	36	43	23
Cadmium	28	8	115	60	8

[1]Alpena sludge, October 1981
[2]Alpena sludge, November 1981
[3]Rogers City sludge, November 1981
[4]Alpena sludge, June 1982
"Rogers City sludge, July 1982

Table 2 ffeavy **metal concentrations in commercial fertilizer and wastewater sludges** from **Alpena** and Detroit **(Haufler** and **Woodyard 1986).**

Metal	Fertilizer	Alpena	Detroit
	mg/kg (dry wt. basis)		
Zinc	401	1125	1718
Copper	115	1230	527
Chromium	24	49	139
Nickel	6	36	10
Cadmium	3	8	13

Table 3. Solids, **nutrient** and trace efement **loaing** on forest **sites (Brockway and Nguyen** 1986).

Constituent	Aspen	Oak	Pine	Northern Hardwoods
			kg/ha	
Solids	9,980	8,019	8.119	9,210
Nitrogen	560.0	400.6	379.4	783.1
Phosphorus	290.5	272.1	252.9	383.7
Potassium	26.21	21.35	22.12	11.89
Calcium	418.0	619.0	373.5	503.0
Magnesium	44.36	50.89	32.25	49.84
Sodium	31.45	25.21	30.18	18.57
Boron	0.44	0.43	0.71	0.27
Aluminum	304.0	146.3	137.8	79.8
Iron	557.2	491.7	500.9	456.9
Manganese	7.04	6.44	3.80	1.66
Zinc	12.29	9.25	7.61	8.60
Copper	5.68	6.13	4.22	5.50
Chromium	1.81	0.85	0.86	0.58
Nickel	0.42	0.31	0.35	0.21
Cadmium	0.28	0.42	0.36	0.08

creases observed in aspen were also present, though somewhat less pronounced, in oak and pine species (Table 5). This response continued through the 1984 growing season and was expected to persist for several years until the nutrients became immobilized in woody plant tissue.

Increased tree growth is a nearly universal effect of sludge application in the forest. Total 1981 to 1985 increases in diameter growth were 23%, 78%. 25% and 48%; the increases for basal area growth were 48%, 56%, 36% and 56% (Figure 1) for aspen, oak, pine and northern hardwoods, respectively In the same period, a 57 percent increase in aspen biomass growth was observed (Hart and Nguyen 1986).

Although tree sapling numbers and basal area were increased by sludge application and trail clearing, tree seedling numbers and cover of grasses, sedges, shrubs and forbs remained largely unaffected. Competing vegetation neither negated overstory tree growth nor diminished tree regeneration.

In assessing the potential for long-term forest productivity responses, oak site fertility differences two years after sludge applications were observed to be equivalent to a mean annual growth increase of 1.05 m^3/ha/yr (15 ft^3/ac/yr)—a 29 percent growth response-based on fertility-growth regressions from numerous stands sampled in adjacent areas (Merkel et al. 1986).

Forest Floor and Soil

Four years following sludge application, major portions of supplemental nutrients and trace elements were retained as unavailable, undecomposed forms in the humus of the forest floor. Nutrients in available. forms moving from forest floor to mineral soil were readily taken up by plants, as no significant fertility changes were observed in surface or subsurface soils. With no major loss of site nutrients detected, sludge application rates on these forest types did not exceed short-term ecosystem assimilation capacity However, the long-term fate of accumulated nutrients and trace elements remains uncertain in the event of fire or harvest, which leads to their rapid release from the forest floor.

Water Quality

Nitrate-N concentrations in soil water immediately below the major rooting zone at 120 cm (4 ft) were consistent (Figure 2) with those predicted from earlier USDA Forest Service studies (Brockway and Urie 1983). In aspen and pine, the maximums exceeded 15 mg/1 for several months, while the maximums in oak and northern hardwoods soils remained below 5 mg/1 (Urie et al. 1986). Laboratory tests showed that nitrogen mineralization rates in the forest floor and upper mineral soil under pine were much lower than under deciduous trees; however, mineralization capacity in the field remained high on all sites for at least three years following sludge application (Burton et al. 1986). Nitrate-N levels in groundwater (Figure 3) at depths from 3 to 8 m (10 to 26 ft) reflected sludge nutrient additions, but remained well below the 10 mg/1 USEPA water quality limit. Elevated nitrate concentrations were the only chemical change in groundwater consistently related to sludge application.

