Agronomic Effects of Land Application of Water Treatment Sludges

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Economic, regulatory, and legal constraints on alternative disposal methods are raising interest in land application of water treatment sludges. Understanding the agronomic and environmental issues is essential before a land-based disposal program is implemented. Water treatment sludges may favorably modify the pH and water-holding capacity of soils but generally have little fertilizer value. Supplemental phosphorus (P) fertilizer will usually be needed to offset the strong P-binding capacity of these sludges. Heavy metal concentrations can be limited in sludges primarily by controlling the purity of the coagulant chemicals.

Water utilities can no longer be concerned solely with producing a high-quality potable water supply. Disposal of treatment process by-products is becoming increasingly difficult and expensive. Despite early objections about its appropriateness,[1] direct discharge of water treatment sludge (WTS) to a watercourse was standard practice for years.[2] A 1953 survey of 1,530 water treatment plants indicated that more than 96 percent of them discharged untreated sludge directly into rivers or lakes.[3] Concern over potential degradation of downstream water quality has been expressed, with possible adverse effects including sludge-blanketing of benthic ecosystems and aluminum (Al) toxicity to aquatic organisms.[2] Although no federal guidelines exist for water treatment plant effluents, the US Environmental Protection Agency (USEPA) regions or individual states can prohibit direct discharge.[2] Utilities that dispose of sludge in sanitary landfills are faced with problems of dwindling capacity, escalating fees, extensive dewatering requirements, and potential liability for landfill cleanup and closure operations. Codisposal with municipal sewage has been practiced successfully but requires a nearby facility with the capacity, process control capabilities, and willingness to accept the sludge.[4]

Land-based systems are becoming more popular for the ultimate disposal of WTS. Land treatment is the controlled spreading of sludge onto or incorporation into the surface layer of soil to stabilize, degrade, and immobilize sludge constituents. Methods of land spreading include application to cropland, reclamation of strip-mined areas, and use as a cover material for landfills. Besides accomplishing ultimate disposal, such systems can often be engineered to favorably modify soil properties and recycle valuable sludge components.

Barring a grossly contaminated water source, water treatment sludge has fewer potential adverse environmental effects than municipal sewage sludge.

Land application has long been a major disposal technique for sewage sludges because they contain nutrients—like nitrogen (N), phosphorus (P), and potassium (K)—that are valuable in agricultural crop production. Most state environmental agencies have comprehensive regulations and programs for managing wastewater sludges. Policies specifically tailored to WTS are, however, almost nonexistent, and regulatory agencies may virtually ignore waste disposal by water treatment plants. There may then be little incentive to change long-standing sludge disposal practices. Alternately, WTS may fall under the provisions of wastewater sludges or industrial wastes, resulting in unnecessarily restrictive and burdensome regulations.

For many water utilities, major changes in waste disposal practices are inevitable. The rate and extent of change will depend largely on the local regulatory climate. Planning efforts should include evaluation of various land-based disposal options. Innovative strategies that are both technically feasible and environmentally sound must be formulated for each plant to ensure economic viability. A clear understanding of the agronomic and environmental effects is the first step toward implementing a

**A full report of this project, entitled "Land Application of Water Treatment Plant Sludges" (catalog no. 90566), is available from the AWWA Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235.*

TABLE 1
*Characteristics of water treatment sludges**

Parameter	Alum Sludge	Iron Salt Sludge	Lime-Softening Sludge
Al—*percent dry weight*	21.2 (2.8-30)†	1.6, 7.7	0.45 (0.05-1.6)
Ca—*percent dry weight*	2.7 (0.3-5)	15.0	45.1 (31-52)
Fe—*percent dry weight*	3.2 (1.2-6.6)	10.9	0.29 (0.13-0.71)
K—*percent dry weight*	1.7 (0.04-5)	0.3	0.02 (<0.01-0.08)
Mg—*percent dry weight*	0.45 (0.24-0.8)	1.6	2.1 (1.1-3.6)
Si—*percent dry weight*	20		0.8 (0.44-1.1)
P—*percent dry weight*	0.35	0.36	0.02
pH	7.0 (5.1-8.0)	7.3, 9.3	10.2 (8.4-11)
Total organic carbon—*percent dry weight*	3.1 (0.85-6.5)‡	3.1 (0.85-6.5)‡	
BOD_5—*mg/L*	45 (2-104)		
COD—*mg/L*	500 (100-10,000)		
Total Kjeldahl nitrogen—*percent dry weight*	0.68 (0.44-1.0)	0.37 (0.05-0.55)	
Calcium carbonate equivalence—*percent*	15 (10-20)	20 (10-53)	93 (74-99)
Coliforms—*number/g*	<20	<20	

