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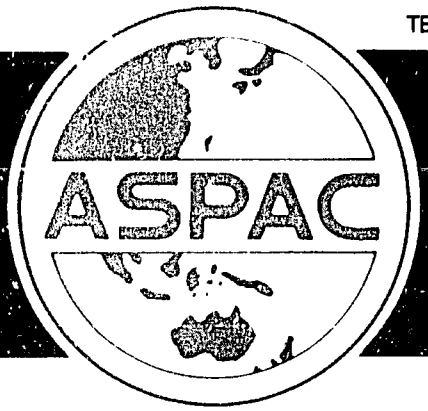

FOOD & FERTILIZER TECHNOLOGY CENTER

POTENTIAL HAZARDS WHEN USING ORGANIC MATERIALS AS FERTILIZERS FOR CROP PRODUCTION

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FOREWORD

There is today a growing interest in the use of organic materials as fertilizers, both for agronomic reasons (improvement of soil physical properties, balanced nutrient supply for crops) and for economic ones (efficient use of wastes and by-products, high consumer demand for organically grown produce etc). However, although organic fertilizers are generally thought to be environmentally sound, they may in fact be at least as polluting and hazardous as chemical fertilizers if improperly used, particularly in an industrial society.

This Bulletin outlines the potential hazards of organic materials used as fertilizers, including the pollution of water resources with nitrates; dangerously high levels of trace elements such as cadmium, particularly in sewage sludge; and the presence of pathogenic organisms which may transmit diseases to human beings and livestock. However, as the author emphasizes, these problems can be overcome by good management. Sensible and practical guidelines are given which allow organic materials to be used in crop production without harmful effects.

The paper on which this Bulletin is based was first presented by its author at an international seminar on *"The Use of Organic Fertilizer in Crop Production"*, held in Suweon Korea (June 1990) with the co-sponsorship of the Rural Development Agency of Korea. It is one of a series of five Extension Bulletins (EB 311-315 inclusive) being published by the Center this year on the use of organic materials as fertilizers for crop production.

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(Chinese Abstract) 摘 要

本文主要討論當有機物施用於土壤從事作物生產時可能發生的一些風險問題，其中包括養分管理，微量元素，微量有機物，病原菌及土壤物理問題。在工業發達國家，人口密集區域所發生有機物質再生問題所引出風險問題可能是大於正開發國家有機物質製造問題。

使用有機肥料最常發生問題是水源的污染，特別是N、P污染，NO_3-N能污染地下水，表土P的累積能增加表土冲蝕，微量元素累積在土壤可以引起毒害，增加植物對微量元素吸收淤泥中，微量有機物危險發生最少，主要由淤泥發生較爲普遍，而時常混攪於土壤中。

人類和動物許多廢棄副產物中含有許多不同微生物可以傳播各種疫病。適當而注意在處理人糞尿施用於土壤時可以減少病害的發生，施用有機物引起土壤物理問題較少，大部份可能在廢水放出時發生。

(Japanese Abstract) 摘 要

作物栽培に有機物を使用する場合の問題点を考察した。問題は養分管理、微量要素、微量有機化合物、病原体、土壌の物理条件に関するものに分けられる。一般的には、病原体を除けば先進工業国の人口集中地域から生ずる有機物の再利用に伴う危害のほうが発展途上国での有機物問題よりも深刻である。

有機肥料によって一番よく問題になるのはNとPによる水質汚染である。硝酸態窒素は地下水を汚染するし、Pの表層土壌への蓄積は流出によって富栄養化の原因ともなる。微量要素は蓄積した場合作物に薬害をもたらしたり食物連鎖を通じて金属汚染をもたらす。スラッジ中の微量有機化合物も土壌負荷をたかめる。

人類や家畜の有機排泄物利用の副産物は各種の腸内細菌を含むため、水、飼料、空気の汚染を通じて発病をもたらす危険があるが、注意をすればその危険は少ない。また有機物の施用で土壌の物理性が損われることはほとんどないが、もっとも問題になるのは屎尿廃水である。

(Korean Abstract) 초 록

곡물생산에 있어서 토양과 작물에 유기물질이 시용될 때 발생할 수 있는 잠재적인 위험성들이 검토되었다. 이들 위험성 중에는 양분관리, 미량성분, 미량유기화합물, 병원균 및 토양물리성 문제들이 있다. 산업화된 선진국에서는 인구집중에 의하여 일어나는 유기물질의 순환과 관련된 위험성이 개발도상국에서 일어나는 병발생 문제보다 더 심각하게 발생한다.

유기질비료 성분과 관련하여 가장 자주 일어나는 문제는 질소와 인산 성분에 의한 수질의 오염이다. 질산은 지하수를 오염시키고, 표토에 집적된 인산은 유거수의 침식에 의하여 표면수로 이동되어 부영양화의 원인이 된다. 미량성분에 의한 잠재적인 위험성은 토양에 집적되어서 식물독소로 나타날 수 있으며, 먹이사슬에 있어서 금속성분의 흡수증대를 야기할 수 있다. 쓰레기 잔사중의 미량유기화합물은 폐기물 잔사가 농업적인 방법으로 사용될 때 흔히 예기될 수 있는 성분의 사용기준치에 대한 위험성이 있다.

인구가 밀집되고 동물개체군이 증가함에 의하여 일어나는 유기폐기부산물은 여러가지 종류의 균을 가지게 된다. 기본적인 것중에 하나가 급수, 식료품 및 공기의 오염으로 병원균에 의하여 사람과 가축에 전염병을 옮기는 위험성이다. 그러나 가축이나 사람의 생활로 부터 오는 유기물의 적절한 관리와 오염을 최소화 하면 경작지에 대한 이러한 유기물질의 시용은 병발생에 거의 영향을 미치지 않는다는 연구 결과들이 나오고 있다. 유기물 시용에 의한 토양물리성 문제는 가장 작은 문제이고 오히려 대부분은 폐수유출에 의하여 문제가 발생하기 쉽다.

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ABSTRACT

Potential hazards that may be encountered when organic materials are applied to the soil-plant system for crop production are reviewed. These have been grouped as they relate to nutrient management, trace elements, trace organic chemicals, pathogens, and soil physical problems. Potential hazards associated with recycling organic materials generated by population centers in industrialized countries are likely to be greater than for organic materials produced in developing countries, with the probable exception of pathogens.

The problem most frequently noted with regard to organic fertilizer nutrients is the pollution of water resources, particularly with N and P. Nitrate-N can contaminate groundwater, and the accumulation of P in surface soils can increase the risk of runoff/erosion losses to surface water, causing eutrophication. Potential hazards with trace elements pertain to their accumulation in soils which may lead to a phytotoxic condition, or result in increased uptake of metals into the food chain. Trace organic chemicals in sludges appear to present a minimal risk, based on their prevalence and anticipated loadings to soils, when agronomic rates of sludges are used.

Most organic waste by-products generated by human and animal populations will contain various kinds of enteric microorganisms. Of primary concern is the potential for disease transmission to humans and domestic animals, resulting from the contamination of water supplies, feedstuffs, or air by pathogenic microorganisms. With proper attention to the handling of organic materials from animals and humans and minimizing exposure, epidemiological studies suggest that applying these materials onto farmland has little effect on disease incidence. Soil physical problems occurring from the application of organic materials are minimal, and most likely to occur with wastewater effluents.

INTRODUCTION

The return of animal and human wastes and plant residues to the soil resources of the world has been taking place for thousands of years These soil resources have long been used for food and fiber production to support mankind's existence. As populations grew and developed higher levels of technology, these soil resources were called upon to assist with the disposal of society's wastes, as well as to help buffer the world's ecosystem against environmental damage resulting from man's activities.

In the developing countries where two thirds of the population now live, the production of food and fiber is not keeping pace with the population increases (Brady 1990). The addition of organic materials to soils as fertilizers is critical to maintaining soil fertility for food and fiber production in these parts of the world. Mineral fertilizers alone are not enough, since the soils of less developed countries are usually located in tropical or subtropical zones. High soil temperatures in these areas lead to rapid decomposition of the organic matter which is a necessary component for the soil to remain productive (Dalzell *et al.* 1987).

