Screening Survey for Metals in Fertilizers and Industrial By-Product Fertilizers in Washington State

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Screening Survey for Metals in Fertilizers and Industrial By-product Fertilizers in Washington State

by
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and
the Interagency Fertilizer Testing Workgroup

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Glossary

For purposes of this report, the following definitions are used*:

Agronomic rate – the rates of application of sludges, manures, or crop residues in accordance with rates specified by the appropriate fertilizer grade for the crop under cultivation.

Annual loading – amount of metal or element applied to land each year, expressed in kilograms per hectare or pounds per acre.

Bioconcentration – the concentration of a hazardous substance in the tissue of an organism.

By-product – a substance that is not one of the primary products of a production process.

Commercial fertilizer / Liming material – any substance containing one or more recognized plant nutrients and which is used for its plant nutrient content and/or which is designated for use or claimed to have value in promoting plant growth, and shall include limes, gypsum, manipulated animal and vegetable manures.

Contaminant – any hazardous substance that does not occur naturally or occurs at concentrations greater than natural background levels.

Cumulative loading – total addition of a metal or element to soil over a period of time, expressed in kilograms per hectare or pounds per acre.

Custom mix – a mixture of commercial fertilizer or materials of which each batch is mixed according to the specifications of the final purchaser.

Hazardous substance – any dangerous or extremely hazardous substance as defined in RCW 70.105 and other applicable regulations. In general, substances determined to present a threat to human health and the environment.

Industrial-derived / Waste-derived – a waste or by-product from any industrial process that is recycled into fertilizer or soil amendments.

Loading – amount of metal or element applied to land, expressed in kilograms per hectare or pounds per acre.

Natural background – the concentration of a hazardous substance consistently present in the environment which has not been influenced by localized human activities.

Non-essential element – an element not necessary for plant or animal metabolism.

Nutrient – an element that promotes plant or animal growth.

Soil amendment / Soil conditioner – any of various organic or inorganic materials added to soil to affect its physical and/or chemical properties.

Solid waste – all liquid, solid, and semi-solid materials which are not the primary products of public, private, industrial, commercial, mining and agricultural operations.

Tag-along – an unintended or unnecessary element or substance found in a product.

Toxic – an element or substance that is or has potential to be harmful to human health or the environment.

** Many of these definitions are codified in the Washington Administrative Code.*

Executive Summary

Fertilizers and soil amendments from natural, manufactured, and industrial by-product sources can contain "tag-along" substances. Metals are potentially hazardous tag-along contaminants. As a first step in response to concerns about potential adverse effects on human health and the environment from recycling some wastes in fertilizers or in soil amendments, three state agencies and Washington State University conducted a screening survey for metals. This survey assessed metal concentrations in some fertilizers and liming agents. In addition, analyses of metal concentrations in potato samples were conducted.

The difference between nutrients present in soils and the nutrients required for optimum plant vitality is usually balanced through fertilizer and/or soil amendment applications. The essential nutrients needed by plants include nitrogen, phosphorus and potassium. Other nutrients needed include calcium, magnesium, sulfur, and trace metals such as copper and zinc. The total amount of fertilizers and liming materials used in Washington State in 1996 was about 1.2 million tons. The major factors determining the rate of fertilizer application are: 1) concentration of nutrients in the fertilizers, 2) soil type, nutrient level, and quantity of irrigation water, and 3) crops grown.

Fertilizers include "simple" fertilizers made to supply a single nutrient, "mixed" fertilizers made from multiple nutrients, and "custom" fertilizers formulated with certain nutrient specifications. For this survey custom-mixed fertilizer samples collected in 1993-94, and some commonly used fertilizers collected in 1997, were analyzed. Thirty-six samples analyzed for 24 metals were collected in 1997 from a variety of commercial fertilizers and liming materials. The metals analyzed include those regulated under the federal Biosolids Rule and other metals typically found in fertilizers.

Currently there are no adopted standards that apply to tag-along components in fertilizer products used in the U.S. Due to this lack of standards, the concentrations of metals found in fertilizer samples were compared to three related standards: the EPA Biosolids Rule, the Canadian sewage sludge and fertilizer regulations, and the Washington State hazardous waste Land Disposal Restrictions.

Eight of the nine metals regulated under the Biosolids Rule were detected in the fertilizer samples tested. Initial concern has focused on three of the biosolids metals: arsenic, cadmium and lead. The highest concentrations of cadmium were found in triple superphosphate, rock phosphate, ammonium phosphate sulfate, granular zinc samples, and micronutrient mix No. 2. The highest concentrations of lead were found in kiln dust lime, granular zinc samples, and micronutrient mix No. 2. The highest concentrations of arsenic were found in wood ash, kiln dust lime, micronutrient mix No. 2, and Boronat (micronutrient) samples.

Wood ash was the only product that exceeded the annual application rate derived from the Biosolids Rule (for arsenic and lead). This indicates that continued application of wood ash could cause the soil concentrations to exceed the cumulative pollutant loading limits in the Biosolids Rule. Most of the other samples were well below (generally less than a tenth of) the biosolids metals application rates with the exception of cadmium in triple superphosphate. Phosphate fertilizers may also create a concern similar to waste-derived fertilizers. These data do not take into account factors such as ambient soil conditions or plant uptake in determining when potentially adverse human or environmental health effects may be seen.

Wood ash, when adjusted for annual application rates, exceeds the Canadian standards for arsenic, lead, zinc, nickel, and molybdenum. Triple superphosphate exceeds the Canadian standards for cadmium. Two samples of granular zinc products exceed the Canadian standards for zinc; however, zinc is an intentional ingredient in these products because it is a micronutrient, so the standard would not be applicable. Concentrations of metals in eight of the non-waste-derived products appear to exceed the state hazardous waste Land Disposal Restrictions. Only the waste-derived products are potentially subject to the Land Disposal Restriction. Both of the granular zinc products tested are derived from hazardous waste; however, the granular zinc product with the highest metal concentrations (No. 1) is excluded from these standards.

The relative amounts of metals added on an annual basis indicate that certain non-waste-derived fertilizers pose a level of risk similar to some waste-derived fertilizers. The data indicate policy addressing the amount of metals added to agricultural lands should include both waste-derived and non-waste-derived fertilizers and the impact of long-term fertilizer applications on metal accumulations in soils.

Recommendations from this survey include:

- ongoing sampling to monitor fertilizers for metals, as well as sampling of fertilizers, soils and soil amendments for dioxins and other organic substances;
- field soil sampling for metal concentrations in the root zone;
- adoption of Canadian standards for fertilizers on an interim basis;
- collaboration with federal agencies to develop national risk-based standards; and
- a comprehensive study of plant uptake of metals.

Because some industrial by-products may contain dioxins, a follow-up survey is being conducted to determine concentrations of metals and dioxins in industrial by-products. Results of that survey will be published as an addendum to this report.

Introduction

Problem Statement

No federal or state standards exist that regulate the level of contaminants in most fertilizer products. Under existing Washington State Department of Ecology regulations, some materials classified as hazardous and solid wastes are recycled as ingredients in fertilizers and soil amendments. Examples of products made from waste-derived ingredients include liming agents and sources of micronutrients (e.g., zinc). Waste-derived fertilizer products can also contain "tag-along" contaminants. Metals are potentially hazardous tag-along contaminants; however, some products may also contain organic contaminants.

Fertilizer products from natural sources can contain non-essential elements, such as metals, that are identical to the tag-along contaminants from waste-derived ingredients. The risk of having non-essential elements or contaminants present in fertilizer products has not been fully evaluated.

Study Purpose

In response to concerns about potential adverse effects to human health and the environment from recycling solid and hazardous wastes in fertilizers or in soil amendments, the Washington State Department of Agriculture (WSDA), Washington State Department of Ecology (Ecology), Washington State Department of Health, and Washington State University conducted a screening survey.

The goal of this study is to determine the concentration of metals in (1) some fertilizers primarily produced from raw materials, (2) some fertilizers produced from industrial by-products, and (3) soil amendments that include lime. Related information used in this study includes examining archived WSDA fertilizers and potato samples. This initial study is not a formal risk assessment on health risks based on exposure pathways. Rather, its purpose is to compare the results with existing standards and information.

Ecology is gathering data on sources of chlorinated dioxins in Washington State (*Washington State Dioxin Source Assessment* – in prep.). By-products from several industrial processes have been identified as possible sources. Based on this information, the screening survey was expanded to include some additional sampling for dioxins and metals in some by-products and liming materials at four facilities in October 1997. These results will be published in early 1998 as an addendum to this report.

Fertilizer Use in the U.S. and Washington State

Modern farming and natural processes, like erosion, decrease the level of nutrients in soils. The difference between nutrients present in the soil and nutrients required by the plants is usually balanced through fertilizer application in recommended amounts. Synthetic fertilizers containing concentrated nutrients eliminate the need for organic fertilizers (animal manure, biosolids) to sustain crop production if applied at sufficient quantities. Economics and environmental considerations (e.g., groundwater protection) necessitate routine analyses of soils and sometimes plant tissues, for proper nutrient management.

The total amount of fertilizer used in the United States in 1996 was approximately 53.4 million tons[1]. In Washington State, the total amount of fertilizer and liming material used in the same period was about 1.2 million tons. The types and amounts of fertilizers used in Washington State during the 1995-1996 crop year are listed in Appendix A. All the products tested for this survey were either commercial fertilizers or liming agents.

Plant Nutrients Classification

Plant nutrients can be classified into three groups based on the relative quantities of nutrients required to sustain crop productivity. For example, the term "micronutrient" refers to those elements that are required in minute quantities by plants. The micronutrient requirements are often expressed in parts per million (ppm). In comparison, the relatively larger amounts of primary and secondary nutrients required are expressed as a percentage (Rules Relating to Fertilizers, Minerals and Limes, WAC 16-200-711).

The plant nutrient classification is:

Primary plant nutrients
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Secondary plant nutrients
- Calcium
- Magnesium
- Sulfur

Micronutrients
- Boron
- Chlorine
- Cobalt
- Copper
- Iron
- Manganese
- Molybdenum
- Sodium
- Zinc

[1] Endnote citations are given in the References section of this report.

Essential Nutrients for Plants and Animals

Many nutrients are essential for healthy humans and animals[2]. Nitrogen is required by plants to synthesize amino acids, which are the building blocks for protein formation. Phosphorus is required by plants for nucleic acid formation, energy utilization, and plant growth. Potassium has numerous roles in plants. Chromium, iodine and selenium are required for human nutrition but they are not recognized as plant nutrients. Conversely, boron is classified as an essential micronutrient for plants but is not essential for animal or human nutrition.