*Compiled from Che et al,[7] Lin,[21] Elliott and Singer,[13] Schmitt and Hall,[26] Dhage et al,[36] Heil and Barbarick,[14] Russell,[10] and Elliott et al[5]
†Parameters for which three or more values were obtained are listed as mean values followed by the ranges in parentheses. One or two reported values are listed separately.
‡Data reported for coagulation sludges collectively, with no separation of those generated from alum and iron salts

land-based option that will win regulatory approval and public acceptance.

Sludge characterization

The chemical, physical, and biological characteristics of WTS determine its potential beneficial and adverse effects on the soil. Although the nature and quantity of sludge produced depend on treatment process design and performance, WTS consists primarily of the precipitated hydroxide or carbonate of the coagulant [e.g., $Al(OH)_3$ for alum sludges] along with the other treatment additives (carbon, polymers) and material removed from the raw water (sand, silt, clay, bacteria, color-forming compounds). Table 1 shows some of the major compositional parameters for chemical coagulation and lime softening sludges, which together represent the by-products of about 95 percent of all water treatment processes.[4]

Barring a grossly contaminated water source, WTS has fewer potential adverse environmental effects than does municipal sewage sludge. Transfer of harmful constituents—trace elements, toxic organic compounds, and pathogens—to the food chain is the principal concern in the land spreading of sewage sludge. For the typical water treatment plant, pathogens and toxic organic materials in the sludge are expected to be low. Reported microbiological or specific organic analyses of WTS are limited. Elliott et al[5] reported that alum and ferric chloride sludges contained <20 coliforms/g. They cite long storage time prior to analysis and contact with chlorine in the treatment process as reasons for the low coliform numbers. This compares with 10^3–10^6 coliforms/g of dry digested sewage sludge. Grabarek and Krug[6] found concentrations of six pesticides in two alum sludges to be below detection limits. Heavy metals will invariably exist in WTS (Table 2), and their potential impact on soil-plant systems must be considered.

Although WTS poses a less serious environmental threat than that posed by sewage sludge, its agronomic benefits, at least as a fertilizer, are appreciably fewer. Although sewage sludge can be considered a low-grade fertilizer, roughly equivalent to a 4-2.5-1 (percent N-P-K) commercial mixture, WTS has considerably lower nutrient levels (Table 1). Because alum and iron salts are major additives, coagulant sludges contain large quantities of Al and Fe hydrous oxides that can bind soluble P and reduce its availability to crops. Water sludges can also modify the water retention and structural properties of soils. All of these factors must be considered in the design and management of land-based disposal systems for WTS.

> *Land application has long been a major disposal technique for sewage sludges because they contain nutrients that are valuable in crop production.*

Sludge as an agricultural limestone substitute

Historically, the most notable land-based disposal practice in the water treatment industry has been the use of lime softening sludge as a substitute for agricultural limestone. Farming practices and natural weathering tend to remove bases from soils more rapidly than they are replenished by mineral dissolution; consequently, soils become acid. Most commercial crops grow poorly in acid soils, generally because low pH results in high soluble levels of certain ions (e.g., Al^{3+}) that are toxic to plants. Periodic addition of limestone and related materials is standard farming practice in many areas.

Although the substitution of water treatment sludges for agricultural limestone has been mentioned recently,[7] the practice is quite old. From a comprehensive review of disposal methods for lime softening sludges,[8] it appears that farmland application has been practiced for at least 40–50 years. This method seems to have received wide acceptance in the midwestern United States, particularly Ohio,[9] Illinois,[10] and Michigan,[11] where large-scale water softening is routinely practiced.

The soil-neutralizing capacity of lime softening sludges is generally quite high and frequently greater than that of commercial limestone. The calcium carbonate equivalence (CCE), or neutralizing power relative to pure calcium carbonate, of agricultural limestone is typically 80–103 percent. Russell[10] reported a lime sludge to have a CCE of 95 percent, compared with an 87–91 percent range for locally available agricultural-grade limestone. With an average CCE of 93 percent, 11 lime sludges collected in Ohio were found to increase soil pH more than limestone.[7] Schamblis[12] found that a lime softening sludge raised the pH of an acid soil from 5.9 to 8.5 when it was incorporated into the soil at a 2 percent rate.