In developed countries, the soil resources are used not only for food and fiber production, but also for the disposal of the liquid and solid wastes generated by urban and in-

dustrial activity. From an agricultural point of view, the concept of recycling waste nutrients and organic matter back to cropland is highly desirable (Kurihara 1984, Logan 1990, Werner 1988). However, utilizing organic wastes from industrialized societies may result in negative impacts to animals and humans, to the soil-plant system, and to the environment.

This paper will focus on the use of organic materials which can be used as fertilizer and on organic matter amendments to soils for crop production. To provide the reader with a better understanding of the kinds of organic (biological) materials which are produced by the world's societies, the basic categorization used by the U.S. Department of Agriculture in their report (USDA 1978) has been selected. While this report used the term "organic wastes" to represent the various kinds of organic materials discussed, these are actually "organic resources". In industrialized societies, these organic materials are often not being used, because huge quantities are generated by population centers physically separated from areas of soil resources large enough to be able to make use of them. These materials are "resources out-of-place" and can pose major disposal problems. In contrast, developing countries recognize all organic materials as highly valuable resources which can be returned to the soil to aid in the critical battle of supplying adequate supplies of food for an ever-increasing population.

The grouping used by the U.S. Department of Agriculture (USDA 1978) seemed to include most organic materials listed in a number of additional references I reviewed (APO 1983, Cointreau 1982, Elliott and Stevenson 1977, FAO 1975, 1978, Kurihara 1984, Loehr 1984, Lu 1988, Lunin 1971, SCSA 1976, Wadleigh 1968). A listing of these different categories of organic materials and a description of each category, as used in this paper, follows:

- **Animal manure** — Feces and urine excreted by cattle, horses, sheep, goats, swine, poultry, etc., with any accompanying bedding or litter;
- **Crop residues and green manures** — The stems, leaves, roots, chaff, and any other plant parts remaining after crops are grazed or harvested; and plant material which is green and growing to maturity and is incorporated into the soil;
- **Human wastes** —Various forms of organic materials containing human feces and urine, such as night soil, septage, sewage sludge or sewage waste water;
- **Food processing** — Organic by-products from the fruit, vegetable, seafood, sugar, fats, oils, and dairy food processing industries;
- **Industrial organics** — By-products from the manufacture of paper and allied products; fermentation, including pharmaceutical and food additives; soap and detergent; alcoholic fermentation, including distilleries, wineries and malt beverage industries; meat packing and related industries, including those producing pet food, seafood, and poultry products; leather tanning and finishing; organic fiber processing; petroleum refining and related industries; and milling;
- **Logging and wood manufacturing residues** — Waste debris in forests after logging such as limbs, leaves, needles, diseased/decayed wood; manufacturing residues such as chips, bark, sawdust, etc.
- **Municipal refuse** — The organic portion of collectable solid wastes generated by households, institutions, offices, commercial and industrial premises, and in the streets of urban areas. The organic portion of these solid wastes can be quite variable depending on the *per capita* income of the urban populations, as shown in Table 1 (Cointreau 1982).

Not only does the quantity of municipal refuse generated by industrialized countries increase with *per capita* income, but the number of potential hazards associated with recycling organic materials from population centers to cropland also generally increases. In preparation for discussing these potential hazards, a number of sources in the literature which discussed waste application to soils were used. Some provided in-depth reviews of the subject (Elliott and Stevenson 1977, IRRI 1979, 1984, Moormann and van Breemen 1978, PAHO 1984, Parr *et al.* 1983, Runge 1986, SCSA 1976, Tomlinson 1974, USDA 1974); some reported on research

Table 1. Patterns of municipal refuse quantities and characteristics for low, middle and upper income countries (taken from Cointreau 1982)

	Low-income countries[a]	Middle-income countries[b]	Industrialized countries
Waste generation (kg/person/day)	0.4-0.6	0.5-0.9	0.7-1.8
Waste densities			
(wet weight basis - kg/m^3)	250-500	170-330	100-170
Moisture content			
(% wet weight at point of generation)	40-80	40-60	20-30
Composition (% by wet weight)			
Paper	1-10	15-40	15-40
Glass, ceramics	1-10	1-10	4-10
Metals	1-5	1-5	3-13
Plastics	1-5	2-6	2-10
Leather, rubber	1-5	-	-
Wood, bones, straw	1-5	-	-
Textiles	1-5	2-10	2-10
Vegetable/putrescible	40-85	20-65	20-50
Miscellaneous inerts	1-40	1-30	1-20
Particle size	5-35	-	10-85

[a] Includes countries having a *per capita* income of less than US$360 in 1978
[b] Includes countries having a *per capita* income of more than US$360 and less than US$3,500 in 1978

findings (Berglund *et al.* 1984, Brogan 1981, Davis *et al.* 1983, Kofoed *et al.* 1986, OME 1974, Williams *et al.* 1985); a few contained reviews and research reports (Cole *et al.* 1986, Inst. of Soil Sci., Academia Sinica 1981, L'Hermite and Ott 1981, 1984, Welte and Szabolcs 1988, 1989); three summarized state-of-the-knowledge and identified research needs (NASULGC 1973, Page *et al.* 1983, 1987); and several provided technical information for the safe use of organic materials on crop land (Dalzell *et al.* 1987, EPS 1984, Flaig *et al.* 1978, Jacobs 1977, Knezek and Miller 1976, USDA 1979, USEPA 1978, 1983, 1984). I have attempted to discuss all the "potential hazards" which may be encountered in the wide range of organic materials generated by developing and developed countries. Potential hazards to be discussed are those relating to:

- nutrient management,
- trace elements,
- trace organic chemicals,
- pathogens, and
- soil physical problems.

NUTRIENT MANAGEMENT

Organic materials (as described in the Introduction) contain varying quantities of essential plant and animal nutrients (APO 1983, Elliott and Stevenson 1977, FAO 1975, Loehr 1984, SCSA 1976, Smith and Peterson 1982, Sommers and Giordano 1984, Sommers and Sutton 1980). Organic fertilizers can provide part or all of the major nutrients needed by plants, but usually not in the proper proportions.

If enough organic fertilizer is applied to ensure adequate quantities to avoid yield

limitations, excessive additions of one or more nutrients are likely to occur. Plants will take up, not only those elements essential for their growth and those which need to be passed along in the food chain to animals, but also non-essential elements such as cadmium, mercury and lead which may also get into the food chain. Potential hazards from such trace elements will be discussed later.

Organic materials can also provide organic matter to improve or maintain soil organic matter levels. Depending on the type of organic fertilizer and the type of soil receiving the organic material, the amount of organic matter added by an agronomic* application of sludge may be small compared to the amount of organic matter already present in most agricultural soils. However, the return of these organic solids to the soil will contribute to the maintenance of organic matter levels.

The potential hazard most frequently noted with regard to nutrients is the pollution of water resources, particularly with nitrogen (N) and phosphorus (P). Considerable attention is being given to nitrate (NO_3-N) contamination of groundwater, and P contamination of the surface water. In addition, a number of other potential hazards involving nutrients may occur.

Nitrogen

Not all of the N present in organic fertilizers is immediately available to plants, since some is present as organic N (i.e., N present in microbial cell tissue and other organic compounds). Organic N must decompose into mineral, or inorganic forms of N such as ammonium NH_4 and NO_3-N before plants can use it. Therefore, the availability of organic N for plants depends on the microbial breakdown of organic materials in soils, as does the availability of N present in soil organic matter (Fig. 1).