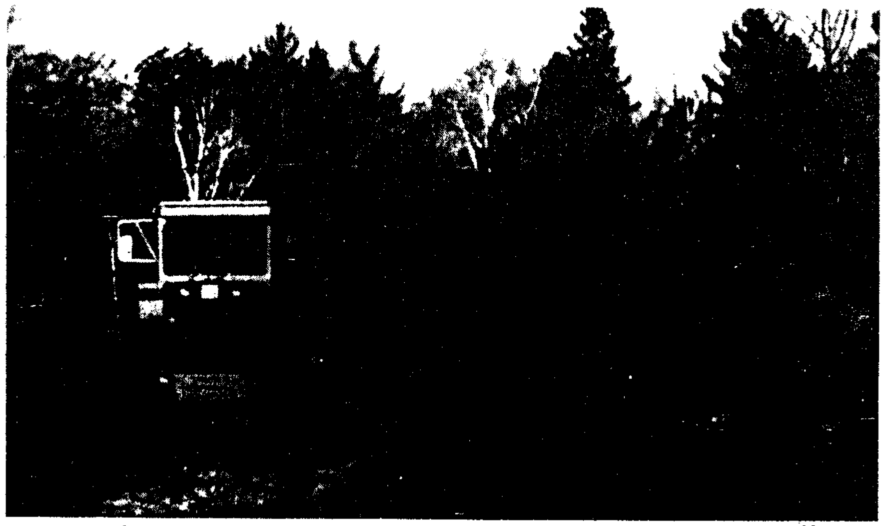
Wildlife

While plant species composition was unaffected by sludge application, the quantity and vertical distribution of cover beneficial to important wildlife species was substantially enhanced (Campa et al. 1986). Understory vegetation was universally increased and the greatest gains in vertical cover were observed in the lower 2 m (6 ft) strata. Annual production of herbaceous species under aspen increased 200 percent one year following sludge fertilization and remained 50 percent higher than untreated areas three years later. A similar response, but of lesser magnitude, was observed in oak, pine (Figure 4) and northern hardwoods. Protein and phosphorus increases of 20 to 50 percent in important wildlife forage plants were observed within one year and persisted for three years following sludge application. Within one year of sludge application, improved habitat structure and forage nutritive quality increased populations of small mammals (Woodyard et al. 1986) and browse utilization by whitetail deer and elk (Campa et al. 1986).

Bioassays of plant and animal tissues from organisms exposed to sludge-fertilized soil in upland forest and laboratory trials indicated only minor accumulation of toxicants to levels that would not be harmful to forage plants, herbivores or carnivores at higher trophic levels, including humans (Woodyard et al. 1986). Food chain studies conducted in the laboratory using Detroit sludge yielded minor accumulations of cadmium, chromium and nickel in mice kidney and liver tissue. These accumulations were not unlike those found in free ranging small mammals sampled during field studies where sludge was applied from local sources with little industrial input. Only when laboratory confined woodcock (a lowland insectivore) were fed an exclusive diet of earthworms grown in soil treated with sludge contaminated by high levels of heavy metals did liver and kidney tissues show significantly elevated (Table 6) but non-lethal concentrations of cadmium (Haufler and Woodyard 1986). Since free ranging woodcock would not so intensively forage on sludge treated upland forest sites, and because their livers and kidneys are discarded with the entrails by hunters prior to consumption, the actual risk to human health from cadmium transmission by this route is minimal.