Most coagulation sludges have a limited ability to serve as agricultural liming materials because their CCE values generally range from 10–20 percent of commercial limestone.[5] The extent of this effect, however, depends on the alkalinity of the sludge, the soil pH, and the sludge application rate. Addition of lime in the treatment process for pH control can impart significant liming ability to coagulation sludges. A $FeCl_3$ coagulation process resulted in an alkaline (pH 9.3) sludge with a CCE of 53 percent.[13] Even at the 2 percent application rate, this sludge increased the soil pH from 5.3 to 8.0 and dramatically increased growth of tomato plants.[13] Similarly, Heil and Barbarick[14] found the pH of an acid soil was raised from 4.7 to 7.0 when amended with 0.5–2.5 percent $FeCl_3$ sludge. Bugbee and Frink[15] found that alum sludge applications raised the pH about 0.5–1.0 pH units in the top 10 cm of a forest soil. When the sludge and soil have nearly equal pH values, however, little change in pH is expected. In greenhouse studies, even a 3:1 alum sludge-to-soil mixture had a pH less than

0.5 units greater than the unamended soil value of 5.6.[15]

Typically, soils are limed to pH 6.0–6.5, depending on the crop grown. Lime softening sludges having neutralizing power that is comparable to commercial limestone are applied to agricultural soils at 2–4 tons/acre roughly every three years, depending on the initial soil pH and farming practices. For materials with lower CCEs and for highly acid soils, higher application rates can be used. A softening sludge with a CCE of 34 percent was applied at rates up to 11 tons/acre to neutralize an acid soil to pH 6–6.5.[16] The extremely acidic surface material at reclaimed strip-mined sites can accommodate about 10 tons of softening sludge/acre, a practice that is allowed in Ohio.[8] Increasing soil pH above the optimum may cause micronutrient or P deficiencies. This imposes an upper limit on the amount of sludge that can be spread.[13]

Reduced availability of phosphorus to crops may be the most limiting consequence of the application of water treatment sludge to agronomic soils.

TABLE 2
Metal concentrations in water treatment sludges and soils

	Sludges		Soils*		Maximum Allowable‡
Metal	Range *mg/kg*	Mean† *mg/kg*	Range *mg/kg*	Typical *mg/kg*	*mg/kg*
Cd	<0.1–2	1	0.01–0.7	0.06	25
Cu	135–485	234	2–100	30	1,000
Cr	40–513	187	1–1,000	100	1,000
Ni	26–218	102	5–5,000	40	200
Pb	18–840	230	2–200	10	1,000
Zn	195–865	557	10–300	50	2,500

*Background soil values from Lindsay[35]
†Mean of eight coagulation sludges from Elliott et al[5]
‡Recommended maximum allowable metal levels for municipal sludges used in agricultural production

Impact on soil fertility

Aside from the liming capacity of softening sludges,[17,18] the potential benefits of WTS to the soil have generally been considered limited. Cornwell and Westerhoff[4] state that "attempts to use coagulation sludges as soil conditioners or stabilizers have had little success." Lending support to this notion is the conclusion, based on chemical analysis, that an alum sludge contained "few if any plant nutrients."[15] The total Kjeldahl nitrogen (TKN) content of a $FeCl_3$ sludge was reported to be a scant 554 mg/L (0.06 percent).[13] Other investigations,[19-21] however, suggest higher N levels in WTS. Dempsey and co-workers[20] found that the average TKN for eight alum and $FeCl_3$ sludge samples was 0.6 percent. Reports of 1 percent TKN[19] and 0.47 percent total N[21] for alum sludges support these higher levels.

The amount of N in water sludges is linked to the characteristics of the raw water and treatment chemicals.[5] If a water source contained 0.4 mg/L dissolved N and half was removed in the treatment process, the sludge would contain roughly 1 percent N for a treatment plant generating 150 lb of dry solids for each million gallons of water treated. A second possible source of N is polyelectrolyte coagulant aids. These polymers are often N-containing polyacrylamide or related compounds. A common cationic polymer* contains about 11 percent N. Because a given weight of polymer produces an equivalent weight of sludge, a 1 mg/L dose of this cationic polymer would produce a sludge containing 0.6 percent N, assuming the aforementioned solids generation rate.