Animals and humans depend on plants for essential amino acids, fatty acids, carbohydrates, minerals and certain vitamins. For example, phosphorus from plants is used for bone formation, energy utilization, and formation of structural components of cells. Potassium and other electrolytes (sodium and chloride) are crucial determinants of acid-base balance in animal tissues. The proper balance of sodium, chloride and potassium is required for growth, bone development and protein utilization in animals and humans. Cobalt is required for ruminant animals for synthesis of vitamin B12. Additionally, chromium has been classified as an essential element for human nutrition.

Nonessential Elements

In addition to essential elements (nutrients), many naturally occurring fertilizers, synthetic materials and sources of micronutrients may contain elements that are not classified as essential. Some of these elements (e.g., mercury), even in small amounts, may be toxic to living organisms and may accumulate in the environment. Nutrients (e.g., copper and zinc) in excessive amounts could become toxic to plants and animals.

Application Rates of Fertilizers

Fertilizers may be applied in a gaseous, liquid, suspension (slurry) or solid (dry) state. In the United States, application rates of fertilizers for agricultural purposes are generally expressed in terms of liters (gallons) for liquid products per hectare (acre) or kilograms (pounds) of pure nutrients or product per hectare (acre) for both liquids and solids. Three major factors determine the rate of application of fertilizers: (1) concentration of nutrients in the fertilizers, (2) soil type, nutrient level, and quality of irrigation water, and (3) crops grown. Application rate and concentration of nutrients determine the amount of nutrients delivered to the land.

Under practical conditions, the results of soil and plant tissue analyses for a given location are used to determine the application rate of any plant nutrient. Concentrations of nutrients in fertilizers and application rates of fertilizers are inversely related, i.e., the higher the concentration of nutrients, the lower the application rates. However, since several soil samples are normally collected from each field and tested to help determine the fertilizer recommendations, the highest recommendation will normally be used across the entire field to ensure adequate nutrient additions. Considering all the factors involved in determining the application rate of fertilizers (e.g., diverse soils, crops, and environmental conditions), it is impractical to state a rate that would apply throughout Washington State.

Types and Specifications of Fertilizers

When fertilizers are made to supply a single nutrient, they are called "simple" fertilizers. Multinutrient fertilizers contain more than one nutrient and are referred to as "mixed" or "complex" fertilizers[3]. Others known as "customer-formula" or "custom-mix" fertilizers are made from simple or complex fertilizers in accordance with certain specifications for nutrient content.

The labels of fertilizers containing primary nutrients are given a numerical designation of three numbers called "grade." Grade refers to the weight percentage of total nitrogen, available phosphoric acid, and soluble potash (e.g., 10-15-20). If any of the three primary nutrients is not included in the fertilizer, a zero value appears in the grade for that nutrient (e.g., 10-15-0). The "guaranteed analysis" statement on the label includes the minimum percentage of each plant nutrient claimed to be present in the fertilizer.

While the majority of fertilizers are materials that are mined or manufactured for the purpose of supplementing soil nutrients, most micronutrients and some liming materials may be by-products from other industries. These by-products contain nutrients needed for plant growth or sufficient amounts of neutralizing chemicals for changing soil pH.

1997 Sampling Overview

Thirty-six samples were collected in the spring of 1997 from a variety of commercial fertilizers and liming materials to determine the concentrations of metals. The samples were analyzed for a standard list of 24 metals, see Table 1. Target analytes were primarily selected for the nine metals regulated under the EPA Biosolids Rule[4]; however, the samples were also analyzed for an additional 15 metals. Testing for these analytes was conducted because the laboratory procedure used to determine concentrations of metals in biosolids also provided concentrations for these other elements.

Table 1. Target analytes.

	Biosolids metals		
Arsenic	(As)	Molybdenum	(Mo)
Cadmium	(Cd)	Nickel	(Ni)
Copper	(Cu)	Selenium	(Se)
Lead	(Pb)	Zinc	(Zn)
Mercury	(Hg)		
	Additional analytes		
Aluminum	(Al)	Magnesium	(Mg)
Antimony	(Sb)	Manganese	(Mn)
Barium	(Ba)	Silver	(Ag)
Beryllium	(Be)	Sodium	(Na)
Calcium	(Ca)	Thallium	(Tl)
Cobalt	(Co)	Tin	(Sn)
Chromium	(Cr)	Vanadium	(V)
Iron	(Fe)		

Most of the 15 additional analytes are not as great a concern as those regulated under the Biosolids Rule. Exceptions to this include tin, barium, beryllium, chromium, and thallium. Several of the other elements are generally only considered harmful at high exposure levels[5].

Nineteen archive samples of custom-mix fertilizers from WSDA were also analyzed for metals (Appendix B). These samples, which were mostly customer-formula fertilizers, were originally collected and analyzed for the guarantees (nitrogen, phosphoric acid, soluble potash, boron, sulfur) in 1993 and 1994 as part of the WSDA routine fertilizer sampling program. The samples have been in a WSDA storage lab and were submitted for analyses in April 1997.

The fertilizers that were sampled in 1997 were selected primarily based on the annual tonnage report and the availability of the material at the time of sampling. For example, a higher percentage of samples were collected from materials with the greatest distribution and use. Ten of the 36 samples were collected from fertilizers containing industrial by-products, which included materials from magnesium mining, cement production, wood ash/paper production, steel mill emission control dust, tire ash, and recycled wallboard.

A description of the by-products sampled, including product definition, manufacturing information and agronomic information can be found in Appendix C. Table 2 lists the products sampled, the composition or grade for each product, and its physical state. A summary description of sampling protocols and quality assurance/quality control procedures is in Appendix D.

Data Limitations

At the time this study was conceived resources were limited, and there was a very short timeframe for sample collection. In order to examine as many products as possible, only one sample per product was collected. The sample collection method ensured the sample was representative of a particular product lot being sampled. The sampling method used is more typically employed to obtain data for evaluating compliance with label guarantees. This method does not provide for statistical analysis of the variability of the products. Therefore, caution in the interpretation of the results must be used.

Due to time constraints and product availability, the collection of ammonium phosphate sulfate was conducted outside of accepted methodology. Although the sampling method did not meet all guidelines, the data are acceptable for purposes of this report

Table 2. Fertilizer products sampled.

Product	Grade	Physical state
<u>Industrial By-Product Origin</u>		
Dical lime (Ag Lime)	33% $CaCO_3$	dry
High Mag Gro (Mixed fertilizer with magnesium)	82% $CaCO_3$	dry
Kiln dust lime	85% $CaCO_3$	dry
Gypsum	85% $CaSO_4$	dry
Wood Ash (CaCO3-7.6%)	CCE-31.3%	dry
Granular Zinc (micronutrient) No. 1	18% Zn	dry
Granular Zinc (micronutrient) No. 2	18% Zn	dry
Manganese sulfate	29.5% sol. Mn	dry
Micronutrient mix No.1 (S,B,Cu,Mn,Zn)	not applicable*	dry
Micronutrient mix No.2 (B,Fe,Cu,Co,Mn,Mo,Zn)	not applicable*	dry
<u>Other</u>		
Boronat (micronutrient)	10% boron	dry
Urea	46-0-0	dry
Aqua ammonia	20-0-0	liquid
Urea ammonium nitrate	32-0-0	liquid
Calcium ammonium nitrate	17-0-0	liquid
Thiosol	12-0-0-26S	liquid
Nitrosol	20-0-0-40S	liquid
Monoammonium phosphate	11-52-0	dry
Muriate of potash	0-0-62	dry
Diammonium phosphate	18-46-0	dry
Rock phosphate	0-30-0	dry
Ground limestone	96% $CaCO_3$	dry
Calcium nitrate	15.5-0-0-19Ca	dry
Prilled blend	16-15-15	dry
Liquid ammonium phosphate	11-37-0	liquid
Ammonium phosphate suspension	11-30-0	liquid
Cal pril lime (Limestone)	91% $CaCO_3$	dry
Ammonium phosphate sulfate	16-20-0-14S	dry
Ammonium polyphosphate	10-34-0	liquid
Triple superphosphate	0-45-0	dry
Phosphoric acid	0-68-0	liquid
Potassium nitrate	13.75-0-46	dry
Ammonium sulfate	21-0-0-24S	dry
Ammonium nitrate	34.5-0-0	dry
K-Mag (Sulfate of potash-magnesia)	0-0-22	dry
Dolomite	102% $CaCO_3$	dry

* = These products are intended for use in mixing or blending with other fertilizer materials to produce fertilizers whose total primary nutrient guarantees equal or exceeds 24%.

Results

Concentrations of Metals in Fertilizer Samples

The concentrations of metals, in parts per million (ppm), detected in the 36 fertilizer samples are listed in Table 3. Each value represents the results of a single composite sample of a product. Values followed by a "U" indicate that the metal was not detected at or above the concentration listed (detection limit). Values followed by a "J" indicate that the metal was detected, but the concentration is an estimate. For purposes of this report, the "J" data are used. The results are categorized into metals regulated under the EPA Biosolids Rule (nine metals) and metals not regulated under the Biosolids Rule (15 metals). The following section focuses on the results for the nine biosolids metals.

Arsenic was detected in nine of the 36 samples. Concentrations in products ranged from 4.2 to 1040 ppm. The highest concentrations of arsenic were found in Boronat (1040 ppm), micronutrient mix No. 2 (83 ppm), and wood ash (66 ppm). The micronutrient mix and wood ash are industrial derived products while Boronat is a naturally occurring material. Arsenic was also detected in kiln dust (37 ppm), in four of the ammonium phosphate products (4.2 - 18J ppm), and in phosphoric acid (7.8 ppm).

Cadmium was detected in 12 fertilizer samples ranging from 0.63 to 275J ppm. The highest concentration of cadmium was detected in granular zinc (micronutrient) sample No. 1 (275J ppm), ammonium phosphate sulfate (145 ppm), and triple superphosphate (119 ppm). Granular zinc is an industrial by-product; ammonium phosphate sulfate and triple superphosphate are not derived from wastes. Cadmium was also detected in three other industrial by-products and six other non-industrial derived fertilizers.