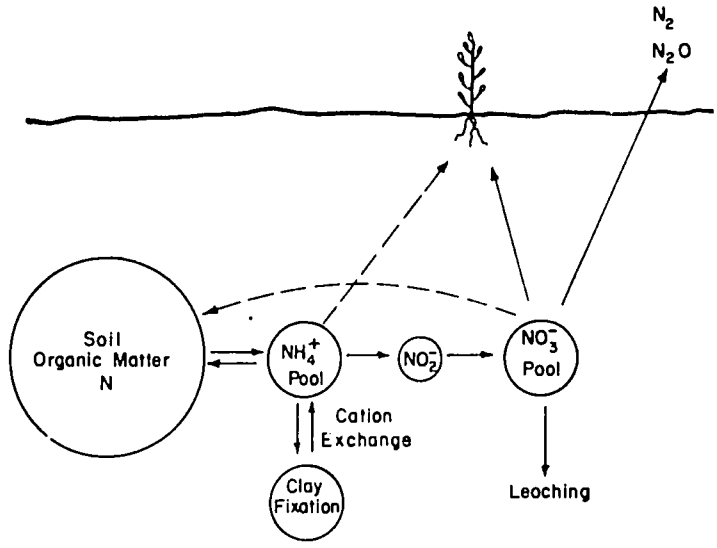

Fig. 1. A simplified N cycle in soils showing how N in organic matter becomes available to plants

Source: Jacobs 1981

* "Agronomic" refers to the use of an organic fertilizer in the soil-plant system at a rate which provides adequate nutrients for crop growth, but which is not so excessive as to cause environmental pollution

The proportion of sludge organic N that is mineralized in a soil depends on the various factors which influence immobilization and mineralization of organic forms of N (Bartholomew 1965, Harmsen and van Schreven 1955, Smith and Peterson 1982, Sommers and Giordano 1984). Some schemes for estimating the amount of mineralizable N from various organic fertilizers have been suggested, particularly for animal manure and sewage sludge (Pratt *et al.* 1973, Powers *et al.* 1975a, 1975b, Smith and Peterson 1982, USDA 1979, USEPA 1983).

Estimates of mineralizable N using decay series is not precise, since the actual N availability will depend on organic N composition, degree of treatment or stabilization of the organic material before land application, climate, soil conditions, and other factors. Another approach to predicting N availability is to model (mathematically) the transformations of N in the soil. However, modeling has not yet been found to be accurate enough to give more than a general estimate of N availability (Schepers and Fox 1989).

Applying too much organic material and N fertilizer has caused NO_3-N pollution of groundwater in some temperate regions (Hallberg 1989, Schrøder 1985). In the U.S., major areas with NO_3-N contamination include: 1) areas of widespread crop production (particularly corn), 2) areas with locally intensive animal operations, and 3) areas of irrigation and fertilization of vegetable and specialty crops (Hallberg 1989).

Management strategies must attempt to balance the addition of plant-available N provided by land application of organic materials with the needs of the crop. Otherwise, excess NO_3-N can be leached into groundwater by precipitation or poor management of irrigation water, and can present an environmental hazard (Keeney 1989). Several countries have enacted regulations controlling the number of livestock which can be kept for each hectare of available arable land, based on the N content in manure, e.g., LU/ha (livestock units/ha), DU/ha (dung units/ha), fertilizer or manure livestock units/ha, number of animals or birds/ha, and 4 mt of live weight/ha (Amberger 1988, Hartung 1986, Lohm 1988, Sangiori *et al.* 1988, Steffens 1988, Tietjen 1977).

Another potential environmental hazard is ammonia volatilization from the agricultural use of fertilizers and animal manure (Besson and Flueckiger 1988, Denmead *et al.* 1974, Hinrichsen 1986, Nihlgård 1985, Schrøder 1985, van Breemen *et al.* 1982). Ammonia volatilization losses, when animal manure or sewage sludge is applied to land, have long been recognized (Adriano *et al.* 1974, Beauchamp *et al.* 1978, 1982, Brunke *et al.* 1988, Christensen 1986, Döhler and Wiechmann 1988, Hall and Ryden 1986, Hoff *et al.* 1981, Lauer *et al.* 1976, Rank *et al.* 1988, Reddy *et al.* 1979, Terman 1979, Vallis *et al.* 1982). The inability to estimate accurately this N loss, combined with the difficulty of estimating the amount of mineralizable N, means that it is very difficult to estimate the level of N after the application of organic fertilizers.

The C/N (carbon-nitrogen) ratio of organic materials can be an important determinant of the decomposition rate of organic matter in the soil. A high C/N ratio can result in slow decomposition and reduced growth of higher plants because of a lack of available N. A low C/N ratio may result in excess NO_3-N, which can reduce crop quality or percolate into water supplies. As a general guideline, decomposing materials with a C/N ratio of 30:1 or greater will decrease the level of available N in the soil. Materials with a ratio of between 15:1 and 30:1 will not markedly affect the N available, and those with ratios of less than 15:1 usually increase the available N. Nearly all plant materials contain 40-45% carbon, so the C/N ratio of these materials can be estimated if the N content is known (Stewart and Webber 1976).

The C/N ratios of plant materials vary widely. For example, wood wastes commonly have a ratio of 400:1; cereal straw, 80:1; and young clover, 10:1. Animal manures generally have a ratio of less than 30:1, so they seldom tie up available soil N. In fact, they often have ratios of less than 15:1, and increase the available N level. However, the rate of N release may be slow. Wastewater and solid material from vegetable canning plants or pulp and paper mills normally have a fairly high C/N ratio and the material is readily attacked by microorganisms, which can cause a rapid decrease in available soil N. Immature compost made from municipal refuse, with a C/N >30, is another example of an organic

material that may induce N deficiency in plant growth when added to soils (Gallardo-Lara and Nogales 1987).

Large amounts of organic materials can be decomposed in soil, and the rate of decomposition will not be affected by the amount added under well-aerated conditions. However, adverse effects can occur when decomposition in the soil takes place under anaerobic conditions, which can produce phytotoxic levels of organic acids, ammonia, nitrite-N and possibly iron (Fe) and manganese (Mn) (Cannell and Lynch 1984, Cook *et al.* 1978, Elliott *et al.* 1978, Epstein 1973, Kimber 1967, Lixandru 1988, Lynch 1977, 1978, McCalla *et al.* 1970, Miller *et al.* 1985, Parr 1974, Patrick 1971, Patrick *et al.* 1963, Sawyer and Hoeft 1990).

Some organic materials, such as olive tree leaves, contain phytotoxic compounds that can be a potential hazard unless these materials are thoroughly composted and matured before being applied to soil (Manios *et al.* 1989). Another special type of organic material, antibiotic production wastes, has caused phytotoxic effects. These effects have been observed when some types of antibiotics have been applied shortly before the crop was planted (B.G. Ellis, Michigan State University, East Lansing, Michigan, personal communication; Nelson and Sommers 1979).

Phosphorus

Excess P is seldom a concern in groundwater, and volatilization of P into the atmosphere does not occur. With regard to organic materials such as sewage sludge and animal manure, applying a large enough quantity to supply all of the crop's N needs will usually add more P than is needed by the crop.

Some additional P beyond what is recommended can be tolerated for a period of time. This excess P will contribute to an increase in the P fertility level of a soil which can be monitored annually with soil fertility tests. However, when the optimum or maximum P fertility levels recommended by soil fertility specialists are reached, application rates of organic fertilizers should be determined on the basis of supplying P needs (Jacobs 1981). For example, the Dutch government has decided to regulate manure loadings on the basis of balancing P additions to soils with average crop P removal, to avoid long-term build-up in the soil (Titulaer 1988).

With the continuous over-application of P from organic fertilizers, the soil solution P concentration in surface soils and subsoils can be increased to a level which can contribute significant amounts of P to runoff water flowing into streams and lakes (Ellis and Olson 1986). This is true both of soluble P, and of P bound to eroded soil particles.

Since P is frequently a limiting nutrient in aquatic systems, increased levels of P in surface waters may lead to an increase in algae blooms and nuisance weed growth. Ultimately, the result is eutrophication which causes a decrease in the recreational value of these waters.

Major problems of runoff and loss of organic fertilizer nutrients to surface waters from animal feedlots, housing areas, or application sites can occur (Brogan 1981, Gilbertson *et al.* 1981, Loehr 1972, 1984, Lunin 1971, Miner and Willrich 1970, Pratt 1979, Stewart and Webber 1976, USDA 1978). Good soil and water conservation practices are necessary to control potential runoff/erosion hazards at sites receiving organic fertilizers.

Nutrient Balance and Salts

Because organic fertilizers do not usually contain a balanced quantity of nutrients for the crop being fertilized, long-term applications may disrupt soil fertility. For example, long-term slurry applications have caused an enrichment of available magnesium (Mg), P, and potassium (K) in some surface soils (Mackowiak 1988). Where high K levels build up in soils and Mg levels decrease, grass tetany can be a problem for grazing animals. High NO_3-N concentrations can occur in forages and can make these feeds unsafe for animals (Powers *et al.* 1975a, Pratt 1979).

Under certain climatic and soil conditions, or when salty or excessive organic fertilizers are used, a salinity hazard to crops can occur (Powers *et al.* 1975a, 1975b, Stewart and Webber 1976, USDA 1979). How much salt can be applied safely to cropland depends on the quantity of rainfall, or on the availability of good quality irrigation water (USDA 1979). Potential

hazards due to salinity or nutrient imbalances can normally be avoided by good management techniques.