The agronomic benefits of N in WTS depend more on its availability than on the total amount present. The mineralization rate, or rate at which wasteborne nutrients are converted into forms available to plants, varies widely and depends on the treatment process, climate, method of application, and soil and waste properties. For sewage sludges, 5–60 percent of the total N is mineralized in the first year after application, with values of 20–40 percent often used by regulatory agencies for calculating waste application rates.

Lin[21] reported that levels of N and other nutrients in the grain and leaves of corn and soybeans were not significantly changed for applications of up to 20 tons/acre of an alum sludge containing 0.47 percent N. Recently, Elliott et al[5] found that the addition of WTS to soil did not increase the N mineralization rate. In another study, nutrient uptake by forest vegetation was largely unaffected by alum sludge application.[15] These results suggest that a low percentage of N in WTS is available to crops in the first growing season. A 10 percent N availability has been suggested to determine the WTS loading rate to soils.[5]

Other plant nutrients like P and K are also present in WTS (Table 1). It has been reported that application of lime sludge increased exchangeable (available to plants) K by increasing the percentage of Ca saturation.[16] At a rate >4 tons/acre, however, exchangeable K decreased. Recently, Heil and Barbarick[14] attributed positive growth responses in sorghum–Sudan grass from WTS application to improved availability of Fe. It was concluded that WTS can possibly correct Fe deficiencies in soils.[14] Water treatment sludges could also be used to correct soil deficiencies of micronutrients like B, Cu, Mn, Zn, and Mo, which are needed by crops. Although this hypothesis is widely documented for wastewater sludges—and suggested for water plant residues[13]—confirmatory field studies supporting it are lacking.

Phosphorus availability

Reduced availability of P to crops may be the most significant disadvantage of WTS application to agronomic soils. Soil P occurs in three forms based on availability to crops: highly available dissolved P in soil solution, labile (exchangeable) P adsorbed on soil surfaces, and unavailable P that is bound within the mineral matrix. Phosphorous deficiencies in crops rarely occur because of an inadequate total P content but rather from slow release of labile P into solution.[22] Sludges contain large quantities of Fe and Al hydrous oxides, well known for their P-fixing properties. These oxides exist in sludges as X-ray amorphous compounds,[19] which have significantly higher P sorption capacity than their crystalline counterparts.[23]

for Scott's work. Maybe solubility not important be P-fixing difference may be.

The conversion of readily available P by WTS to forms inaccessible to crop roots has been demonstrated by several studies. Rengasamy et al[19] found that application of alum sludge (20 tons/acre) reduced P uptake and caused yield reductions in maize. Tissue analysis showed that tomato shoots[13] and lettuce[15] grown in potting media amended with WTS contained significantly lower P levels. Heil and Barbarick[14] found that applications >10 tons/acre of alum and $FeCl_3$ sludges induced P deficiency in sorghum–Sudan grass.

Although the P-fixing tendency of water sludges has been validated experimentally, the relationships are far from straightforward. Lin[21] found that P levels in leaf, grain, and whole-plant samples of corn and soybeans grown on

*Cat-Floc, Calgon Corp., Pittsburgh, Pa.

soils treated with up to 20 tons/acre of WTS were not significantly different from results using untreated soils. He concluded that "application of alum sludge to farmland had neither beneficial nor adverse effects on soils and crops." Complicating the issue is the strong pH dependence of P availability. It has been suggested that application rates of $FeCl_3$ sludge that do not excessively raise soil pH will not cause P deficiencies.[13] Other studies[6,19] have likewise documented a threshold sludge application rate below which P fixation is not a problem. Fixation of P is not usually characteristic of softening sludges. Sievers and Winburn[16] found that a lime sludge actually increased the P available to plants when the application rate brought the pH of the soil–sludge mixture into the 6–6.5 range, ostensibly the optimum acidity for maximum P uptake.