Copper was detected in 23 of the 36 samples. Copper concentrations in samples ranged from 0.094 to 39,900 ppm. Samples of micronutrient mix No. 2 (39,900 ppm) and micronutrient mix No. 1 (19,400 ppm) contained the highest concentrations of copper. Both of these products are derived from industrial by-products. Seven other industrial derived fertilizers (7.2 - 1,680 ppm) and 14 non-industrial derived fertilizers (0.094 - 80.7 ppm) contained detectable concentrations of copper. In general, the industrial by-product samples contained higher levels of copper than the non-industrial derived product samples. Copper is commonly added to soils for its nutrient value.

Lead was detected in 11 fertilizer samples. Lead concentrations ranged from 2.5J to 11,300J ppm. Lead was detected in seven of the 10 industrial by-product samples (11 – 11,300J ppm), with granular zinc (micronutrient) sample No. 1 containing the highest concentration. Lead was detected less frequently and, in general, in lower concentrations in the non-industrial samples. Concentrations of lead in the four non-industrial samples that had detectable levels ranged from 2.5J - 49 ppm.

Mercury was detected in 16 of the 36 fertilizer samples ranging from 0.006 to 3.36J ppm. The highest concentration of mercury was detected in granular zinc (micronutrient) sample No. 1. Mercury was detected in eight of 26 non-industrial derived fertilizers.

Molybdenum was detected in 14 fertilizer samples. Detected concentrations of molybdenum ranged from 1.3J to 17.8 ppm. The highest concentration of molybdenum was detected in diammonium phosphate, a non-industrial by-product derived fertilizer. Molybdenum was detected in five of ten industrial by-product derived products (1.3 – 14 ppm) and in nine of the 26 non-industrial by-product derived products (3.4J – 17.8 ppm).

Nickel was detected in 16 fertilizer samples in concentrations ranging from 1.5 to 195J ppm. The highest concentrations of nickel were detected in non-industrial by-product derived fertilizers, ammonium phosphate sulfate (195J ppm) and triple superphosphate (151 ppm). Nickel was detected in eight of ten industrial derived fertilizers.

Selenium was not detected in any of the 36 fertilizer samples.

Zinc was detected in 33 of the 36 fertilizer samples. Concentrations of zinc ranged from 0.21 to 203,000 ppm. The highest concentrations of zinc were detected in the industrial derived fertilizers: granular zinc, a micronutrient, (203,000 and 178,000J ppm); micronutrient mix No. 2 (94,300 ppm); and micronutrient mix No. 1 (67,000 ppm). Zinc was detected in all of the industrial derived fertilizers and was detected in all but three of the non-industrial derived fertilizers. Zinc has been the micronutrient most often needed by crops grown in calcareous and alkaline soils in the western United States. The micronutrient products containing the highest concentrations of zinc have been marketed to correct zinc deficiencies where demonstrated.

Concentrations of Metals in Archive Fertilizer Samples

The analytical results of metals for the archive samples are shown in Appendix B. The majority of the samples (16 of 19) were custom-mix fertilizers formulated for specific crops and fields. The metal concentrations listed in Appendix B (sample collected in 1993 & 1994) may provide useful information with regard to the range of levels of metals found in some mixed fertilizers compared to individual fertilizer materials listed in Table 3 (samples collected in 1997). Custom-mix fertilizers are made from various fertilizer materials. Some of the elements listed (including calcium, magnesium, boron, cobalt, copper, iron, manganese, molybdenum, and zinc) are plant nutrients. Appendix B also lists application rates for the mixed fertilizers that range widely depending on nutrient concentration in the blend of fertilizers, location (soil texture and nutrients present), and the crops grown.

Potato Sampling

Appendix E lists the analytical results of 44 potato samples collected by the WSDA Food Safety Program in April 1997. The samples were collected from storage/packing sheds, retail stores and processing plants from several areas throughout the state. The samples were collected from the

1996 fall harvest of potatoes and were analyzed with peels for lead and cadmium by the Food and Drug Administration (FDA) regional laboratories in Seattle and San Francisco. The average concentrations of lead and cadmium in the samples were 0.01 ppm (trace – 0.046) and 0.03 ppm (0.006 – 0.068), respectively.

The levels of lead and cadmium found are similar to U.S. average concentrations of these metals previously reported by FDA for raw potatoes of 0.009 ppm lead and 0.031 ppm cadmium[6]. This study also reported average lead and cadmium concentrations in potatoes collected in Washington State of .009 ppm lead and .022 ppm cadmium. Potatoes in the 1983 FDA study were analyzed without peels and were collected from uncontaminated areas considered to be background.

Table 3. Results - Concentrations of metals (mg/kg) in fertilizers and soil amendments, 1997 sampling

Metals regulated under EPA Biosolids Rule

Material	As	Cd	Cu	Pb	Hg	Mo	Ni	Se	Zn
Industrial By-Product Origin									
Dical lime	30 U	3 U	10 U	20 U	0.0063	5 UJ	10 U	40 U	7.7
High Mag Gro	6 U	0.6 U	13.1	15	0.023	1.3 J	10.4 J	9 U	65.9
Kiln dust lime	37	3.6	158	150	0.041	7.5 J	18	40 U	1770
Gypsum	17 U	1.7 U	7.2	11	0.011	2.8 UJ	6 U	22 U	53.8
Wood Ash	66	2.1 U	159	171	0.414	7.5 J	32	27 U	581
Granular Zinc (micronutrient) No.1	34 U	275 J	1680 J	11300 J	3.36 J	14 J	83 J	45 U	178000 J
Granular Zinc (micronutrient) No.2	35 U	52.1	672	1400	-----	6 U	61.6	50 U	203000
Manganese sulfate	30 U	3 U	21	100 U	0.005 U	5 UJ	50	40 U	60.8
Micronutrient mix No. 1 (S,B,Cu,Mn,Zn)	17 U	1.7 U	19400	11 U	0.028	2.8 UJ	21	22 U	67000
Micronutrient mix No. 2 (B,Cu,Co,Fe,Mn,Mo,Zn)	83	54.7	39900	3590	0.226	3.8 J	3.89	21 U	94300
Other									
Boronat (micronutrient)	1040	1.5 U	8.1	11 U	0.17	2.6 UJ	5 U	21 U	6 J
Urea	3 U	0.3 U	1 U	2 U	0.005 U	0.5 UJ	1 U	4 U	7.7 J
Aqua ammonia	0.6 U	0.06 U	0.27	0.4 U	0.005 U	0.1 UJ	0.2 U	0.8 U	3.85
Urea ammonium nitrate	0.6 U	0.06 U	0.14	0.4 U	0.005 U	0.1 UJ	0.2 U	1 U	0.526
Calcium ammonium nitrate	3 U	0.3 U	0.4 U	2 U	0.005 U	0.5 UJ	1 U	4 U	0.4 U
Thiosol	0.6 U	0.06 U	0.08 U	0.4 U	0.0058	0.1 UJ	0.2 U	1 U	0.21

U = analyte was not detected at or above the listed numerical value
J = analyte was positively identified; associated numerical result is an estimate
UJ = analyte was not detected at or above the reported estimated result

Table 3 - p.2

Metals regulated under EPA Biosolids Rule

Material	As	Cd	Cu	Pb	Hg	Mo	Ni	Se	Zn
Other									
Nitrosol	0.6 U	0.06 U	0.094	0.4 U	0.005 U	0.1 UJ	0.2 U	1 U	42
Monoammonium phosphate	6.8	0.3 U	3.6	2 U	0.005 U	5 J	19.2	4 U	54
Muriate of potash	3 U	0.3 U	1 U	2 U	0.005 U	0.5 UJ	1 U	4 U	0.69 J
Diammonium phosphate	18 J	6.92 J	5.4 J	2.5 J	0.025	18 J	19.1 J	4 U	81.6 J
Rock phosphate	30 U	36.1	11	20 U	0.005 U	11	18	40 U	385
Ground limestone	30 U	3 U	10 U	2 U	0.0075	5 UJ	10 U	40 U	16
Calcium nitrate	16 U	1.6 U	5 U	11 U	0.005 U	2.7 UJ	5 U	21 U	2 U
Prilled blend	15 U	1.5 U	80.7	10 U	0.005 U	2.5 UJ	5 U	20 U	81.6
Liquid ammonium phosphate	3 U	0.63	1 U	2 U	0.005 U	3.4 J	1 U	4 U	25.3
Suspension phosphate	3 U	1.6	5.8	2 U	0.005 U	3.6	13.9	4 U	301
Cal pril lime	30 U	3 U	10 U	20 U	0.0060	5 UJ	10 U	40 U	21
Ammonium phosphate sulfate	4.2	145	16	4.4	0.024	5.7 J	195 J	4 U	1480 J
Ammonium polyphosphate	4.8	25	3.3	2 U	0.005 U	6.5	1 U	4 U	315
Triple superphosphate	31 U	119	40.2	21 U	0.005 U	13 J	151	42 U	1260
Phosphoric acid	7.8	0.3 U	0.4 U	4 U	0.005 U	5.9 J	1 U	4 U	31.3
Potassium nitrate	3 U	0.3 U	1 U	2 U	0.005 U	0.5 UJ	1.5	4 U	0.73 J
Ammonium sulfate	3 U	1.2	1 U	15	0.403	0.5 UJ	1 U	4 U	17 J
Ammonium nitrate	3 U	0.3 U	1 U	2 U	0.005 U	0.5 UJ	1 U	4 U	2.5 J
K-Mag	6 U	0.6 U	0.19 J	4 U	0.005 U	1 UJ	5.1	8 U	8 U
Dolomite	15 U	1.5 U	3.4	49	0.022	2.5 UJ	5 U	20 U	224

U = analyte was not detected at or above the listed numerical value
J = analyte was positively identified; associated numerical result is an estimate
UJ = analyte was not detected at or above the reported estimated result

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Metals not regulated under the Biosolids Rule