TRACE ELEMENTS

Any discussion of potential hazards regarding trace elements must include both those elements essential for animal and plant nutrition that might best be referred to as "micronutrients" (Tiller 1989), and those elements commonly termed "heavy metals". The latter is a more imprecise term than micronutrients but is widely used, and is a useful umbrella term for metals classed as environmental pollutants (Tiller 1989).

There is an extensive literature pertaining to trace-element additions to the soil-plant system, and their potential hazards (see e.g. Allaway 1977, Berglund *et al.* 1984, CAST 1976, 1980, Chaney 1973, 1974, 1983b, 1984, Chaney and Giordano 1977, Davis *et al.* 1983, L'Hermite and Dehandtschutter 1981, Lindsay 1973, Logan and Chaney 1983, MAFF 1980, Melsted 1973, Page 1974, Page *et al.* 1987, Sommers and Barbarick 1986, Walsh *et al.* 1976).

In this paper, most of my discussion on the addition of inorganic elements to soils will focus on sewage sludge, since it is the most likely organic fertilizer to add appreciable quantities of trace elements to the soil-plant system. Most of my comments will be taken from three references: Jacobs 1981, Logan and Chaney 1983, and Sommers and Barbarick 1986.

The concentrations of trace elements in sewage sludge can vary widely, as shown in Table 2. A major consideration regarding the use of sewage sludges on agricultural soils is the possible addition of heavy metals which accumulate in the soil with repeated applications. This buildup of metals may be toxic to plants, or may be taken up by plants to be passed on in harmful amounts to animals or humans.

Table 2. Trace element concentrations in sewage sludges

Unit: mg/kg (dry weight basis)

Trace element	Michigan[a]		United States[b]		United Kingdom[c]		Suggested median[d, e]
	Median	Worst	Typical	Worst	Typical	Worst	
Ag	5	580	-	-	-	-	-
As	8	50	5	21	20	30	10
B	24	1,400	-	-	30	1,000	33
Be	1	23	0.3	1.2	-	-	-
Cd	11	1,200	8	88	20	1,500	10
Co	10	250	12	40	15	260	30
Cr	130	7,600	230	1,500	400	14,000	500
Cu	580	5,600	410	1,400	650	8,000	800
F	-	-	86	740	250	40,000	260
Hg	2	38	1.5	5.8	5	18	6
Mn	250	3,800	-	-	-	-	260
Mo	32	3,700	10	40	6	40	4
Ni	49	3,000	45	660	100	5,300	80
Pb	270	5,200	250	1,100	400	3,600	500
Sb	16	140	-	-	-	-	-
Se	32	260	1.1	4.8	3	10	5
Sn	-	-	-	-	-	-	14
Zn	1,200	24,000	680	4,600	1,500	20,000	1,700
Fe (%)	1.3	16	2.8	7.9	-	-	1.7

[a] Jacobs *et al.* 1981
[b] USEPA 1985
[c] Webber *et al.* 1983
[d] Logan and Chaney 1983
[e] Data for B from Chaney 1983a

The elements of primary concern to plant, animal and human health include arsenic (As), boron (B), cadmium (Cd), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). Of these, Cd poses the greatest long-term threat to human health and will be discussed in more detail later. A CAST (1976) report found that Cd, Cu, Ni, Zn and Mo were the main elements which plants could accumulate and pass along the food chain. Copper, Ni and Zn can cause phytotoxicity at elevated levels in soils. Boron, Mo and As are of concern for both plant and animal health, and Se is of concern for animal health. Mercury and Pb have not posed a problem in the land application of sewage sludge, since these elements form relatively insoluble minerals in the soil. They are non-mobile in fibrous root systems, and phytotoxicity occurs at plant tissue concentrations that are not injurious to animals.

All these elements have been categorized according to their impact on plants and on animal health by Chaney (1983b). The "Soil-Plant Barrier" concept, summarized in Table 3, indicates that environmental or phytological factors prevent certain elements from concentrating at harmful levels in above-ground plant growth. A number of pathways, in addition to plant uptake from sludge-treated soils, can result in the transfer of metals into the food chain. These are discussed in considerable detail by Logan and Chaney (1983).

The greatest concern over metal additions to the soil-plant system has been with regard to Cd. The reviews by Logan and Chaney

Table 3. Maximum tolerable levels of dietary minerals for domestic livestock in comparison with levels in forages (taken from Logan and Chaney 1983)

Element	Soil-plant barrier	Level in plant foliage[a] Normal - mg/kg dry foliage -	Level in plant foliage[a] Phytotoxic - mg/kg dry foliage -	Maximum levels chronically tolerated[b] Cattle - - - - - - - mg/kg dry diet - - - - - - -	Sheep	Swine	Chicken
As, inorganic	Yes	0.01-1	3-10	50	50	50	50
B	Yes	7-75	75	150	(150)	(150)	(150)
Cd[c]	Fails	0.1-1	5-700	0.5	0.5	0.5	0.5
Cr^{3+}, oxides	Yes	0.1-1	20	(3000)	(3000)	(3000)	3000
Co	Fail?	0.01-0.3	25-100	10	10	10	10
Cu	Yes	3-20	25-40	100	25	250	300
F	Yes?	1-5	-	40	60	150	200
Fe	Yes	30-300	-	1000	500	3000	1000
Mn	?	15-150	400-2000	1000	1000	400	2000
Mo	Fails	0.1-3.0	100	10	10	20	100
Ni	Yes	0.1-5	50-100	50	(50)	(100)	(300)
Pb[c]	Yes	2-5	-	30	30	30	30
Se	Fails	0.1-2	100	(2)	(2)	2	2
V	Yes?	0.1-1	10	50	50	(10)	10
Zn	Yes	15-150	500-1500	500	300	1000	1000

[a] Based on literature summarized in Chaney (1983b)
[b] Based on NRC (1980b). Continuous long-term feeding of minerals at the maximum tolerable levels may cause adverse effects. Levels in parentheses were derived by interspecific extrapolation by NRC
[c] Maximum levels tolerated based on human food residue consideration

(1983) and Ryan *et al.* (1982) indicate that the safety factor for dietary Cd is larger than previously believed. The larger safety factor should reduce concerns of the food industry regarding utilization of sewage sludge containing a low level of Cd on cropland for the production of fruit and vegetables (USEPA, USFDA, USDA 1981).

In their evaluation of the potential effects of sludge-borne Cd in the food chain, Logan and Chaney (1983) made the following statement:

> "The 'Soil-Plant Barrier' does not protect the food chain from excessive Cd, so Cd is not easily kept out of food crops. Unregulated application of Cd-bearing wastes can cause health effects in humans. Recent research on gardens polluted with Cd by mining wastes or smelter emissions support the view that gardens can provide much Cd in locally grown foods to the family maintaining the garden for many years. Some aspects of the Cd-waste-soil-plant-animal food chain are not well established, and research is needed to avoid unnecessarily restrictive limits in the regulations."

The relationship between plant toxicity and the accumulation of metals is illustrated in Fig. 2. The yield curve shows the relationship between the supply or availability of an essential plant nutrient in the soil, and the amount of crop growth (or yield). Three distinct stages occur as the availability of a nutrient increases:

1. Deficiency — supply of the nutrient is inadequate and limits yield; an addition of the nutrient increases yield.
2. Sufficiency — the maximum yield has been reached and the nutrient supply does not limit yield; increasing the supply in this range has no effect on yield.
3. Toxicity — further additions of a nutrient beyond the sufficiency range decrease the yield until eventually no growth occurs.