It has been noted that the P-fixing properties of water plant sludges should not be cause to prohibit their land application.[5] Severe P deficiency is common in soils newly brought into cultivation. Supplemental P fertilizer additions, judicious crop selection, and proper soil pH maintenance can be used to circumvent P deficiencies in sludge-amended soils. Furthermore, the reduction in P mobility becomes an asset when WTS is applied to soils that have a high P pollution potential.[5]

Soil conditioning

Soil conditioning refers to treatment that modifies a soil's physical properties for the improvement of crop growth.[24]

Soil conditioning resulting from increased organic matter content is often cited as an advantage of sludge application, but such effects from water treatment sludge are probably quite small.

Most often, amendments are studied for their ability to alter soil aggregation, moisture retention properties, and water permeability. Ideal growing conditions usually correspond to well-aggregated soils, in which primary soil particles (sand, silt, clay) are bonded together into small but stable aggregates. Such soils have relatively large pores between aggregates to promote water movement and gas transfer and smaller pores within the aggregates to impart water-holding capacity. Most desirable is an intermediate water-holding capacity that will allow drainage and prevent anaerobic soil conditions yet provide adequate moisture for crop production throughout the year. Well aggregated soil particles are also less susceptible to detachment and erosion.

Soil conditioning resulting from increased organic matter content is often cited as an advantage of sludge application. In liquid form, WTS has relatively low biological oxygen demand (BOD) and low to moderate chemical oxygen demand (COD) levels (Table 1). The organic matter content of the dry sludges is apparently variable and depends primarily on the raw water quality and treatment methods, e.g., polymer additions. Reed et al[25] quote a source that lists WTS with 15–25 percent organic matter. Based on loss on ignition, the organic matter content of alum sludges has been reported to be 16.2 percent[26] and range from 25 to 35 percent.[15] Analysis of an alum sludge indicated an organic matter content of 14.4 percent.[21] Ignition at 600°C, however, overestimates organic content because decomposition of inorganic compounds also occurs.[5] A 3 percent average total organic content has been reported for alum and ferric chloride sludges.[5] These levels are much lower than those of sewage sludges, which must be applied at very high rates to induce substantial changes in the physical properties of the soil.[24] Soil conditioning effects from the organic matter in WTS are thus probably quite small.

Hydrous Al and Fe oxides in coagulation sludges can, however, significantly affect soil aggregation. At typical field pH levels, Al and Fe oxide colloidal particles are oppositely charged and tend to flocculate the soil silicate particles.[27] Upon dehydration, the Al and Fe hydroxides act as cementing agents between soil particles,[28] imparting favorable structural properties to soils, such as reduced swelling and increased aggregate stability.[29] A few studies have attempted to document WTS-induced changes in soil structural properties. Rengasamy et al[19] found that adding wet alum sludge markedly altered the mechanical properties of soils, increasing aggregation and decreasing the modulus of rupture of molded soil briquettes. Scambilis[12] also found that soil cohesion was increased by alum and softening sludge additions.

Changes in soil moisture properties have also been documented. Bugbee and Frink[15] found that improvements in soil moisture-holding capacity and aeration from alum sludge additions were sufficient to offset induced P deficiencies. Water retention was increased by alum addition,[19] and both alum and softening sludges modestly increased soil drainability.[12] Positive effects are more difficult to document under actual field conditions. Lin[21] found that the inherent variability in test plots masked differences in soil moisture content following alum sludge application.

Heavy metal content

Although metal contamination of soils from application of sewage sludge has been extensively studied,[30] related studies for drinking water sludges are rare. The few pertinent studies report metal analyses for one or two isolated sludges,[26] thus limiting extrapolation to WTS characteristics in general. A recent project sponsored by the AWWA Research Foundation reported the metal content of a variety of sludges.[5] Table 2 shows the WTS levels of six metals normally monitored in land-applied wastes. Also shown are the maximum metal levels allowed for sludges to be used in agricultural production in Pennsylvania and other states. Mean metal levels in sludges are generally well below these values.

Utilities that dispose of sludge in sanitary landfills are faced with problems of dwindling capacity, escalating fees, extensive sludge dewatering requirements, and potential liability for landfill cleanup and closure.

A balanced view of the potential impacts of sludge-borne metals must include an understanding of the metal levels in sludge relative to those already present in soils. Table 2 shows the common range and typical concentrations of metals in unpolluted soils. It is noteworthy that mean sludge values for Cr and Ni are within the common range for soils, whereas those for Cu, Pb, and Zn are less than three times the maximum background value. This implies that total metal levels in the soils will be largely unaffected by sludge application at typical loading rates. Consider a sludge containing 600 mg Ni/L (three times the allowable maximum) being applied at 10 tons/acre. This will result in roughly an additional 6 mg Ni/L in the surface soil, increasing the background Ni content (40 mg/L) by only 15 percent.