Material	Al	Sb	Ba	Be	Ca	Co	Cr	Fe	Mg	Mn	Ag	Na	Tl	V	Sn
Industrial By-Product Origin															
Dical lime	63700	30 UJ	17.3	1 U	348000	3 U	5 U	6.37	23700	19.5	3 UJ	2190	40 U	2 U	50 UJ
High Mag Gro	12600	6 UJ	24.9	0.2 U	58600	1.4	2	3450	209000	305	1.4 J	2790	9 U	0.89	11 UJ
Kiln dust lime	10500	30 UJ	99.5	1 U	363000	4.2	73.2	11400	5210	247	3 UJ	7030	40 U	48.7	50 UJ
Gypsum	1170	17 UJ	34.8	0.6 U	211000	1.7 U	2.8 U	1890	4240	203	1.7 UJ	1460 J	22 U	2.8	28 UJ
Wood Ash	40800	21 UJ	581	0.7 U	148000	11	46.7	200	10400	1190	2.1 UJ	6100	27 U	56	34 UJ
Granular Zinc No.1 (micronutrient)	3030 J	42 J	95.7 J	1.1 U	27700 J	291 J	580 J	106000 J	9300 J	6670 J	38.5 J	8140 J	45 U	40.9 J	438 J
Granular Zinc No.2 (micronutrient)	3370	44 J	61.2	1.2 U	9250	786	67.8	38200	2120	783	5.4	2970	100 U	1 U	
Manganese sulfate	100 U	150 UJ	1 U	1 U	2080	65.6	10	120 J	13500	285000	3 UJ	350	200 U	3 U	50 U
Micronutrient mix No.1 (S,B,Cu,Mn,Zn)	2120	17 UJ	71	3	14900	11	3.1	12700	3070	34400	1.7 UJ	10900	22 U	1.1 U	30 J
Micronutrient mix No.2 (B,Cu,Co,Fe,Mn,Mo,Zn)	10900	38 J	328	10.5	12100	162	457	76000	2860	56200	3.8 J	15300	21 U	32.6	765 J
Other															
Boronat (micronutrient)	894	16 UJ	42.8	0.5 U	107000	1.8	2.6 U	1160	7650	24.7	1.5 UJ	69700	21 U	16.9	26 UJ
Urea	28	3 UJ	0.16	0.1 U	68	0.3 U	2.2	28	19	0.95 J	0.3 UJ	11	4 U	3.12	5 UJ
Aqua ammonia	4.02	0.6 U	0.02 U	0.02 U	0.61	0.06 U	0.1 U	0.61	0.4 U	0.034	0.06 U	49.2	0.8 U	0.05	1 UJ
Urea ammonium nitrate	0.66	0.6 U	0.04	0.02 U	52	0.06 U	0.15	2.04	2.8	0.13	0.06 U	4.54	0.8 U	0.19	1 UJ
Calcium ammonium nitrate	40.9	3 UJ	0.27	0.1 U	87600	0.3 U	2	14.6 J	1450	12.4	0.3 U	629 J	4 U	0.2 U	5 UJ
Thiosol	0.83	0.6 U	0.03	0.02 U	5.08	0.06 U	0.1 U	3.12	0.4 U	0.035	0.06 U	37	0.8 U	0.06	1 U

U = analyte was not detected at or above the listed numerical value

J = analyte was positively identified; associated numerical result is an estimate

UJ = analyte was not detected at or above the reported estimated result

Metals not regulated under the Biosolids Rule

Material	Al	Sb	Ba	Be	Ca	Co	Cr	Fe	Mg	Mn	Ag	Na	Tl	V	Sn
Other															
Nitrosol	1.3	0.6 U	0.02	0.02 U	5.51	0.06 U	0.1 U	1.2	5.11	0.034	0.06 U	51.8	0.8 U	0.05	6.1
Monoammonium phosphate	7090	3 UJ	3.82	1.69	5640	1.3	5.79	4290	11600	1.08 J	0.3 UJ	2790	4 U	37.9	9.5 J
Muriate of potash	10 U	3 UJ	0.1 U	0.1 U	172	0.3 U	0.5 U	2.3 U	61	0.31 J	0.3 UJ	3050	4 U	0.2 U	5 UJ
Diammonium phosphate	9900 J	3 UJ	7.35 J	3.86 J	4300 J	6.31 J	91.8 J	8250 J	4450 J	377 J	0.43 J	2020 J	4 U	174 J	6.9 J
Rock phosphate	2620	30 UJ	50.1	2.5	386000	3 U	136	4220	4310	21.1	3 UJ	101	40 U	28.6	50 UJ
Ground limestone	390	30 UJ	4.6	1 U	389000	3 U	5 U	450	3150	105	3 UJ	1800	40 U	2 U	50 UJ
Calcium nitrate	170	16 UJ	91.6	0.5 U	205000	1.6 U	2.7 U	67 J	447	4 J	1.6 UJ	1020 J	21 U	1 U	27 UJ
Prilled blend	1120	15 UJ	140	0.5 U	28100	1.5 U	4.3	1050	4480	116	1.5 UJ	3760	20 U	25.7	25 UJ
Liquid ammonium phosphate	4820	3 U	0.17	1.36	39.8	0.3 U	433	2280	507	29.3	0.3 U	424	4 U	31.7	5 U
Suspension phosphate	5100	3 U	6.33	1.12	5950	0.82	379	3000	9450	68.1	0.3 UJ	2170	4 U	32	6.9
Cal pril lime	902	30 UJ	6.9	1 U	395000	3 U	5 U	2270	2600	139	3 UJ	2190	40 U	2 U	50 UJ
Ammonium phosphate sulfate	3970	3 UJ	13.2 J	1.15	7830	3.2	214	3190	4880	64.3	0.3 UJ	1490	4 U	396	6.1 J
Ammonium polyphosphate	4250	3 U	0.16	1.29	58.4	0.3 U	400	2680	539	35.9	0.3 UJ	375	4 U	228	5 U
Triple superphosphate	7760	31 UJ	2.4	2.7	177000	4.8	516	4920	6500	133	3.1 UJ	1700 J	42 U	721	52 UJ
Phosphoric acid	10200	3 U	0.22	2.75	31.1	0.3 U	896	3490	1130	59.5	0.3 U	826	1.1	57.2	7.8
Potassium nitrate	10 U	3 UJ	0.1 U	0.1 U	79	0.3 U	2.5	15	490	6.65	0.3 UJ	4260	4 U	0.2 U	5 UJ
Ammonium sulfate	31	3 UJ	0.21	0.1 U	137	0.3 U	0.68	69.1	29	4.5	0.3 UJ	36.3	4 U	0.41	5 UJ
Ammonium nitrate	10 U	3 UJ	0.21	0.1 U	20	0.3 U	0.5 U	8.5	63.2	0.43 J	0.3 UJ	4.6	4 U	0.2 U	5 UJ
K-Mag	46 J	6 UJ	0.82	0.2 U	588 J	0.81	1 U	111	99600	13.7	0.6 UJ	4080	8 U	0.4 U	10 UJ
Dolomite	887	15 UJ	6.87	2	216000	1.5 U	2.5 U	3300	127000	1070	1.5 UJ	944	20 U	1.1	25 UJ

U = analyte was not detected at or above the listed numerical value

J = analyte was positively identified; associated numerical result is an estimate

UJ = analyte was not detected at or above the reported estimated result

Discussion of Results

This section describes the results from the screening survey. The concentration of metals is compared to:

- EPA Biosolids Rule
- State regulations: Dangerous Waste, WAC 173-303; Biosolids Rule, WAC 173-308
- Regulations in other countries.

The potato sampling results are compared to historical FDA data. For a more detailed discussion of applicable regulations, see Appendix F.

Fertilizer Application Rates and Metals Loading

As previously mentioned, fertilizer products are added to agricultural soils at different rates depending on factors such as crop type, nutrient concentration in the fertilizer, soil nutrient levels, and physical characteristics of the soil. Because fertilizer products are applied at variable rates, absolute metal concentrations do not provide sufficient information on the amount of metals actually applied to agricultural land, or the relative hazard of each product.

In order to estimate the amount of metal applied to land each year (annual loading), the metals results in Table 3 were adjusted by an annual application rate for each product in order to estimate the amount that each metal is applied to land each year. This adjustment was also done so that fertilizer sample results could be compared to the standards for metals in the Biosolids Rule and the Canadian standards.

Because application rates may vary with nutrient needs and other factors, the maximum application rate was used for each product to estimate the "worst case" amount of metals added to soil. The maximum annual loadings for each product are listed in Table 4. Table 4 results for cadmium, lead and arsenic are displayed graphically in Figure 1.

The maximum annual loading is based on using the highest application rate reported. This rate was obtained from several sources including fertilizer manufacturers, distributors, and the Washington State University Extension. The two exceptions to using the maximum application rate are wood ash and granular zinc, for the following reasons:

- Liming materials (wood ash) are generally applied once every three years, so the maximum application rate was divided by a factor of 3, the number of years that may lapse between applications. The wood ash sampled was reported as having been applied only once to a specific acreage of land.

- Granular zinc is applied once every three years (when used at levels approaching the maximum rate), so the maximum application rate for granular zinc is divided by a factor of 3.