This curve is applicable to Cu, Zn and other essential trace elements needed by plants, but only partly applies to nickel and other elements not essential for plant growth. For nonessential elements, increases in the available supply in soils will not affect plant

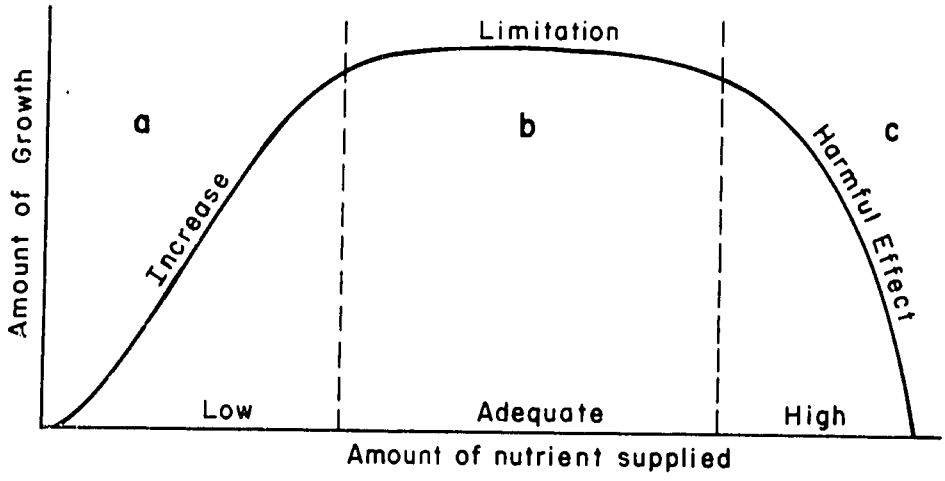

Fig. 2. The relationship between growth (or yield) and the availability (or supply) of an essential plant nutrient in the soil
Source: Jacobs 1981

growth until levels become high enough to cause toxicity.

Effect of Soil pH

The impact of pH on metal accumulation by plants has been extensively reviewed by Logan and Chaney 1983 (see also Sommers *et al.* 1987). Basically, metal availability (except for Mo and Se) tends to decrease with liming. Solubility of solid phase minerals, including metal carbonates, phosphates, and sulfides, is enhanced at low soil pH. However, the importance of this phenomenon in sewage sludge-treated soils has not yet been adequately defined by solid phase equilibria studies.

Soil pH influences the plant uptake of most metals, at least to some extent, but the current recommendation of pH 6.5 should be reconsidered for food-chain agricultural soils, since some reports indicate adequate control of metal uptake at pH 6. This conclusion is supported by field trials using barley. More specific pH values may be required where accumulator crops such as tobacco are grown on highly buffered acid soils. Therefore, a soil pH≈6.0 may be as acceptable as pH 6.5 in the regulation of metal uptake.

Regulating Heavy Metal Additions to Soils from Organic Fertilizers

Guidelines for regulating sludge use and metal additions to soils have been adopted in many countries. These have developed in several different ways (Tiller 1989):

- By restricting the heavy metal concentrations in sludge being applied to agricultural land.
- By restricting the amount of pollutant metal that can be added over a prescribed period. In practice, this is achieved by controlling both the maximum permissible concentrations of metals in sludge, and the amounts of sludge that can be added. An important benefit of this approach is the incentive to improve controls over industrial effluents.
- By defining a maximum permissible concentration of heavy metals in agricultural soils.
- By controlling the heavy metal contents of foodstuffs.
- By combinations of these, in addition to restrictions related to soil characteristics, land use and crop type, and the metals controlled.

Webber *et al.* (1983) summarized various guideline levels for heavy metals used by several countries (see Tables 4, 5, 6, and 7). Tiller (1989) commented that

> "... it is surprising that the huge available literature on soil pollution has not resulted in greater similarity in approach and better consensus of recommendations in different countries."

The U.S. Environmental Protection Agency has proposed new sewage sludge regulations based on risk assessment methodology for trace elements and trace organic chemicals. This approach has recently been reviewed by a group of agricultural scientists, and recommendations were made to correct certain aspects of the proposed risk assessment methodology (Logan and Page 1989). The significance of suggested changes on the quantities of trace metals that would be permitted by these regulations, and the concept of a "clean sludge" with minimal regulations, is discussed below.

TRACE ORGANIC CHEMICALS

Describing the impact of trace organic chemicals (occurring in organic fertilizers) on soil plant systems presents a greater challenge than is faced with trace elements. One reason is the sheer number of compounds potentially involved. Literally thousands of trace organics exist, and many of these can be present in biological materials, depending on the level of technology which exists in the society producing these materials. The potential hazard presented by a particular organic chemical depends on its toxicity to biological organisms, its persistence in the environment, and its bioavailability for entering into the food chain.

An important difference between trace metal and trace organic chemical additions to a soil is the time each may reside or persist in that soil. Fries (1982) concluded that the half-life of the most persistent organics (e.g., PCBs) in soil was ten or more years, whereas the residence time for most metals was estimated to be several thousand years (Bowen

Table 4. Maximum permissible heavy metal concentrations (mg/kg dry weight) in sludges considered to be acceptable for use on agricultural lands (taken from Webber *et al.* 1983)

Element	Canada[a]		Finland		Germany		Norway		Switzerland		All countries		CEC Directive[b]	
	Belgium		Denmark		France		Netherlands		Sweden		Range	Median	R	M
As	10	75	-	-	-	-	10	-	-	-	10-75	10	-	-
Cd	10	20	8	30	20	20	10	10	15	30	8-30	7	20	40
Co	20	150	-	100	-	-	-	20	50	100	20-150	75	-	-
Cr	500	-	-	1000	1000	1200	500	200	1000	1000	200-1200	1000	750	-
Cu	500	-	-	3000	1000	1200	600	1500	3000	1000	500-3000	1100	1000	1500
Hg	10	5	6	25	10	25	10	7	8	10	5-25	10	16	-
Mn	500	-	-	3000	-	-	-	500	-	-	500-3000	500	-	-
Mo	-	20	-	-	-	-	-	-	-	20	-	20	-	-
Ni	100	180	30	500	200	200	100	100	500	200	30-500	200	300	400
Pb	300	500	400	1200	800	1200	500	300	300	1000	300-1200	500	750	1000
Se	25	14	-	-	100	-	-	-	-	-	14-100	25	-	-
Zn	2000	1850		5000	3000	3000	2000	3000	10000	1000	1000-10000	3000	2500	3000

[a] Values apply to sludge and sludge-based commercial products containing ≤5% nitrogen

[b] Commission of the European Communities, Proposal for a Council Directive on the Use of Sewage Sludge in Agriculture
CEC Directive – Recommended (R) maximum and Mandatory (M), not to be exceeded, concentrations

United Kingdom – Sludge for public distribution should not contain more than 20 mg Cd/kg dry wt. Sludge applied to pasture land should not contain more than 3,500 mg F/kg dry wt. and applied to pasture land, gardens and recreational areas should not contain more than 2000 Pb/kg dry wt.

United States – Sludge applied to fruit and vegetable crop land should not contain more than Cd, 25; Pb, 1000 and polychlorinated biphenyls (PCB's), 10 mg/kg dry wt.

Table 5. Limit values for sludge use in agriculture (taken from Webber *et al.* 1983)

Parameter	Canada	Denmark	Finland	France	Germany	Netherlands	Norway	Sweden	United Kingdom	United States	All countries Range	All countries Median	CEC Directive R	CEC Directive M
Minimum soil pH	-	-	-	6.0	-	-	-	-	6.5	6.5	-	-	-	-
Maximum sludge solids loadings to soil (t/ha)	200	-	20	-	167	200	20	5	-	-	20-200	167	-	-
Minimum application period (yr)	45	20	5	-	100	100	10	5	30	-	5-100	30	-	-
Maximum heavy metal loadings to soil (kg/ha)														
As	15	-	-	-	-	2	-	-	10	-	2-15	10	-	-
Cd	4	0.2	0.1	5.4	8.4	2	0.2	0.075	5	5, 10, 20	0.1-20	5	2.4	8.4
Co	30	-	-	-	-	-	0.4	0.25	-	-	0.4-30	-	-	-
Cr	-	-	-	360	210	100	4	5	1000	-	4-1000	210	60	-
Cu	-	-	-	210	210	120	30	15	280	125, 250, 500	30-500	210	60	210
F	-	-	-	-	-	-	-	-	600	-	-	-	-	-
Hg	1	-	-	2.7	5.7	2	0.14	0.04	2	-	0.14-5.7	2	2.7	
Mn	-	-	-	-	-	-	10	-	-	-	-	-	-	-
Mo	4	-	-	-	-	-	-	-	4	-	-	-	-	-
Ni	36	-	-	50	60	20	2	2.5	70	50, 100, 200	2-200	60	0	60
Pb	100	-	-	210	210	100	6	1.5	1000	500, 1000, 2000	6-2000	210	60	210
Se	2.8	-	-	-	-	-	5	-	5	-	2.8-5	-	-	-
Zn	370	-	-	750	750	400	60	50	560	250, 500, 1000	60-1000	500	300	750
Zn equivalent	-	-	-	-	-	-	-	-	560	-	-	-	-	-