PUBLIC OPINION

Public opinion surveys conducted in northern Michigan revealed that, while two-thirds of residents believe sludge generation to be a significant problem, the majority was undecided (Figure 5) about sludge application on forest land (Gigliotti and Peyton 1986). The absence of strongly held opinions resulted from little technical information about risks and benefits of various options available to the public; however, 87 percent of residents indicated an interest in learning more about



Forest **soils** are generally porous, resulting in minimal surface **runoff** of applied nutrients.

Fig 1 Basal area **growth** response of trees at the pine, oak, northern hardwoods and aspen sites to trails (T) and trails plus sludge (S) compared to control (C) areas (Hart and Nguyen 1986).

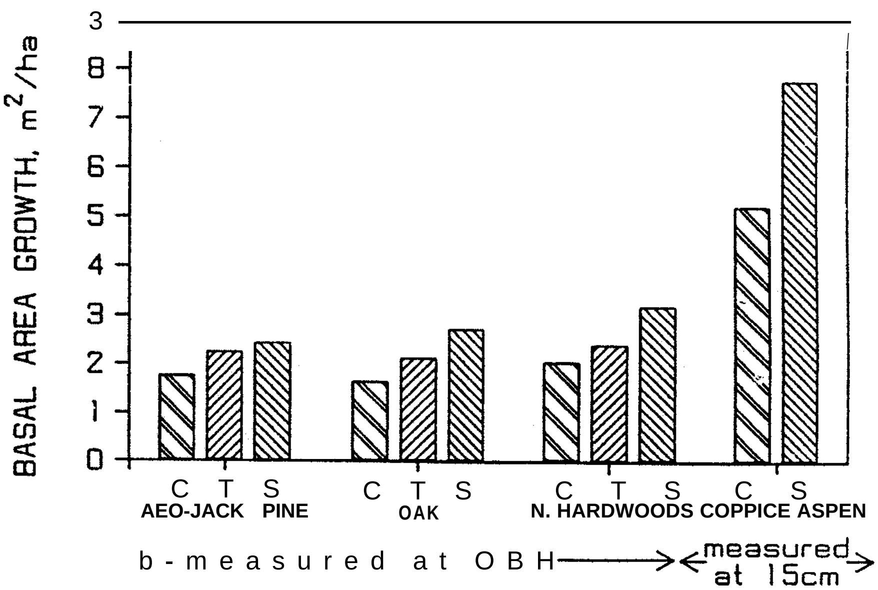


Fig 2. Mean annual nitrate-N concentrations in soil leachate at 120 cm (4 ft) on the aspen (A), northern hardwoods (NH), oak (O) and pine (P) sites following sludge application (Urie et al. 1986).

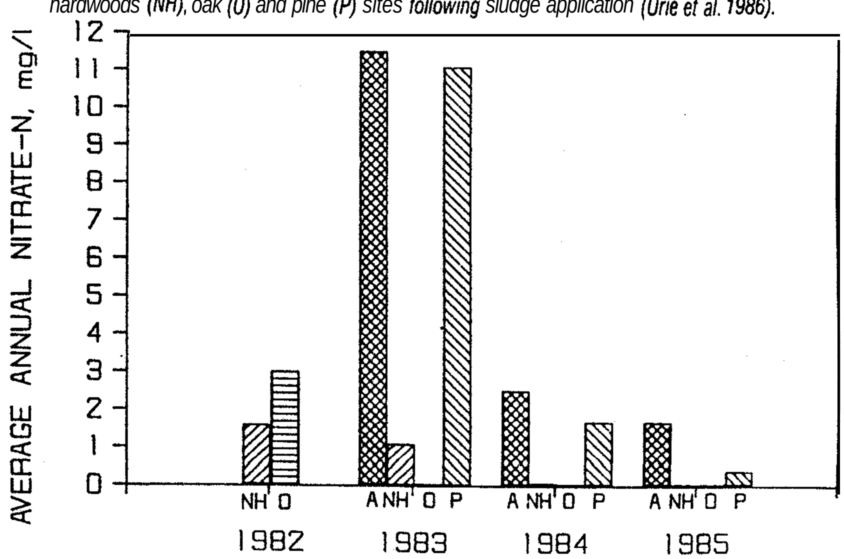


Fig 3. Mean annual nitrate-N concentrations in groundwaler at 6 to 8 mm (20 to 26 ft) on the aspen (A), northern hardwoods (NH) and pine (P) sites following s ;dge application (Urie et al. 7986).