Table 4. Maximum amount (kg/ha) of metal added to soil on an annual basis

Material	Maximum Annual Load	As	Cd	Cu	Pb	Hg	Mo	Ni	Zn	Se	Metal Key	
		Materials regulated under EPA Biosolids Rule										
Biosolids Standards		*0.41*	*0.39*	*15.00*	*3.00*	*0.17*	NA	*4.20*	*28.00*	*1.00*		
Canadian Standards		*0.33*	*0.09*	NA	*2.22*	*0.02*	*0.09*	*0.80*	*8.22*	*0.06*		
Industrial By-Product Origin											**Metal Key**	
Dical lime	8968	ND	ND	ND	ND	<0.01	ND	ND	0.07	ND	As	Arsenic
High Mag Gro	4484	ND	ND	0.06	0.07	<0.01	<0.01	0.05	0.30	ND	Cd	Cadmium
Kiln dust lime	2989	0.11	0.01	0.47	0.45	<0.01	0.02	0.05	5.29	ND	Cr	Chromium
Gypsum	336	ND	ND	<0.01	<0.01	<0.01	ND	ND	0.02	ND	Cu	Copper
Wood Ash	21011	1.39	ND	3.34	3.59	0.01	0.18	0.67	12.21	ND	Pb	Lead
Granular Zinc (micronutrient) No 1	25	ND	0.01	0.04	0.28	<0.01	<0.01	<0.01	4.46	ND	Hg	Mercury
Granular Zinc (micronutrient) No 2	25	ND	<0.01	0.02	0.04	<0.01	ND	<0.01	5.08	ND	Mo	Molybdenum
Manganese sulfate	67	ND	ND	<0.01	ND	ND	ND	<0.01	<0.01	ND	Ni	Nickel
Micronutrient mix No 1 (S,B,Cu,Mn,Zn)	34	ND	ND	0.65	ND	<0.01	ND	<0.01	2.03	ND	Se	Selenium
Micronutrient mix No 2 (B,Cu,Co,Fe,Mn,Mo,Zn)	14	<0.01	<0.01	0.56	0.05	<0.01	<0.01	<0.01	1.32	ND	Zn	Zinc
Other											Al	Aluminum
Boronat (micronutrient)	34	0.03	ND	<0.01	ND	<0.01	ND	ND	<0.01	ND	Sb	Antimony
Urea	1009	ND	ND	ND	ND	ND	ND	ND	0.01	ND	Ba	Barium
Aqua ammonia	1121	ND	ND	<0.01	ND	ND	ND	ND	<0.01	ND	Be	Beryllium
Urea ammonium nitrate	1261	ND	ND	<0.01	ND	ND	ND	ND	<0.01	ND	Ca	Calcium
Calcium ammonium nitrate	989	ND	ND	ND	ND	ND	ND	ND	ND	ND	Co	Cobalt
Thiosol	215	ND	ND	ND	ND	<0.01	ND	ND	<0.01	ND	Fe	Iron
Nitrosol	112	ND	ND	<0.01	ND	ND	ND	ND	<0.01	ND	Mg	Magnesium
Monoammonium phosphate	1121	0.01	ND	<0.01	ND	ND	<0.01	0.02	0.06	ND	Mn	Manganese
Muriate of potash	1345	ND	ND	ND	ND	ND	ND	ND	<0.01	ND	Ag	Silver
Diammonium phosphate	1121	0.02	0.01	<0.01	<0.01	<0.01	0.02	0.02	0.09	ND	Na	Sodium
Rock phosphate	785	ND	0.03	0.01	ND	ND	0.01	0.01	0.30	ND	Tl	Thallium
Ground limestone	4484	ND	ND	ND	ND	<0.01	ND	ND	0.07	ND	V	Vanadium
Calcium nitrate	1121	ND	ND	ND	ND	ND	ND	ND	ND	ND	Sn	Tin
Prilled blend	420	ND	ND	0.03	ND	ND	ND	ND	0.03	ND		
Liquid ammonium phosphate	1513	ND	<0.01	ND	ND	ND	<0.01	ND	0.04	ND		
Suspension phosphate	1794	ND	<0.01	0.01	ND	ND	0.01	0.02	0.54	ND		
Cal pril lime	4484	ND	ND	ND	ND	<0.01	ND	ND	0.09	ND		
Ammonium phosphate sulfate	561	<0.01	0.08	0.01	<0.01	<0.01	<0.01	0.11	0.83	ND		
Ammonium polyphosphate	561	<0.01	0.01	<0.01	ND	ND	<0.01	ND	0.18	ND		
Triple superphosphate	1121	ND	0.13	0.05	ND	ND	0.01	0.17	1.41	ND		
Phosphoric acid	336	<0.01	ND	ND	ND	ND	<0.01	ND	0.01	ND		
Potassium nitrate	1457	ND	ND	ND	ND	ND	ND	<0.01	<0.01	ND		
Ammonium sulfate	2242	ND	<0.01	ND	0.03	<0.01	ND	ND	0.04	ND		
Ammonium nitrate	1345	ND	ND	ND	ND	ND	ND	ND	<0.01	ND		
K-Mag	3027	ND	ND	<0.01	ND	ND	ND	0.02	ND	ND		
Dolomite	3906	ND	ND	0.01	0.19	<0.01	ND	ND	0.88	ND		

Results are based on weight basis for liquids, dry-weight for dry products.

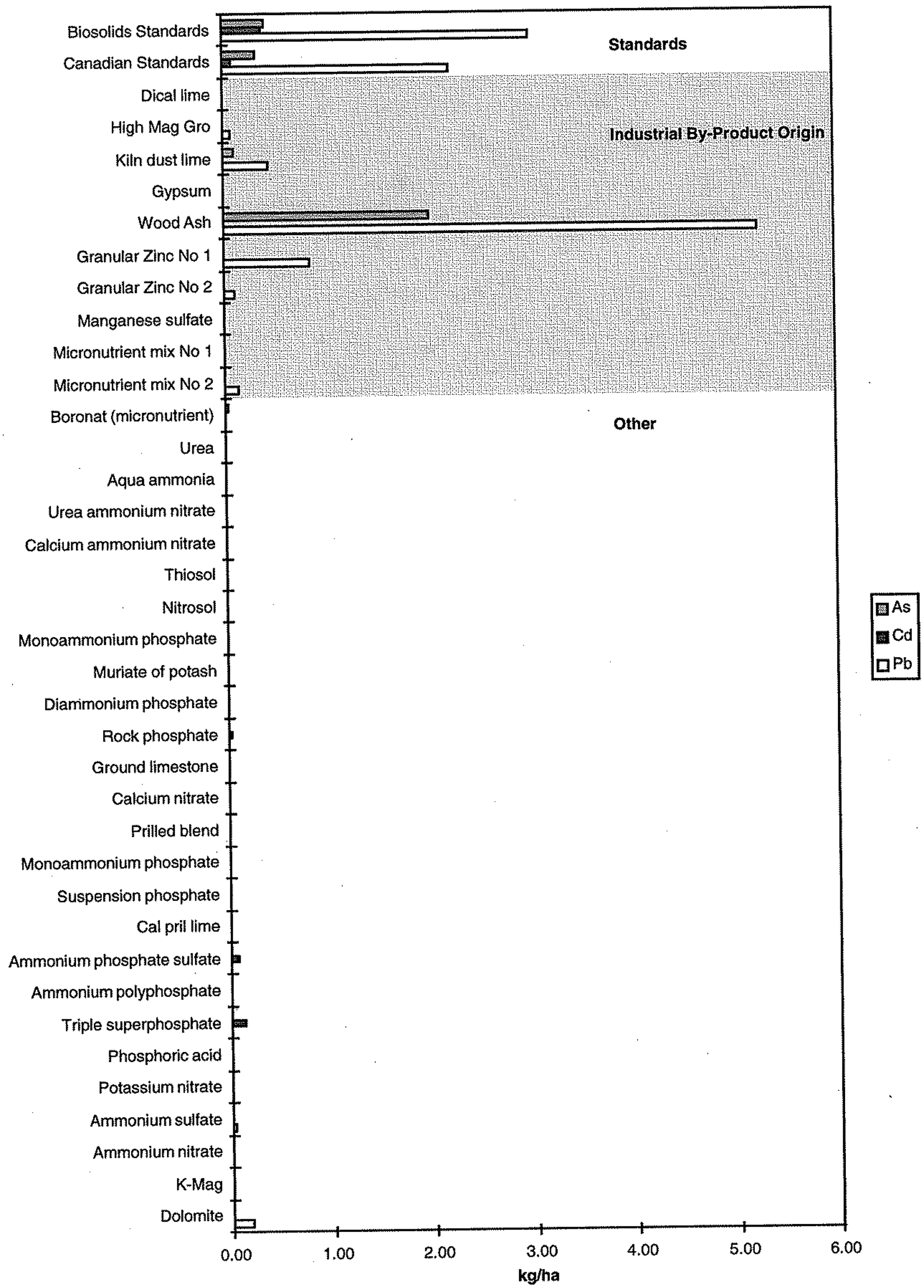
ND = not detected (specific detection limits appear in Table 3 with the U data qualifier).

Table 4. Maximum amount (kg/ha) of metal added to soil on an annual basis

	Metals not regulated under the Biosolids Rule														
Material	**Al**	**Sb**	**Ba**	**Be**	**Ca**	**Co**	**Cr**	**Fe**	**Mg**	**Mn**	**Ag**	**Na**	**Tl**	**V**	**Sn**
Canadian Standards						*0.67*									
Industrial By-Product Origin															
Dical lime	571.26	ND	0.16	ND	3,120.86	ND	ND	0.06	212.54	0.17	ND	19.64	ND	ND	ND
High Mag Gro	56.50	ND	0.11	ND	262.76	<0.01	0.01	15.47	937.16	1.37	<0.01	12.51	ND	<0.01	ND
Kiln dust lime	31.39	ND	0.30	ND	1,085.13	0.01	0.22	34.08	15.57	0.74	ND	21.02	ND	0.15	ND
Gypsum	0.39	ND	0.01	ND	70.96	ND	ND	0.64	1.43	0.07	ND	0.49	ND	<0.01	ND
Wood Ash	857.25	ND	12.21	ND	3,109.63	0.23	0.98	4.20	218.51	25.00	ND	128.17	ND	1.18	ND
Granular Zinc No 1	0.08	<0.01	0.00	ND	0.69	0.01	0.01	2.65	0.23	0.17	<0.01	0.20	ND	<0.01	0.01
Granular Zinc No 2	0.08	<0.01	<0.01	ND	0.23	0.02	<0.01	0.96	0.05	0.02	<0.01	0.07	ND	ND	<0.01
Manganese sulfate	ND	ND	ND	ND	0.14	<0.01	<0.01	0.01	0.91	19.17	ND	0.02	ND	ND	ND
Micronutrient mix No 1	0.07	ND	<0.01	<0.01	0.50	<0.01	<0.01	0.43	0.10	1.16	ND	0.37	ND	ND	<0.01
Micronutrient mix No 2	0.15	<0.01	0.00	<0.01	0.16	0.00	0.01	1.06	0.04	0.79	<0.01	0.21	ND	<0.01	0.01
Other															
Boronat (micronutrient)	0.03	ND	<0.01	ND	3.60	<0.01	ND	0.04	0.26	<0.01	ND	2.34	ND	<0.01	ND
Urea	0.03	ND	<0.01	ND	0.07	ND	<0.01	0.03	0.02	<0.01	ND	0.01	ND	<0.01	ND
Aqua ammonia	<0.01	ND	ND	ND	<0.01	ND	ND	<0.01	ND	<0.01	ND	0.06	ND	<0.01	ND
Urea ammonium nitrate	<0.01	ND	<0.01	ND	0.07	ND	<0.01	<0.01	<0.01	<0.01	ND	<0.01	ND	<0.01	ND
Calcium ammonium nitrate	0.04	ND	<0.01	ND	86.61	ND	<0.01	0.01	1.43	0.01	ND	0.62	ND	ND	ND
Thiosol	<0.01	ND	<0.01	ND	<0.01	ND	ND	<0.01	ND	<0.01	ND	0.01	ND	<0.01	ND
Nitrosol	<0.01	ND	<0.01	ND	<0.01	ND	ND	<0.01	<0.01	<0.01	ND	<0.01	ND	<0.01	<0.01
Monoammonium phosphate	7.95	ND	<0.01	<0.01	6.32	<0.01	0.01	4.81	13.00	<0.01	ND	3.13	ND	0.04	0.01
Muriate of potash	ND	ND	ND	ND	0.23	ND	ND	ND	0.08	<0.01	ND	4.10	ND	ND	ND
Diammonium phosphate	11.10	ND	0.01	<0.01	4.82	0.01	0.10	9.25	4.99	0.42	<0.01	2.26	ND	0.20	0.01
Rock phosphate	2.06	ND	0.04	<0.01	302.89	ND	0.11	3.31	3.38	0.02	ND	0.08	ND	0.02	ND
Ground limestone	1.75	ND	0.02	ND	1,744.28	ND	ND	2.02	14.12	0.47	ND	8.07	ND	ND	ND
Calcium nitrate	0.19	ND	0.10	ND	229.81	ND	ND	0.08	0.50	<0.01	ND	1.14	ND	ND	ND
Prilled blend	0.47	ND	0.06	ND	11.81	ND	<0.01	0.44	1.88	0.05	ND	1.58	ND	0.01	ND
Liquid ammonium phosphate	7.29	ND	<0.01	<0.01	0.06	ND	0.66	3.45	0.77	0.04	ND	0.64	ND	0.05	ND
Suspension phosphate	9.15	ND	0.01	<0.01	10.67	<0.01	0.68	5.38	16.95	0.12	ND	3.89	ND	0.06	0.01
Cal pril lime	4.04	ND	0.03	ND	1,771.18	ND	ND	10.18	11.66	0.62	ND	9.82	ND	ND	ND
Ammonium phosphate sulfate	2.23	ND	0.01	<0.01	4.39	<0.01	0.12	1.79	2.74	0.04	ND	0.84	ND	0.22	<0.01
Ammonium polyphosphate	2.38	ND	<0.01	<0.01	0.03	ND	0.22	1.50	0.30	0.02	ND	0.21	ND	0.13	ND
Triple superphosphate	8.70	ND	<0.01	<0.01	198.42	<0.01	0.58	5.52	7.29	0.15	ND	1.91	ND	0.81	ND
Phosphoric acid	3.43	ND	<0.01	<0.01	0.01	ND	0.30	1.17	0.38	0.02	ND	0.28	<0.01	0.02	<0.01
Potassium nitrate	ND	ND	ND	ND	0.12	ND	<0.01	0.02	0.71	0.01	ND	6.21	ND	ND	ND
Ammonium sulfate	0.07	ND	<0.01	ND	0.31	ND	<0.01	0.15	0.07	0.01	ND	0.08	ND	<0.01	ND
Ammonium nitrate	ND	ND	<0.01	ND	0.03	ND	ND	0.01	0.09	<0.01	ND	<0.01	ND	ND	ND
K-Mag	0.14	ND	<0.01	ND	1.78	<0.01	ND	0.34	301.46	0.04	ND	12.35	ND	ND	ND
Dolomite	3.47	ND	0.03	0.01	843.80	ND	ND	12.89	496.12	4.18	ND	3.69	ND	<0.01	ND