Denmark - Sludge with ≤3 mg Cd/kg dry wt. may be applied as a P fertilizer (maximum solids loading, 1.5 mt/ha/yr) indefinitely

France - Maximum heavy metal loadings were estimated assuming the German normal background and French permissible concentrations in soil (see Table 7), and that 1 kg/ha metal results in 0.33 mg/kg increase in soil concentration

Germany - Maximum heavy metal loadings were estimated assuming the normal background and maximum permissible concentrations in soil (see Table 7), and that 1 kg/ha metal results in 0.33 mg/kg increase in soil concentration

Netherlands - Sludge solids and heavy metal loadings are for arable land. Loadings to pasture land are one-half the values shown

Sweden - Five-year loading; can be repeated. Values are not included in "All Countries Range and Median"

United Kingdom - Sludge may be applied to pasture land with pH ≥6.0. Zinc, Cu and Ni loadings are subject to the Zn equivalent limitation as discussed in the text. The Zn, Cu, Ni and Zn equivalent loadings shown are for non-calcareous soil and may be doubled for calcareous soil

United States - Sludge with ≤2 mg Cd/kg dry wt. may be applied to soil with pH <6.5. Heavy metal loadings increase with increasing soil cation exchange capacity. The Pb loading to fruit and vegetable crop land should not exceed 800 kg/ha

CEC Directive - Recommended (R) maximum and Mandatory (M), not to be exceeded, loadings. Heavy metal loadings were estimated assuming the German normal background and CEC Directive R and M permissible concentrations in soil (see Table 7) and that 1 kg/ha metal results in 0.33 mg/kg increase in soil concentration

Table 6. Suggested annual sludge solids (mt/ha) and heavy metal (kg/ha) loadings to agricultural lands (taken from Webber *et al.* 1983)

Sludge constituent	Canada	Denmark	Finland	France	Germany	Netherlands	Norway	Sweden	Switzerland	United Kingdom	All countries		CEC Directive	
											Range	Median	R	M
Solids	4.4	1.5	4	-	1.7	2	2	1	2.5	-	1-4.4	2	-	-
As	0.33	-	-	-	-	0.02	-	-	-	0.33	0.02-0.33	0.33	0.35	
B	-	-	-	-	-	-	-	-	-	3.5	-	-	-	-
Cd	0.09	0.01	0.02	0.06	0.033	0.02	0.02	0.015	0.075	0.17	0.01-0.17	0.04	0.1	0.15
Co	0.67	-	-	-	-	-	0.04	0.05	0.25	-	0.04-0.67	0.15	-	-
Cr	-	-	-	3	2	-	0.4	1	2.5	33	0.4-33	2.5	10	-
Cu	-	-	-	3	2	1	3	3	2.5	9.3	1-9.3	3	10	12
F	-	-	-	-	-	-	-	-	-	20	-	-	-	-
Hg	0.022	0.01	-	0.03	0.042	1.2	0.014	0.008	0.025	0.067	0.008-1.2	0.025	0.4	-
Mn	-	-	-	-	-	0.02	1	-	-	-	0.02-1	-	-	-
Mo	0.09	-	-	-	-	-	-	-	0.05	0.13	0.05-0.13	0.09	-	-
Ni	0.8	0.045	-	0.6	0.33	0.2	0.2	0.5	0.5	2.3	0.045-2.3	0.5	2	3
Pb	2.2	0.6	-	2.4	2	1	0.6	0.3	2.5	33	0.3-33	2	10	15
Se	0.06	-	-	0.3	-	-	-	-	-	0.17	0.06-0.17	0.17	-	-
Zn	8.2	-	-	9	5	4	6	10	2.5	18.6	2.5-18.6	7.1	25	30
Zn equivalent	-	-	-	-	-	-	-	-	-	18.6	-	-	-	-

Netherlands - Loadings are for arable land. Loadings to pasture land are one-half the values shown
United Kingdom - The first year B loading may be 4.5 kg/ha. Zinc, Cu and Ni loadings are subject to the Zn equivalent limitation
CEC Directive - Recommended (R) maximum and Mandatory (M), not to be exceeded, loadings
France, Germany, United Kingdom and CEC Directive - Sludge loading may continue until the maximum permissible heavy metal concentrations in soil (see Table 7) are reached
United States - Cadmium loadings are ≤2 kg/ha

Table 7. Normal background (bkgd) and maximum permissible (perm) heavy metal concentrations (mg/kg dry weight) in agricultural soils (taken from Webber *et al.* 1983)

				United Kingdom				
					- - - - - perm - - - - -		CEC Directive	
	France	Germany			non-		- - perm - -	
Element	perm	bkgd	perm	bkgd	calcareous	calcareous	R	M
As	-	-	-	5	10	10	20	-
B	-	-	-	1	3.25	3.25	-	-
Cd	2	0.2	3	1	3.5	3.5	1	3
Cr	150	30	100	100	600	600	50	
Cu	100	30	100	5	140	280	50	100
F	-	-	-	200	500	500	-	-
Hg	1	0.1	2	<0.1	1	1	2	-
Mo	-	-	-	2	4	4	-	-
Ni	50	30	50	1	35	70	30	50
Pb	100	30	100	50	550	550	50	100
Se	10	-	-	0.5	3	3	-	-
Zn	300	50	300	2.5	280	560	150	300
Zn equivalent	-	-	-	20.5	280	560	-	-

Values are total concentrations in soil, except United Kingdom. Zn, Cu and Ni extracted by EDTA and B extracted by hot water

United Kingdom - Values shown are mg/L. Maximum permissible Zn, Cu and Ni concentrations are subject to the Zn equivalent limitation

CEC Directive - Recommended (R) maximum and Mandatory (M), not to be exceeded, concentrations

1977). These differences are largely due to assimilation mechanisms, such as degradation (biotic and abiotic) and volatilization, which can assist with the removal of trace organic chemicals from the soil-plant system.

The following discussion focusses on the potential impact of synthetically produced trace organic chemicals, and does not include those organic chemicals produced biologically. The organic fertilizers most likely to contain a large array of synthetic, trace organic chemicals are sewage sludge, municipal refuse, and municipal/industrial wastewater. Only limited studies are available which report the concentrations of trace organics in these biological materials. Lester (1983) identified a number of major sources of organic contaminants in wastewater from industrial and domestic sources. Harms and Sauerbeck (1983) discussed toxic organic compounds likely to be found in municipal wastes, such as compost made from municipal garbage and sewage sludge, and Jacobs *et al.* (1987) summarized available data on concentrations of trace organics in sewage sludges.

Because of industrial discharge into sewerage systems, municipal raw sewage contains virtually all the wastes from human activities. One could expect the sludge resulting from the treatment of this sewage to contain these same products. Because as many as 15,000-20,000 man-made chemicals (with an array of functional groups) exist, it is impossible to analyze all the chemical constituents in a sewage sludge.

Sludges have been analyzed according to predetermined lists of specific organic chemicals, such as the U.S. Environmental Protection Agency's organic priority pollutants list. Another approach is to separate the organics into "chemical groups" which have similar physical-chemical properties, and focus on selected groups anticipated to have a greater toxicological and/or environmental risk. With either approach, the wastewater treatment plant should first determine what organics are being discharged by users, particularly industry. This information can then be used to identify

organic compounds which should be tested for unusually high concentrations in sewage sludges.

Prevalence of Trace Organic Chemicals in Sewage Sludges

Because the available data is very limited, definitive statements cannot be made concerning the prevalence of organic chemicals in sewage sludge. However, data summarized by Jacobs *et al.* (1987) show that sewage sludge can be highly contaminated with organic chemicals. Unusually high concentrations, such as those reported for butylbenzylphthalate (12,800 mg/kg), bis (2-ethylhexyl) phthalate (58,300 mg/kg), and pentachlorophenol (8,490 mg/kg), suggest a high degree of industrial contamination. Sludges containing these "maximum concentrations" could have a significant impact on soil-plant systems, depending on the rate of sludge applied.