Understanding the behavior and fate of metals in soils amended with WTS requires an evaluation of speciation, availability, and mobility in addition to total concentration. In order to assess the potential mobility and bioavailability of sludge-borne metals, Elliott et al[5] performed a five-step sequential fractionation analysis on nine water plant sludges. Cr, Cu, Ni, and Zn were predominantly associated with the oxide-bound fraction. Coupled with small amounts in an exchangeable or acid-soluble form, these metals should have low plant uptake or leaching potential. Similarly, Grabarek and Krug[6] reported low soluble metal concentrations for two alum sludges. Amorphous hydrous oxides, which dominate the composition of WTS, strongly adsorb trace metals and fix them in an insoluble form.[31] Consistent with this hypothesis is the finding that addition of alum or iron salts during sewage treatment reduced the soluble metal concentrations in sludge through coprecipitation.[32]

The degree of sludge dewatering is a complex function of several factors and may be dictated by the available spreading equipment, hauling distance to the application site, and regulatory policies.

Cd in WTS exists primarily in acid-soluble and organically bound forms.[5] A smaller proportion of Cd is easily exchangeable. Strongly acid soil conditions should be avoided to prevent mobilization of the labile Cd.[14] Because maintaining circumneutral soil pH is part of a sound crop management program, and Cd levels in WTS are typically low (Table 2), Cd solubilization should not be a problem at properly managed sites.

This suggestion is reinforced by the reported low uptake of metals following land application of water sludges. Lin[21] analyzed the grain and leaves from corn and soybeans grown on soil treated with alum sludge and found no statistically significant increase in the concentration of nine metals, including Cd. Elliott and Singer[13] documented a substantial decrease in metal uptake by tomato plants following the application of $FeCl_3$ sludge, even at a 10 percent amendment rate. This reduced uptake seemed to be related causally to the elevated soil pH that accompanied sludge incorporation.

Although some metals in WTS originate from the raw water source, evidence suggests that the WTS composition largely reflects the purity of the coagulant chemicals.[5] When $FeCl_3$ is derived from reprocessed pickle liquor from the steel industry, the resulting WTS sludges tend to be enriched in metals, particularly Cr and Ni.[5] Many utilities require chemical suppliers to meet quality standards as a condition of purchase.[33] Limiting metal levels in WTS is important for long-term application programs because most state regulations dictate the useful life of an application site on the basis of cumulative metal loadings to the soil.

Aluminum in sludge-amended soils

Poor plant growth in acid soils resulting from restricted root penetration is usually associated with high concentrations of soluble Al. Phytotoxicity occurs at soluble Al concentrations as low as 1 ppm.[34] Some concern has been expressed over soil incorporation of WTS containing high Al levels. However, Al is the most abundant metal in the earth's crust, exceeded only by the elements oxygen and silicon in total concentration. The common range of Al in soils is 1–30 percent, with 7.1 percent considered typical.[35] Even a 10-ton/acre application of the highest Al sludge reported in the literature (30 percent Al)[4] would only increase the Al content of the typical soil by 0.3 percent.

Because all soils contain substantial levels of Al, phytotoxicity is directly related to conditions controlling Al solubility and not the total amount in the soil. If the soil pH is maintained in the 6–6.5 range by liming or sludge addition, Al toxicity does not pose a problem. The addition of up to 10 percent $FeCl_3$ sludge (containing 1.6 percent Al) actually caused crop tissue Al levels to decrease because soil pH was raised from 5.3 to 8.0.[13] Bugbee and Frink[15] determined that the soluble Al in alum sludge extracts was typical of levels found in soils at pH 5 and was not suggestive of Al toxicity. This hypothesis is supported by the lack of Al toxicity when alum sludge was applied to forests[6] and in greenhouse studies, even when lettuce was grown on pure alum sludge.[15] Tissue analysis of corn and soybeans[21] confirmed that Al uptake was not correlated to alum sludge application.