Results are based on weight basis for liquids, dry-weight for dry products. ND = not detected (specific detection limits appear in Table 3 with the U data qualifier).

Figure 1. Maximum Amount of Metals Added to Soil on an Annual Basis (kg/ha)



Application rates reported for the samples collected from 1993 and 1994 were those reported by the fertilizer manufacturers or applicators involved (Appendix B).

The application rate is a range of rates that may be used depending on crop and soil variability. Potential application rates for the fertilizer products sampled were not used to calculate annual loadings of metals to soil, but are presented for information purposes (Table 5). If known, the specific fertilizer application rate at the time of sampling is listed.

The annual load in italics in the first row for the first nine metals in Table 4 represent the annual loading of metals expected from application of "exceptional quality (EQ)" biosolids (40 CFR 503.13) applied at a rate of 10 metric tons/ha. These annual loading values are used as screening values[7]; they do not appear in the Biosolids Rule. They were derived from the typical application rate of biosolids in Washington (5 to 10 metric tons/ha) and the standard for EQ biosolids. The maximum concentrations for metals in EQ biosolids are listed in Table 6. Currently, the Biosolids Rule does not contain an EQ concentration for molybdenum, although the Biosolids Rule does contain a non-risked based ceiling concentration for molybdenum of 75 mg/kg (dry weight). In the absence of an EQ value for molybdenum, a screening value for molybdenum with which to compare to fertilizer results will not be used here.

These screening values provide a reasonable annual loading comparison. The 10 metric ton per hectare application rate is at the upper range of what is typically applied on fields in Washington. Biosolids that do not exceed the limits in Table 6 are not subject to record-keeping requirements, because they will not cause the soil concentrations to exceed the cumulative pollutant loading limits (40 CFR 503.13) reported in Table 6. If the cumulative metal loadings for any of the nine regulated metals exceed the limits listed in Table 6, no additional biosolids may be applied. The first row in Table 4 is left blank for the 15 metals not regulated under the Biosolids Rule since there are no other comparable screening values.

Wood ash was the only product that exceeded the EQ biosolids metals application rates (i.e., for both arsenic and lead). The estimated arsenic application rate from the wood ash sample is 1.39 kg/ha compared to the EQ biosolids arsenic application rate of 0.41 kg/ha. The lead application rate estimated from the wood ash sample is 3.59 kg/ha compared to 3.00 kg/ha for the EQ biosolids application rate. The estimated annual application rate for copper in wood ash (3.34 kg/ha) was one-fifth the EQ biosolids application rate (15.00 kg/ha).

Most of the other samples were well below (i.e., less than 10 percent) the EQ biosolids metals application rates with the exception of cadmium in triple superphosphate. The EQ biosolids application rate for cadmium is 0.39 kg/ha while the annual application rate calculated for the triple superphosphate sample 0.11 kg/ha is approximately 30 percent of the biosolids value.

Table 5. Potential application rate ranges and method of application of various fertilizers in Washington.

Material	Application rate in kg/ha	Number of applications per year or less frequently	Crops used on (food/feed or nonfood/nonfeed)	Dry land, irrigated or both
Industrial By-Product Origin				
Dical lime	2240 - 8960	one	apples some sandy circles	irrigated acid soils
High Mag Gro	26.7 - 3560	**	**	**
Kiln dust lime	4484 - 8768	once every 3 years	wide range in Spokane area	both
Gypsum	89 - 178 for S nutrition	one	all	both
Wood Ash	67260 - 91922	once every 3 to 5 years, usually	spring oats, clover seed and/or hay	in Camas vicinity in W. WA
Granular Zinc (micronutrient)	6.2 – 62.7	once every 3 years	all crops with low Zn soils	**
Manganese sulfate	26.2 – 56	one	any	irrigated
Micronutrient mix No. 1 (S,B,Cu,Mn,Zn)	8.4 - 34	one	any	irrigated, dryland tree fruits
Micronutrient mix No. 2 (B,Cu,Co,Fe,Mn,Mo,Zn)	14	one	any	irrigated, dryland tree fruits
Other				
Boronat (micronutrient)	11 - 34	one	any	both
Urea	122 - 841	one*	any (i.e., potatoes)	both lower rates dry land
Aqua ammonia	561 - 1121	one	predominately wheat	both
Urea ammonium nitrate	336 - 1261	one*	any	both
Calcium ammonium nitrate	330 - 989	one*	tree fruits	irrigated

* Application in one year can be split over several applications.
** Information pending.

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Material	Application rate in kg/ha	Number of applications per year or longer	Crops used on	Dry land, irrigated or both
Other				
Thiosol	22 - 168	one	any	both
Nitrosol	22 - 112	one	any	both
Monoammonium phosphate	224 - 673	one	any	mostly irrigated
Muriate of potash	336 - 897	one	any	mostly irrigated
Diammonium phosphate	224 - 673	one	any	mostly irrigated
Rock phosphate	890	one	any	**
Ground limestone	2224 - 4484	one	any	mostly acid soils
Calcium nitrate	336 - 1121	one (split)*	any tree, fruits mainly	irrigated
Prilled blend	420	**	**	**
Liquid ammonium phosphate	336 - 896	one	any	mostly irrigated
Suspension phosphate	336 - 896	one	any	mostly irrigated
Cal pril lime	1682 - 4484	**	**	**
Ammonium phosphate sulfate	44.8 - 78.5	**	any	irrigated
Ammonium polyphosphate	561	**	any	irrigated
Triple superphosphate	224 - 785	one	any	irrigated
Phosphoric acid	systems 168 - 336	acidification	**	**
Potassium nitrate	733	**	greenhouse use	**
Ammonium sulfate	448 - 1682	one*	any	irrigated, some dryland low rates
Ammonium nitrate	336 - 1009	one*	any	both
K-Mag	561 - 2018	one	any	irrigated
Dolomite	1953 - 3907	**	garden use	**

* Application in one year can be split over several applications.
** Information pending.

Table 6. Pollutant concentrations for exceptional quality biosolids (40 CFR 503.13)

Pollutant	Limit*
Arsenic	41
Cadmium	39
Copper	1500
Lead	300
Mercury	17
Molybdenum	NA**
Nickel	420
Selenium	100
Zinc	2800

* Monthly average concentration in milligrams per kilogram (ppm) - dry weight basis

** Not Available. Mo does not currently have an EQ concentration

Background on the Biosolids Risk Assessment

The EPA evaluated 14 exposure pathways in developing the Biosolids Rule (EPA 503)[8]. Nine exposure pathways focused on impacts to people and five exposure pathways focused on impacts to ecological receptors (livestock, soil organisms, predators of soil organisms, and plants). The pathway which gave the highest risk for each metal (thus requiring the lowest protective concentration in biosolids) was determined to be the "limiting pathway" for that metal. The limiting pathways for arsenic, cadmium, lead, and mercury are based on preventing impacts to people. The limiting pathways for copper, nickel, and zinc are based on preventing impacts to ecological receptors, namely plant toxicity (phytotoxicity). Some of the numerical criteria in the biosolids regulation (cumulative loading rates and pollutant concentrations in biosolids) are based on the limiting pathway for each metal.

Contaminants in Fertilizers and Ecological Risk

In terms of assessing ecological risk from contaminants in fertilizers applied to agricultural land, the impact of fertilizer application should be studied. Fertilizer may contain both inorganic and organic contaminants that exhibit unique characteristics in terms of bioavailability. Literature in this specific area appears limited[9]. In a related but limited effort, ecological risk has been assessed in the Biosolids Rule that evaluates risk from application of sewage sludge (biosolids) to agricultural and non-agricultural land.