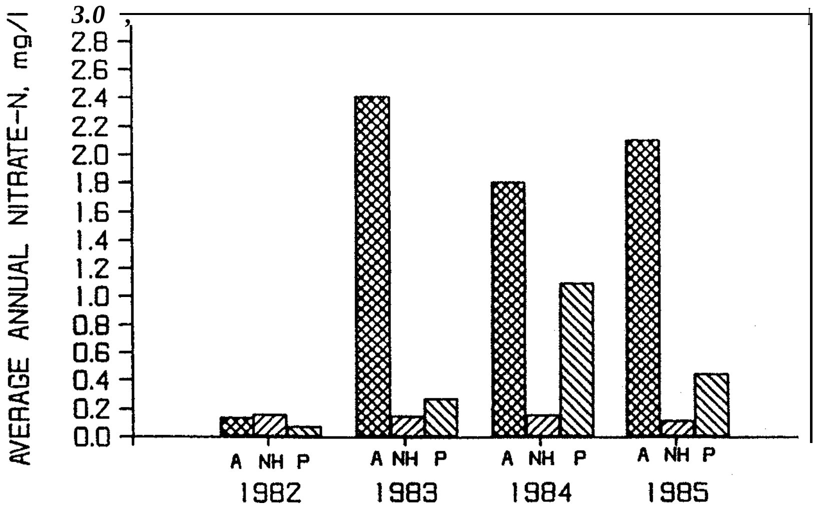


*Fig. 4 Vegetation growth under pine on **(left)** control plot and (right) sludge **fertilized** plot.*

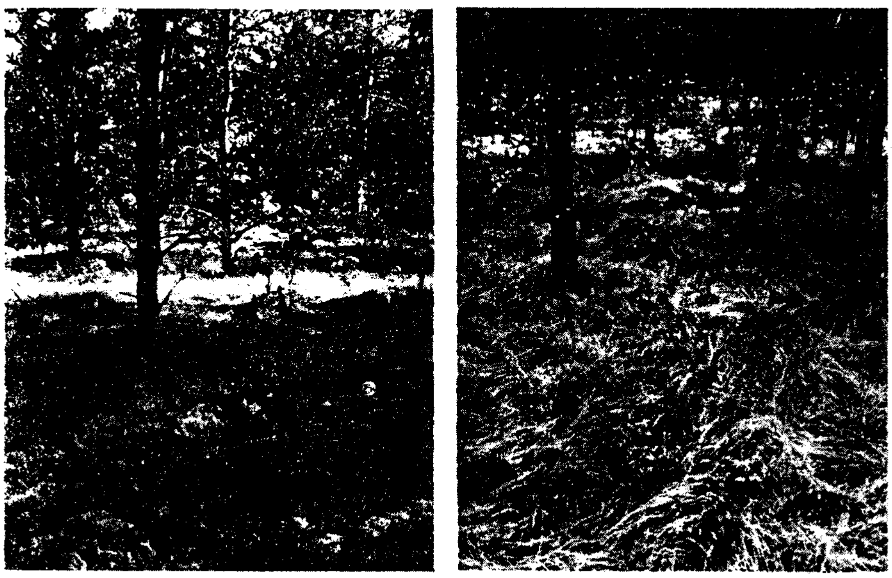
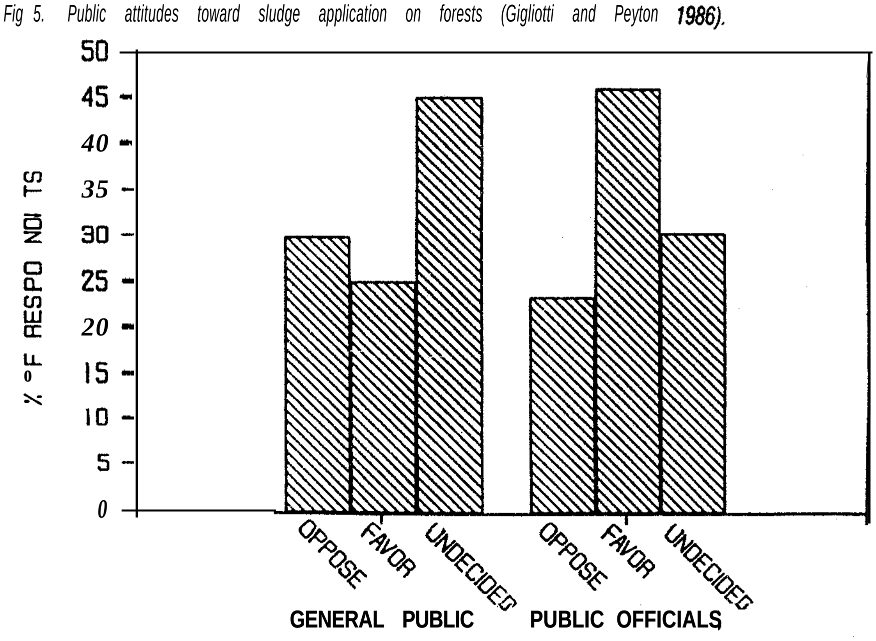