Concerns about organic chemicals in sludges must be kept in perspective, however. Of the 219 organic chemicals identified by Jacobs *et al.* (1987) as being present in sewage sludge, about one-fourth (53) of these organics were present in >50% of the sludges, but 70 (or 32%) were below detection limits. Even if there is no discharge from industrial plants, the presence of "background concentrations" of many organics in purely domestic sewage sludges can be expected, given the wide variety of synthetic organic chemicals found in many household products (Hathaway 1980). In fact, domestic septic tank effluent was found to contain more than 100 trace organics (DeWalle *et al.* 1985, Tomson *et al.* 1984).

More important than the presence or absence of organics in sewage sludge is the total amount which may be added to the soil-plant system when the sludge is applied to farmland. Table 8 summarizes part of the analysis data reported by Jacobs *et al.* (1987). This summary suggests that about 90% of the organics in sludge will be present in concentrations of less than 10 mg/kg. About 10% of the organics tested had median concentrations of 11-100 mg/kg, and only one organic had a median value of >100 mg/kg.

To put potential organic chemical loadings into perspective, one can make a comparison with agricultural pesticides. Many

Table 8. Summary showing the distribution of median concentrations of organic chemicals, reported for sewage sludges (taken from Jacobs *et al.* 1987)[a]

Trace organics listed by chemical group	Number of organic chemicals tested	Number of organic chemicals tested having median concentrations in sludges (mg/kg, dry wt. basis)				
		ND[b]	<1	1-10	11-100	>100
Phthalate esters	6	0	0	1	4	1
Monocyclic aromatics	23	12	5	2	4	0
Polynuclear aromatics (PAH)	7	0	4	2	1	0
Halogenated biphenyls	9	1	3	5	0	0
Dioxins and furans	(inadequate data; all concentrations reported were significantly <1 mg/kg or 1000 ug/kg)					
Halogenated aliphatics	10	0	6	4	0	0
Triaryl phosphate esters	3	0	0	2	1	0
Aromatic & alkyl amines	16	6	9	0	1	0
Phenols	12	0	1	11	0	0
Chlorinated pesticides and hydrocarbons	21	4	14	3	0	0
Miscellaneous	2	1	0	1	0	0
Totals	109	24	42	31	11	1

[a] Note that median values used are only for those samples having detectable concentrations and are not true median values, which would be lower if all "ND" samples were included as zeroes

[b] ND = organic was "not detected" in any sludge samples tested

pesticides used today are organic chemicals which are added to soil-plant systems at rates of 0.2-4.0 kg of active ingredient per hectare. Assuming an agronomic rate of sludge application of 10 mt/ha (dry weight basis), organic chemical loadings would be 0.01, 0.1, and 1.0 kg/ha, if a trace organic was present in the sludge at a concentration of 1, 10, and 100 mg/kg, respectively. At these same concentrations, the trace organic chemical loadings would be 0.1, 1.0, and 10 kg/ha, respectively, if the sludge was applied at a rate of 100 mt/ha (a rate which might be used to reclaim drastically disturbed land).

Therefore, both the trace organic concentration, and the rate of sludge added, determine the total quantity of any one trace organic added per hectare. When this combination results in loadings comparable to those used for pesticides, the trace organic chemical, depending on its chemical/toxicological properties, must be viewed as potentially having an impact on the soil-plant system. This means that at agronomic rates (i.e., ≈10 mt/ha), organic chemical concentrations in sludges approaching 100 mg/kg must be viewed as a potential concern. Similarly, at high sludge rates (e.g., 100 mt/ha), concentrations approaching 10 mg/kg in sludge could be expected to add amounts of an organic chemical comparable to quantities of pesticides used in agricultural operations.

Based on the concentrations of trace organics normally found in sewage sludges and the amount that might be applied to agricultural soils, the agronomic or environmental risks from organics when domestic sewage sludge is applied to agricultural soils appear to be minimal. Many organics will be bound by soil organic matter and biologically degraded by soil microorganisms (Kaufman 1983). Although persistent compounds such as PCBs and the chlorinated pesticides can accumulate in soils from repeated sludge applications, and can be a concern for food crop production, this potential hazard can be reduced when the use of chemicals is restricted or completely banned, as was found in Sweden (Sjöqvist 1984).

Potential Hazards Based on Trace Organics in Sewage Sludge

A number of conclusions were drawn by Jacobs *et al.* (1987) concerning the risk to humans from trace organic chemicals in sewage sludge applied to soil-plant systems:

1. Because sewage sludges can theoretically contain thousands of organic compounds, wastewater treatment plants should identify the organics being discharged by users, particularly industry. This information should guide the testing of sludges for appropriate organics to determine concentration levels.
2. Available surveys measuring trace organic concentrations in sludge indicate that sewage sludge can have unusually high concentrations (i.e., a few percent, dry weight). Most organics, however, are present at concentrations lower than 10 mg/kg, and about 30% of the organics tested were below detection limits. Considering their low concentration, and low potential loading to soils when agronomic or low application rates are followed, sludge organics appear to present a minimal risk.
3. Mutagenicity tests have been used to evaluate the safety of sewage sludge for land application. While such tests might provide an additional means of checking sewage sludge prior to land application, they are difficult to interpret and have not been correlated with mutagenic activity or biological toxicity of the soil/sludge mixture in the field. Therefore, their value for helping manage land application programs is uncertain at this time.
4. Major assimilative pathways for organic chemicals applied to the soil-plant system include adsorption, volatilization, degradation, leaching, and plant uptake. Many organics are strongly adsorbed to soil organic matter and/or undergo degradation, reducing the potential for plant uptake or leaching.
5. Since a large number of organics may be present in sewage sludge, mathematical models which utilize basic physical/chemical properties of an organic to predict the fate of sludge organics in soil appear to be

a logical approach. However, limited field research on selected sludge organics (representative of organic chemical groups) is needed to validate how well these models will work.

6. In general, risk assessments suggest that most sludge organics will not increase the health risk to animals and humans. However, the current data base used for risk assessments so far is limited, and better methodologies are needed to assess health risks.

PATHOGENS

Most organic waste by-products from human and animal populations contain various kinds of enteric microorganisms. Some of these are pathogenic (disease-causing) and some are not. A primary concern is the potential of pathogenic microorganisms in waste materials to transmit disease to humans and domestic animals when they contaminate water supplies, feedstuffs, or air (Doran *et al.* 1977). Examples of potentially dangerous organic materials are night soil, sewage sludge, animal manure and, to a lesser extent, municipal refuse. There is little if any danger of disease dissemination from the application of food processing wastes to agricultural land (Burge 1974).

A secondary concern may be disease transmission to plants. Crop residues may at times carry plant pathogens (Dalzell *et al.* 1987). The management of surface plant residues is an important cultural practice that can affect the onset and development of plant diseases, particularly when the same crop is replanted (Fenster 1976). While organic amendments have been reported by Cook *et al.* (1978) to be responsible for increased outbreaks of root disease, the same authors also stated that "organic amendments incorporated in adequate amounts and at the right times are generally suppressive to root diseases".

Pathogenic organisms causing disease in humans and animals can be classified into four major groups: bacteria, viruses, protozoa and helminths (Burge 1974, Feachem *et al.* 1983, Gerba 1983, Kowal 1985, 1986, Polprasert 1989). Feachem *et al.* (1983) have given a full report on the presence of pathogenic organisms in excreta (human feces and urine), sullage or graywater (domestic wastewater not containing excreta), and sewage (wastewater containing excreta, sullage, and other domestic and industrial water effluents).

Livestock and their manure can also be a source of disease transmission to humans (Diesch 1970). Zoonoses is the term for diseases and infections which are naturally transmitted between man and other vertebrate animals. For one group of zoonoses, animals act as hosts alternative to man, and for a second group, animals (either cows or pigs) are the intermediate step in disease transmission (Polprasert 1989).

The application of livestock manure to land probably presents little threat to the health of either human beings or livestock, except in special situations (Burge 1974, CAST 1975, Doran *et al.* 1977, Menzies 1977, Powers *et al.* 1975a). In general, the incorporation of manure into the soil is a sound practice. Exceptions to this would be cases where the livestock producing the manure are known to be infected with virulent quarantinable diseases such as anthrax, foot-and-mouth-disease, and possibly hog cholera (Burge 1974). When manure from animals with parasites is applied to pastures and other green fodder, parasites may be transmitted to uninfected animals grazing these pastures (Strauch 1977).