Because EPA standards for the use and disposal of biosolids were developed primarily from a human health perspective, an expanded effort to assess ecological risks from application of biosolids to non-agricultural land is currently underway[10]. This assessment will address risks to wildlife populations, plant community and diversity, soil invertebrate community structure, and microbial processes. The bioavailability of metals in biosolids is a primary determinant of risk in this assessment. Although this assessment is directed toward application of biosolids to non-agricultural land, it may provide insight into an ecological risk assessment of contaminants in fertilizers applied to agricultural land.

Additional information on Biosolids risk assessments can be found in Appendix G.

Applicability of the Biosolids Rule to Fertilizers

The Biosolids Rule is based on the protection of human and ecological health and crop productivity from agricultural applications of biosolids that are known to contain metals. From this perspective, the Biosolids Rule represents a starting point for assessing possible impacts of fertilizer products because it accounts for many of the same potential exposure pathways important for evaluating fertilizers. However, there may be risk assessment and other assumptions used in the Biosolids Rule development that are not appropriate for evaluating potential fertilizer hazards. A brief summary of the important areas where exposures to biosolids may differ from exposures and possible health impacts of biosolids and fertilizers would require a full review of pertinent literature and an extensive risk assessment which is beyond the scope of this report.

Many factors influence plant uptake of metals from soil including the form of the metals, soil pH, presence of other elements, and organic matter content of soil[11]. Estimates of plant uptake used in the Biosolids Rule were taken mainly from studies involving biosolids, either in laboratory or field studies. Biosolids are rich in organic matter that provides reactive sites to bind metals, thereby making metals in biosolids less bioavailable than metals applied as inorganic salts[12]. Some researchers think that metals in biosolids will become more bioavailable once the organic matter degrades in the environment; however, this is an area of much controversy[13].

Several of the pathways used to develop the Biosolids standards (Pathways 1, 2, 4, 6, and 8) rely in part on estimating metals uptake into plants. Therefore, exposures from these pathways may underestimate exposures from fertilizers. Due to the many factors that influence plant uptake, it is not possible to quantify the degree to which the biosolids risk assessment might underestimate plant uptake from different fertilizer products[11].

Pathway 3, which is based on a child eating biosolids and not on an exposure via plant uptake, is the limiting pathway for arsenic, cadmium, lead, mercury, and selenium. If plant uptake of metals from fertilizers is higher than assumed in the biosolids risk assessment, then pathways involving plant uptake may become limiting for these metals.

Other ways in which the Biosolids Rule may not apply to fertilizers relate to differences in possible exposure scenarios. For example, Pathway 1 assumes that 2.5% of the general population's fruits and vegetables are grown on sludge amended soils. If this percentage is higher for fertilizer products, the Biosolids Rule would likely underestimate the general population's exposures from fertilizers. Additionally, since the Biosolids Rule applies only to nine metals, exposures to other possible contaminants in fertilizers including other metals and organic compounds are not accounted for when using the Biosolids Rule as a comparison.

Land Disposal Restrictions

Fertilizer products that are derived from certain hazardous waste are subject to the "Land Disposal Restriction" portion of the state Dangerous Waste Regulations (WAC 173-303) (Appendix F Table). These standards cannot be compared directly with the results in Table 3 because of differences in the test methods used. The results in Table 3 represent the total concentration of metals in the fertilizer products. The dangerous waste standards listed in Appendix F are based on the concentration of metals in an extract of the material. The concentration in the extract will be less than the actual concentration of metals in the product being tested. A 20-to-1 ratio is typically used to estimate the extract value from total metals test results. However, caution is needed when using this approach. The physical and chemical characteristics of the material being sampled can greatly affect the ratio of metals in the product to the extract.

The concentrations of metals in eight of the non-waste derived fertilizers exceed the 20-to-1 ratio. It appears that Boronat would exceed the standard for arsenic. It appears that the standard for cadmium would be exceeded by rock phosphate, ammonium phosphate sulfate, ammonium poly sulfate, and triple superphosphate. It appears that the standard for chromium would be exceeded by rock phosphate, liquid ammonium phosphate, suspension phosphate, ammonium phosphate sulfate, ammonium polyphosphate, and phosphoric acid.

Four of the ten industrial by-product fertilizers are known to be derived from hazardous waste: kiln dust lime, both granular zinc products, and wood ash. The kiln dust lime and granular zinc No. 2 have been tested and meet the Land Disposal Restrictions of the Dangerous Waste Regulations. The granular zinc No. 1 is specifically excluded from the Land Disposal Restrictions.

It appears that Micronutrient mix No. 2 would exceed the standard for chromium.

Regulations in Other Countries

The Canadian standards established in 1980 for sewage sludge were recently reassessed and deemed to be applicable and appropriate for all soil-applied fertilizer products[14]. In 1995-96, Canada established the maximum limits for trace elements in compost. During this process, the Canadian sewage sludge standards were re-evaluated. This review employed three analytical approaches: "no net degradation," "no observable adverse effects," and "best achievable."[15]. As part of the re-evaluation, the Canadian metal standards were compared with other standards development activities, including those conducted by the EPA. The comparison concluded the metal standards established by Agriculture and Agri-Food Canada were valid.

Cumulative pollutant loading limits and toxicological benchmarks for soils from several countries are presented in Table 7. The Canadian metal standards are part of the Fertilizer Act and Regulations of Agriculture and Agri-Food Canada (Memorandum T-4-93, August 1996).

The standards apply to fertilizers, supplements, treated sewage, compost and other by-products, and were developed based on national soil background metal contents. Although the data contained in the tables are not risk-based, the cumulative pollutant loading limits were set with consideration for the unique risks posed by each metal. For example, the loading limits for arsenic and nickel were set at twice the average soil concentrations because of the known toxic effects of arsenic and nickel on plant growth[16]. The maximum acceptable annual and cumulative metal additions to soil under the Canadian regulations are more stringent than the limits adopted under the Biosolids Rule. Maximum acceptable cumulative metal additions to soil in Canada are based on the long term. For the purpose of evaluating individual products, Canadian standards define "long term" as 45 years.

Table 7. Cumulative pollutant loading limits (kg/ha) of sludge-treated soil in several countries and European Community (EC), and soil toxicological benchmarks (mg/kg) for screening potential contaminants established by Oak Ridge National Laboratory (ORNL), Canada, and the Netherlands (NETH).

Element	Cumulative Loading Limits					Toxicological Benchmarks		
	USA*	Canada**	EC***	France	NETH	ORNL	Canada	NETH
As	41	15	---	---	0	10 (20)§	20 (40)	40 (80)
Cd	39	4	1.25-6.25	3.75	1.25	3 (6)	3 (6)	12 (24)
Cu	1500	---	75-300	200	7.5	100 (200)	150 (300)	190 (380)
Cr	---	---	---	250	7.5	1 (2)	750 (1500)	230 (460)
Ni	420	36	12.5-125	62.5	3.8	30 (60)	150 (300)	210 (420)
Pb	300	100	0-625	125	22.5	50 (100)	375 (750)	290 (580)
Zn	2800	370	175-550	550	30	50 (100)	600 (1200)	720 (1440)
Hg	17	1	2.25-3.5	2.3	0.075	0.3 (0.6)	0.8 (1.6)	10 (20)
Co	---	30	---	---	---	20 (40)	40 (80)	240 (480)
Mo	---	4	---	---	---	2 (4)	5 (10)	<480 (<960)
Se	100	2.8	---	---	---	1 (2)	2 (4)	no data

§ Values in parentheses are kg/ha using a conversion factor of 2.
* Loading based on EPA Biosolids Rule and 100 year application.
** Loading based on 45 year application.
*** Application durations for the EC, France and the Netherlands are not available.
--- Not applicable or available.

The Canadian standards, expressed as maximum annual loading to soil, are presented in italics in the second row of Table 4. These values are derived from dividing Canada's maximum acceptable cumulative metal addition to soil standards by 45 years. Wood ash exceeds the Canadian annual metal addition to soil for arsenic, lead, zinc, and molybdenum. Since the application of wood ash may be limited to a one-time use, actual application of this product may not exceed the Canadian cumulative standards. Triple superphosphate exceeds the Canadian standards for cadmium. The two granular zinc samples exceed the Canadian standards for zinc; however, zinc is an intentional ingredient in these products because it is a micronutrient.

The standards for several European countries listed in Table 7 are in general more stringent than the Canadian standards. However, unlike the Canadian standards, the standards for the EC, France and the Netherlands apply to biosolids only and do not apply to fertilizers and liming agents. These standards are based on preventing pollutant accumulation in soil[17]. Documentation describing the technical basis for the different European standards, however, has been difficult to obtain. Therefore, conclusions about how fertilizer results provided in this report compare to standards provided for the EC, France and the Netherlands will not be made.

Screening soil benchmarks for phytotoxicity of metals shown in Table 7 include those developed by Oak Ridge National Laboratory (ORNL), Canada, and the Netherlands[18]. Although these benchmarks are not strictly comparable due to differences in derivation, phytotoxicity may result when metal concentrations in soil exceed any of these benchmarks. ORNL benchmarks are generally conservative, because soluble metal salts which were used in toxicity tests (e.g., field, greenhouse, growth chamber) are typically more bioavailable than indigenous metals in the soil. Canadian benchmarks take into account human health and, presumably, soil organisms as well as the entire food chain dependent upon the soil in an agricultural land-use context. Dutch benchmarks take into account plants, soil fauna, micro-organisms, bioavailability, and biomagnification and represent metal concentrations in soil causing adverse effects in 50% of the species potentially present in the ecosystem. Conversion of these benchmark concentrations (mg/kg) to loading limits (kg/ha), using certain assumptions (i.e., 15 cm mixing depth, 1.33 g/cc soil density), allows comparison to the cumulative loading limits in Table 7. Where cumulative loading limits exceed these converted toxicological benchmarks (shown in parentheses), toxicity may result.

Whenever possible, uniform regulations and standards between neighboring countries would promote better use of resources. Uniform regulations and standards may also prevent unfair trade advantages caused by unacceptable materials distributed to a country with less stringent regulations.

Effects of Fertilizer and Soil Amendments on Metals in Soil

The short-term impact of adding industrial and non-industrial by-products to soils and plants at recommended rates for metal concentrations may be limited. Long-term application of high concentrations of metals in micronutrients, micronutrient mixes, some phosphorus fertilizers, and some wood ash could potentially lead to substantial elevation of metals in soils and plants[19].