*Fig 5. Public attitudes toward sludge application on forests (Gigliotti and Peyton **1986**).*



sludge management practices. Therefore, effective public involvement can be developed by increasing the level of knowledge.

Educational programs should emphasize that forest land application typically affects relatively small acreages and few individual forest users. Public involvement early in the planning process is essential to program success, especially when proposals include fertilization of **publicly-owned** forests.

REGULATORY DEVELOPMENT

Results **from** this and related studies have been incorporated into the Michigan Department of Natural **Resources'** environmental protection programs that regulate activities which may have an impact on the quality of water resources. "Guidance for Land Application of **Wastewater** Sludge in Michigan" and several supporting documents have been developed to help the regulated community and general public understand how by-products, such as sludge, can be productively recycled on farm, forest and mine spoiled lands in a manner that does not threaten public health or the environment (MDNR 1986).

SUMMARY

Land applied sludge substantially enhanced nutrient cycling, tree growth, wildlife habitat and the nutritional quality of forage plants in the forest. At appropriate application rates, these benefits were obtained while avoiding groundwater contamination and **toxicant** transmission in the food chain. Forest land application methods were shown to be technologically feasible and cost effective. Such results could reasonably be anticipated when wastewater sludge is applied in similar forest ecosystems, as those found in the Upper Great lakes and Northeastern regions of the United States.

Forest land application of sludge has great potential **to** become a socially acceptable option, provided accurate @formation is made available to the public. Environmental and natural resources managers in Michigan are committed to further development and utilization of this technology in agency **programs.** ■

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constitute endorsement or recommendation for use.

REFERENCES

Berry, C.R. 1987. Use of municipal sewage sludge for improvement of forest sites in the southeast. USDA Forest Service Research Paper SE-266. Southeastern Forest Experiment Station, Ashville, North Carolina. 33 p.

Brockway, D.G. 1979. Evaluation of northern pine plantations as disposal sites for municipal and industrial sludge. Ph.D. Dissertation. Michigan State University, East Lansing. Univ. Micro films, Ann Arbor, Michigan. (Diss. Abstr. 40-2919B).

Brockway, D.G. 1983. Forest floor, soil and vegetation responses to sludge fertilization in red and white pine plantations. Soil Sci. Soc. Am. J. 47:776-784.

Brockway, D.G. and D.H. Urie. 1983. Determining sludge fertilization rates for forests from nitrate-nitrogen in leachate and groundwater. J. Environ. Qual. 12:487-492.