Overapplication of manure, or its application to sloping land, may increase the risk of runoff and erosion into inland surface waters, or into ocean bays and estuaries. Such runoff may transmit infective agents to potential host animals. Manure should not be applied to land areas from which runoff might flow into bays or estuaries used for the harvest of shellfish, since shellfish are noted for their ability to collect and concentrate viruses and bacteria in the water (Burge 1974).

Excreta, untreated sewage, sewage effluent, sludge or septic tank pumpings should not be applied to land without necessary precautions. Various treatments of excreta such as anaerobic digestion, composting, secondary activation, heating, drying, treating with lime, or aging contribute to the disappearance of pathogenic agents (Burge 1974). Composting, in particular, is suggested as an economical and effective way of limiting disease transmission in developing countries, and yet still allow for the use of biological wastes containing human

excreta as organic fertilizers (McGarry and Stainforth 1978, Obeng and Wright 1987, Shuval *et al.* 1981).

While disease outbreaks have occurred when crops grown on soil receiving untreated sewage were eaten raw, no incidence of disease has been reported from the land application of treated wastes (Elliott and Ellis 1977). Burge and Marsh (1978) similarly found that most sewage-related disease outbreaks were attributed to the use of raw sewage wastewater, raw sludge and night soil on food crops consumed raw; contamination of drinking water from septic tanks; or consumption of raw shellfish from water polluted with sewage.

Nevertheless, all of the above authors caution the reader that any organic waste originating from, or containing, human or animal excreta may contain viable pathogenic organisms. Complete disinfection of these materials prior to land application is unlikely in most instances (Flaig *et al.* 1978), and some experimental evidence suggests that even a single virus particle is enough to transmit a disease if the potential victim is highly susceptible. However, zero tolerance for pathogens in wastes used as fertilizer would seem to be unnecessary, as long as proper management is used (Elliott and Ellis 1977). Examples of management practices stipulated for sewage sludge applied to cropland (USEPA 1983) include: (1) no animals should be grazed on the site for one month after application if the animal product will be consumed by humans and (2) crops consumed raw (e.g., root crops and vegetables) by humans cannot be grown for 18 months after the time of sludge application, unless there is no contact between crop and sludge (e.g., peas or corn, which in any case are not usually eaten raw).

Kowal (1985) concluded in his review of health effects regarding the land application of municipal sludge:

> "Because of the possibility of contracting an infection, it would be wise for humans to maintain a minimum amount of contact with an active application site. Epidemiological studies to date suggest little effect of land application on disease incidence. However, many questions on the public health consequences of land application of wastewater and sludge remain."

POTENTIAL SOIL PHYSICAL PROBLEMS

Physical limitations or hazards associated with the application of organic wastes to soils are encountered less often than the potential chemical and biological hazards discussed above. Physical problems rarely occur from the application of solid or semi-solid materials, but are more likely when nutrient-poor wastewater effluents are applied. Site characteristics, such as climate, geology and hydrology, soil type, and topography then become important (Bouwer 1973, Johannsen 1977, Linden *et al.* 1983, Stewart and Webber 1976).

Organic materials tend to improve the physical properties of soils by increasing the infiltration, hydraulic conductivity, and water-holding capacity, as noted by Pagliai *et al.* (1985). These changes can reduce the potential for surface runoff and erosion. However, soil hydraulics can be reduced if soil pores become blocked by the suspended solids present in wastewater, or by gas bubbles from chemical and biological reactions, microbial biomass (bacteria, fungi, and algae), and soil particles from compaction, erosion, or reorientation during wetting (especially from rain or sprinkler-drop action), thereby restricting water and air movement (Linden *et al.* 1983).

Wastewater with a high level of BOD (biochemical oxygen demand) may cause serious clogging problems because of the bacterial activity it stimulates, causing a decline in infiltration rates (Bouwer 1974, Wolcott and Cook 1976). Drying or resting periods, to allow for drainage, aeration, and the aerobic decomposition of organic clogging material, can restore the infiltration rate. In addition, some kind of mechanical treatment to break up these surface crusts or partially remove them may be necessary. Inorganic clogging materials, such as silt or other fine sediments, should be removed from wastewater before applying it to the land (Bouwer 1974).

Another potential hazard of wastewater applications is excess water. This is likely to be a concern with most land used for crop production, except for submerged soils where rice is grown. Management of the amount and timing of wastewater applications is needed, because the soil's ability to infiltrate and percolate water is limited. Adequate drainage and resting periods to allow for aeration are necessary for root respiration.

If more wastewater is applied than the soil can hydraulically absorb, water will pond on the soil surface or will run off, depending on the topography (Johannsen 1977). Organic materials applied to land become potential pollutants if runoff transports sediments or a portion of these materials into surface waters (Stewart and Webber 1976). If runoff and erosion from waste-treated areas are to be avoided, several site characteristics need to be considered:

- Slope of the land surface,
- Whether the soil is frozen or snow-covered,
- Low permeability,
- Soil moisture conditions prior to waste water application.

Excess salts in soil resulting from high rates of sludge, animal manure, or feedlot lagoon waters, can cause a soil dispersion hazard in irrigated and low-rainfall areas (Powers *et al.* 1973, 1974, 1975a, 1975b, Stewart and Webber 1976, USDA 1979). When the ratio of sodium and potassium is too large in relation to the calcium and magnesium, soil aggregates can be dispersed into individual clay particles. This dispersion can reduce the effective size of soil pores in medium and fine textured soils, and further reduce the infiltration rates of water and soil aeration, as well as causing undesirable soil structure changes which make tillage more difficult.

Soil structure can also be damaged by compaction due to the heavy weight of application equipment when soil conditions are too moist. Equipping application machinery with high flotation tires can reduce the pressure of loaded equipment on the soil surface. Another management challenge for waste handling systems is ensuring the uniform application of organic fertilizers (Thyselius 1988).

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DISCUSSION

Q. (M. Koshino)

We also have the problem of heavy metal accumulation in the soil in Japan. Japan is now badly contaminated with cadmium, and this is a cause of much concern. In Table 2, you show that sewage sludge from Michigan had a cadmium content of 10 ppm. We have found that in Japan, 90% of the sewage sludge contains less than 5 ppm of cadmium. For this reason, we have a limit of 5 ppm of cadmium in any organic waste used as an organic fertilizer. Perhaps most of the U.S.A. sewage sludge could not be applied in Japan.

Even if the sludge in U.S.A. is not contaminated by industrial waste, there is still a very high cadmium level. This may indicate that the U.S.A. already has a high level of cadmium in its food chain.

A. There are several sources of cadmium in U.S. sewage sludge. One major source is the catalysts used to manufacture tires, which run off in wastewater into the sewage system. Sweden is already very restrictive about the maximum permitted cadmium levels in wastes, with a limit of 4-5 ppm, and it plans to reduce this further to 2 ppm. In U.S.A., there has been some decrease as more attention has been paid to cadmium contamination, and we expect levels to fall further over time.

Comment: (M. Koshino)

The monitoring of constant levels of heavy metals in sludge is very important, but we find it difficult in Japan to determine the level of cadmium in soil. This is why we have selected zinc as the metal for monitoring in soil and sewage sludge, since there is usually a constant ratio of cadmium to zinc. If we restrict the concentration of zinc, this will also tend to reduce the concentration of cadmium.

A. Yes, some of our scientists in U.S.A. have been in favor for some time of restricting, not only the absolute levels of cadmium and zinc, but also the ratio between them.

Q. (T. Chakraborty)

Most of the papers on the disposal of sewage sludge are concerned with pollution problems. Ammonia evolution and release when we use organic matter can be checked, and environmental pollution minimized, by adding supplements such as calcium sulfate. The deposition of heavy applications of organic matter might also be less polluting in the tropics, since mineralization is rapid under high temperature conditions. Furthermore, the amount of organic matter produced by farmers in the tropics is usually much less than 20 mt/ha: in India, it is seldom more than 4-5 mt/ha.

Nor are heavy metals likely to be a serious problem in using sewage sludge in most tropical countries, at least for some time.

A. Yes, as far as waste disposal and sludge use are concerned, there is an advantage in not having a high degree of industrialization. In countries that are now industrialized, heavy metals are already in the system and they will have to work at removing them.