Sludge handling

Waste-handling methods at the water treatment plant significantly affect ultimate disposal. Minimizing sludge generation will result in lower land area requirements for disposal. Because raw water composition cannot be controlled, the key to sludge minimization is to optimize chemical additions during treatment. Cornwell and Westerhoff[4] suggest four different methods by which the quantities of sludge can be reduced: change the treatment process to direct filtration; change coagulants, use coagulant aids, or both; conserve coagulant; and recover coagulant. The simplest methods involve optimizing coagulant additions whenever possible. Segregation of flows may also be advantageous. For example, direct discharge of backwash water may be allowed by regulatory agencies, thus reducing the amount of solids for land disposal.

The degree of sludge dewatering is a complex function of several factors and may be dictated by the available spreading equipment, hauling distance to the application site, and regulatory policies. Sludge with a solids content of roughly 10 percent or less can be spread as a liquid slurry using specially designed tank trucks equipped with soil injectors. Some states, however, place a hydraulic loading limitation on land-applied wastes. For dilute slurries, this may result in prohibitive spreading costs per dry ton and excessive land area requirements.

Producing a handleable sludge cake may require dewatering to 35 percent solids or greater,[4] in which case conventional manure-spreading equipment may be employed. The rheology of WTS is complex, and the handling for intermediate solids contents (10–35 percent) must be based on specific sludge and process considerations. Substantial dewatering may be required for cost-effective disposal if the application site is a considerable distance from the water treatment plant.

Acceptance of land spreading

A public relations effort is essential for a successful land application program, regardless of its technical feasibility or lack of environmental impact. The opinions of local citizens and officials may be tainted by previous experiences with land application of sewage sludge. An educational campaign should be initiated at an early stage to inform the public that these materials are generated during the production of drinking water. Major concerns with sewage sludge—pathogens, toxic organic compounds, odors—should be negligible for WTS. Concerns about heavy metal can be allayed by noting that sludge metal levels may be close to, or lower than, background levels already in the soil. A treatment plant open house can be instructive for local citizens.

Although having few of the disadvantages of sewage sludge, WTS has less benefit from the farmer's perspective. When sludge characteristics warrant it, farmers should be alerted to the soil-liming potential of WTS. Regulatory agencies in many states require wastes applied under agricultural utilization programs to have a demonstrated benefit to the soil. It will generally be difficult to promote WTS as a low-grade fertilizer, and its potential as a soil conditioner must be emphasized. As with all soil amendments, application rates must be compatible with sound agronomic practices. Strategies to avoid overly alkaline conditions and induced P deficiencies are required. Yet moderate application rates (up to 20 tons/acre) are high enough to make land application a cost-effective sludge disposal option. It is crucial to apply sludge in a manner that will not interfere with the farmer's cropping schedule or damage his fields.

Land application is currently practiced in Pennsylvania and will continue as an attractive option for some water plants. Land application is potentially the least capital-intensive disposal method,[33] although hauling dilute liquid sludge over long distances can make operational costs very high. Regulatory agency personnel may have little experience with these materials and will need to be informed about their benefits and potential disadvantages in land application. Many questions can be answered by drawing on the wealth of information available on land treatment of wastewater sludges. Gaps in knowledge exist, particularly in developing quantitative predictions of the impact of WTS on soil P fertility. This, of course, is not an environmental impact issue. In fact, the same phenomena that limit the P available to crops also restrict movement of soluble P to surface waters, diminishing eutrophication potential. Based on current understanding, there are minimal health and environmental risks associated with the properly managed application of WTS to soils. This should become increasingly evident as the research base expands and field experience is gained.

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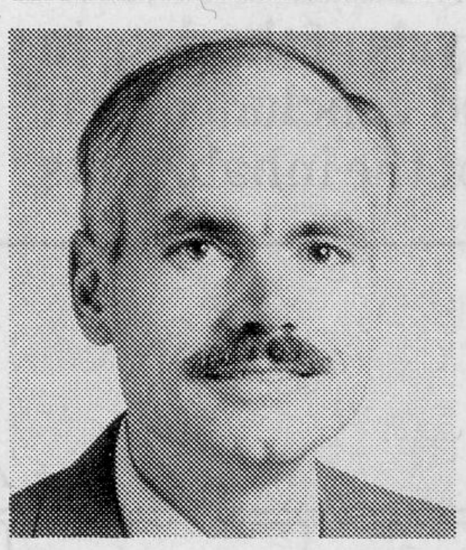

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