Brockway, D.G. and P.V. Nguyen. 1986. Municipal sludge application in forests of northern Michigan, a case study p. 477-496. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Burton, A.J., D.H. Urie and J.B. Hart. 1986. Nitrogen transformations in four sludge-amended Michigan forest types. p. 142-153. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Campa, H., D.K. Woodyard and J.B. Haufler. 1986. Deer and elk use of forage treated with municipal sewage sludge. p. 181-198. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Gigliotti, L.M. and R.B. Peyton. 1986. Utility of a public acceptance survey for forest application planning: a case study p. 367-382. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Hart, J.H., J.B. Hart and P.V. Nguyen. 1986. Aspen mortality following sludge application in Michigan. p. 266-271. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Hart, J.B. and P.V. Nguyen. 1986. Ecological monitoring of sludge fertilization on state forest lands in northern lower Michigan. Final Project Report. Department of Forestry, Michigan State University, East Lansing. 285 p.

Haufler, J.B. and D.K. Woodyard. 1986. Influences on wildlife populations of the application of sewage sludge to upland forest types. Final Project Report. Department of Fisheries and Wildlife, Michigan State University, East Lansing. 288 p.

Henry C.L. and D.W. Cole (eds.). 1983. Use of de watered sludge as an amendment for forest growth: Volume IV. Institute of Forest Re sources. University of Washington, Seattle. 110 p.

Merkel, D.M., J.B. Hart, P.V. Nguyen and C.W. Ramm. 1986. Municipal sludge fertilization on oak forests in Michigan: estimation of long-term

Sludge enhanced nutrient recycling, tree growth and wildlife habitat, as well as nutritional quality of forage plants.

Table** 4. tieawy metal concentrations in **greenhouse soils** amended with sludge or **commercial fertilizer (Haufler** and **Woodyard 1986).

Metal	Fertilizer	Alpena	Detroit
		mg/kg	
Zinc	78a	287b	327b
Copper	15.2a	41.6b	34.4b
Chromium	48.8a	56.5b	58.0b
Nickel	20.6a	24.8b	19.5b
Cadmium	1.6a	3.7b	4.5b

Means in the same row followed by the same letter are nor significantly different at the 0.1 level.

*Tabk 5. Foikr nutrient **concentrations** in 1984 resting from sludge **application (Hart** and **Nguyen 1986).***

	Nitrogen		Phosphorus	
	Control	Treated	Control	Treated
		%		
Aspen	2.04a	2.43b	0.20a	0.23b
Red Oak	2.36a	2.35a	0.22a	0.24a
White Oak	2.27a	2.38a	0.25a	0.25a
Jack Pine	0.90a	1.47b	0.14a	0.16b
Red Pine	0.94a	1.13b	0.13a	0.14b

Means in the same row followed by the same letter are not significantly different at the 0.05 level.

Table** 6. Cadmium concentrations is tissues of woodcock fed earthworms raised in **soil** receiving **sludge** or wmmercki **fertilizer (Haufler** and **Woodyard 1986).

Treatment	Liver	Kidney	Heart	Muscle	Bone
		mg/kg			
Control	3.12a	17.9a	0.78a	1.25a	0.05a
Fertilize(12-12-12)	1.81b	12.6b	0.57a	0.69a	0.02a
Alpena Sludge	7.83c	30.4c	0.61a	0.97a	0.04a
Detroit Sludge	6.21a	36.1c	0.56a	1.12a	0.02a

*Means **in the Same** column **followed** by the **same letter are not significant/y** different at the 0.1 level.*

BOOK REVIEWS

METHANE FROM BIOMASS: A SYSTEMS APPROACH

Edited by W.H. Smith and J.R. Frank

1987. Elsevier Science Publishing Co., New York, NY. 500 pp., cloth, $144.

Methane production from biomass is treated in this publication solely as an alternative energy source. In fact, none of the ?7 papers presented in this highly informative book deal with the use of wastes for methane production. The biomass used as substrate was grown solely with methane production in mind. The "systems approach" in the title refers to "a systems analysis methodology that integrates availability of physical sources (land, climate, etc.) with biomass production functions, conversion options and energy storage, transportation and demand factors". Consequently, the book not only covers the methane production process itself but also biomass production and its relation to biogasification.

PH. Abelson provides an excellent survey and assessment of activities and progress in the use of biogasification of cropped biomass as an energy source.

AIR POLLUTION CONTROL ENGINEERING

By W. Licht

1988. 2nd edition, Basic Calculations for Particulate Collection. Marcel Dekker, Inc., New York, NY. 496 pp, cloth, $89.75.

The book is equally useful as a classroom textbook and as a handy reference source for scientists and **practicing** engineers concerned with air pollution control technology It benefits by being authored by a scientist who has 30 years of experience with particulate collection and now is Professor Emeritus of Chemical Engiieering in the University of Cincinnati.

As Dr. Licht states, the book presents basic scientific principles and basic engineering calculations involved in the design of particulate collection systems.

TOXICOLOGY: A PRIMER ON PRINCIPLES AND APPLICATIONS

By M.A. Kamrin

1988. Lewis Publishers, Chelsea, MI, **145 pp, cloth, $27.50.**

We, the public, are finally becoming aware of our **24-hour** daily exposure to toxic substances by way of the food we eat, the air we breathe, and the water we drink. Not surprisingly, we would like to know more about those toxic substances than we can glean from the media. Reading Kamrin's book would be a significant advance **in the fulfillment** of that desire. The book presents the basic principles and applications of toxicology in a sophisticated yet non-technical style and hence is readily comprehended by virtually any one desirous of a clear understanding of this all-pervasive subject.

(continued from p. 67)

growth responses. p. 292-300. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Michigan Department of Natural Resources (MDNR). 1986. Guidance for land application of wastewater sludge in Michigan. Land Application Unit, Groundwater Quality Division, Lansing. 32 p.

National Oceanographic and Atmospheric Association (NOAA). 1981. Climatologicaldata, annual summary, Michigan. Volume 96.

National Oceanographic and Atmospheric Association (NOAA). 1982: Climatological data, annual summary, Michigan. Volumes 96 and 97.

Nguyen, P.V., J.B. Hart and D.M. Merkel. 1986. Municipal sludge fertilization on oak forests in Michigan: short-term nutrient changes and growth responses. p. 282-291. In D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Smith, W.H. and J.O. Evans. 1977. Special opportunities and problems in using forest soils for organic waste application. p. 429-454. *In* L.F. Elliott and EJ. Stevenson (eds.). Soils for Manage ment of Organic Wastes and Waste Waters. Am. Soc. of Agronomy, Madison, Wisconsin.

Urie, D.H., A.J. Burton J.B. Hart, and P.V. Nguyen. 1986. Hydrologic and water quality effects from sludge application to forests in northern lower Michigan. Final Project Report. Department of Forestry, Michigan State University, East Lansing. 131 p.

Urie, D.H. and D.G. Brockway. 1986. Relating research results to sludge guidelines for Michigan's forests. p. 383-389. *In* D.W. Cole, C.L. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes, University of Washington Press, Seattle.

Urie, D.H., A.R. Harris and J.H. Cooley. 1978. Municipal and industrial sludge fertilization of forests and wildlife openings. p. 467-480. *In* Fist Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste. Dept. of Engineering and Applied Science, University of Wisconsin, Madison.

Wells, C.G., K.W. McLeod, C.E. Murphy J.R. Jensen, J.C. Corey, W.H. McKee and E.J. Christensen. 1984. Response of loblolly pine plantations to two sources of sewage sludge. p. 85-94. *In* Research and Development Conference Proc., T.A.P.P.I. Press, Atlanta, Georgia.

Woodyard, D.K., H. Campa and J.B. Haufler. 1986. The influence of forest application of sewage sludge on the concentration of metals in vegetation and small mammals. p. 199-205. *In* D.W. Cole, CL. Henry and W.L. Nutter (eds.). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Zasoski, R.J., D.W. Cole and C.S. Bledsoe. 1983. Municipal sewage sludge use in forests of the Pacific Northwest, U.S.A.: growth responses. Waste Management and Research 1:103-114.

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