There is relatively little information on the effects of fertilizers on metal concentrations in soils and plants in Washington State; however, there has been much research conducted elsewhere that is summarized in the scientific literature. For example, continued application of phosphate fertilizer at high rates over a period of several decades resulted in soil cadmium concentrations being elevated 10-fold or more[20,21].

In Australia phosphate fertilizer and manure applications caused up to 27% of sampled leafy vegetables to have cadmium concentrations exceeding the maximum permitted concentration, 0.05 mg/kg, set by the Australia, New Zealand Food Authority[22].

A survey of cadmium, lead, zinc, copper, and nickel in agricultural soils in the U.S. found little evidence of significant accumulation of cadmium or lead in most cropland soils, although zinc and copper were both elevated by normal agricultural practices[23]. The authors attributed an increase of cadmium in the Great Lake states, as well as in some soils in Oregon, Florida, and Idaho, to the application of phosphate fertilizer and/or rock phosphate. In summary, given the range of concentrations for various elements in phosphate fertilizers, it is difficult to generalize about possible potential plant uptake from their use.

The direct link between increased soil metal concentrations and the use of soil amendments has been more clearly established for biosolids. Continued application of biosolids at low rates or at an initial high rate of application causes a marked increase in cadmium, chromium, copper, lead, nickel, and zinc in agricultural soils[24,25]. However, the addition of cadmium and lead from the application of phosphate fertilizer, or micronutrient or micronutrient mixes, is very small relative to the amounts of metals that are allowed to be added to soils annually via land application of biosolids[4] and other waste-derived products. It is entirely legitimate to question whether such a small addition can cause soil productivity and crop quality any harm.

Natural Background Metal Concentrations in Soil

Table 8 lists metal concentrations found in U.S. soils. These data are provided to show that many metals are commonly found in soils at a range of concentrations. Additionally, these concentrations may be compared to fertilizer metal concentrations reported in Table 3 for perspective. However, metal concentrations in Table 3 would need to be converted to concentrations of metals in soil in order to make this comparison meaningful. Several factors would need to be accounted for in converting Table 3 results to soil concentrations, such as fertilizer application rates and dilution from mixing with soil, contribution of metals from use of multiple fertilizer products, natural background metal concentrations already present in soil, and possible build-up of metals over time. Due to the limited nature of this screening study, metal concentrations in soils resulting from application of the fertilizer products tested were not estimated.

Table 8. The content of various elements in soils.

Element	Common range for soils (ppm)	Average concentrations for soils*
Al	10,000-300,000	71,000
As	1-50	5
B	2-100	10
Ba	100-3,000	430
Be	0.1-40	6
Ca	7,000-500,000	13,700
Cd	0.01-0.70	0.06
Co	1-40	8
Cr	1-1,000	100
Cu	2-100	30
Fe	7,000-550,000	38,000
Hg	0.01-0.3	0.03
I	0.1-40	5
K	400-30,000	8,300
Li	5-200	20
Mg	600-6,000	5,000
Mn	20-3,000	600
Mo	0.2-5	2
Na	750-7,500	6,300
Ni	5-500	40
Pb	2-200	10
Se	0.1-2	0.3
Sn	2-200	10
Ti	1,000-10,000	4,000
V	20-500	100
Zn	10-300	50

Source [26] *mg/kg or ppm

Table 9 illustrates the natural background concentrations of metals in surface soils in Washington[27]. Natural background soil metal concentrations can be used to establish a cleanup standard for a hazardous substance for which no applicable or relevant and appropriate requirement exists (Model Toxics Control Act [MTCA], WAC 173-340-700). The MTCA standards are useful for comparing with data on soil concentrations of metals. The comparison to MTCA standards will be made as the data from soil sampling become available. These data will be published as an addendum to this report.

Table 9. Statewide and regional 90th percentile values* for some elements in Washington State soils

	Al	As**	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Zn
Statewide	37,200	7	2	1	42	36	42,100	17	1,100	0.07	38	86
Puget Sound	32,600	7	0.6	1	48	36	58,700	24	1,200	0.07	48	85
Clark County	52,300	6	2	1	27	34	36,100	17	1,500	0.04	21	96
Yakima Basin	33,400	5	2	1	38	27	51,500	11	1,100	0.05	46	79
Spokane Basin	21,400	9	0.8	1	18	22	25,000	15	700	0.02	16	66

*All Values=mg/kg and represent total-recoverable analysis.

** Graphite furnace atomic absorption (GFAA) analysis.

Factors Affecting Metal Availability

The amount of metals added to soils is not the only factor that governs their bioavailability. Metal bioavailability and phytotoxicity thresholds are affected by metal solubility that is controlled by a variety of plant factors and intrinsic soil factors[28]. The solubility of metals in phosphate fertilizer, rock phosphate, and industrial by-products is largely unknown presently. To precisely understand the environmental hazard of an element in a fertilizer or soil amendment requires detailed knowledge of metal solubility in soil and its mobility in the environment[9].

The intrinsic soil factors that affect metal availability in soil include pH and the concentrations of metal, organic matter, clay, and aluminum, iron and manganese oxides in soil[12]. Fine textured soils and soils containing high amounts of organic matter and/or iron oxides have lower metal availability compared to coarse-textured soils or soil with low organic matter content[29,30]. Uptake of metals by plants also can be complicated by the presence of other metals in soil. For example, addition of zinc can reduce cadmium accumulation in wheat grain[31].

Generally, leafy vegetables are good metal accumulators, whereas roots and tubers generally are not[32]. As a result, leafy vegetables and food legumes are more susceptible to cadmium and zinc phytotoxicity than grain or grass crops[33,24].

Phosphate fertilizers, industrial by-products, and most soil amendments, with the exception of biosolids or compost, are essentially devoid of organic matter. Thus the protective effect of organic residues that limits metal availability in biosolids cannot be applicable to phosphate fertilizer, rock phosphate, and the industrial by-products used as a micronutrient source.
In this regard, the Biosolids regulations probably are not sufficiently protective of soils and plants

from being adversely affected by metal accumulation resulting from fertilizer application in soil. The more conservative Canadian standards could be used for regulating metals in the interim, until the protection is validated or until better criteria are developed.

Conclusions

This screening survey of metals in fertilizers found the highest concentrations of:

- *cadmium* in ammonium phosphate sulfate, triple superphosphate, micronutrient mix No. 2, rock phosphate, and granular zinc samples
- *lead* in micronutrient mix No. 2, kiln dust lime, and granular zinc samples
- *arsenic* in Boronat (micronutrient), micronutrient mix No. 2, kiln dust lime, and wood ash

Comparing the fertilizers at the maximum annual application rates indicates the highest annual loading for:

- *cadmium* from triple superphosphate, and ammonium phosphate sulfate
- *lead* from wood ash, kiln dust lime, and granular zinc No. 1
- *arsenic* from wood ash, kiln dust lime, and Boronat (micronutrient)

Wood ash was the only product that exceeded the annual loading for exceptional quality biosolids. Wood ash and triple superphosphate were the only products that exceeded the Canadian standards. It will be critical to address whether or not elevated metal accumulation in soil over time is of concern to crop productivity and whether or not the Canadian or biosolids standards are sufficiently protective.

The concentration of metals in several waste-derived fertilizers (granular zinc samples and micronutrient mix No. 2) and non-waste-derived fertilizers (Boronat, ammonium polysulphate, triple superphosphate, liquid ammonium phosphate, suspension phosphate, phosphoric acid, ammonium phosphate sulphate, and rock phosphate) may be of concern with respect to the Land Disposal Restrictions. However, only those fertilizer products derived from certain hazardous wastes are subject to these standards. The two granular zinc products are derived from hazardous waste; however, granular zinc No. 1 which contains the higher concentrations of metals is not subject to the Land Disposal Restrictions because of an exclusion. The wide range of standards that apply to fertilizers indicates that uniform risk-based standards should be developed.

Tag-along metals are found in both waste-derived and non-waste-derived fertilizers. The highest concentration of arsenic is found in the non-waste-derived fertilizer Boronat (micronutrient). The non-waste-derived fertilizer triple superphosphate is projected to have the highest annual loading for cadmium. The data indicate that standards for metals in fertilizers should apply to both waste-derived and non-waste-derived fertilizers.

Washington State is comprised of diverse soil and environmental conditions. Eastern Washington soils are mostly calcareous and/or alkaline, whereas western Washington soils are typically acidic. Bioavailability of heavy metals is highly sensitive to pH and other soil characteristics such as organic matter and clay contents, so that the uptake of metals by a crop may vary considerably among regions and soil types. This variability, along with different sensitivities of crops to pH and heavy metal content in soil, and varied solubilities of metals in fertilizers and industrial by-products, will require a comprehensive study in order to gather sufficient scientific information for the agencies to regulate fertilizers.

Recommendations

Based on the data from this survey, the Interagency Fertilizer Testing Workgroup endorses the following actions previously set forth by Governor Gary Locke and agency directors.

- **Continue Product Sampling**

  To date, 55 fertilizer products have been tested for metals. More testing on different sources are needed. An ongoing sampling program should be established by the Washington State Department of Agriculture (WSDA) to monitor fertilizers for metals; this would provide data for developing and implementing regulations. Both random and targeted samples should be collected. Some of the targeted samples should include fertilizers from out of state that are made from industrial by-products to see if they meet the Land Disposal Restriction (LDR) standards.

  The Washington State Department of Ecology should test other fertilizers, soils and soil amendments to determine if dioxins and other organic substances are present in these substances, and, if so, at what level.

- **Conduct Field Soil and Plant Sampling**

  Sampling of fields in the Columbia Basin and western Washington should be conducted for the purpose of evaluating the concentrations of metals in the soil within the root zone. The purpose of the sampling would be to evaluate the concentrations of metals in the soils compared to statewide background values. Crops grown on the fertilized fields could also be sampled.

- **Adopt Canadian Standards for All Fertilizer Products**

  WSDA should seek legislative authority to adopt the Canadian standards on an interim basis that would apply to all fertilizer, not just recycled fertilizer. Canadian limits are more applicable than the Biosolids standards.

- **Sustain Efforts on National Standards**

  Washington State should work closely with the federal agencies in the development of national risk-based standards. Such standards would provide equal standing for all fertilizer manufacturers (since both recycled fertilizers and non-recycled fertilizers can contain metal contaminants) and eliminate the considerable difficulties inherent in defining a "by-product" and identifying the source of the raw materials in fertilizer products manufactured outside the state of Washington.

- **Conduct Comprehensive Field and Crop Study**

A comprehensive study of plant uptake of metals and comparison to various standards is recommended. The California Department of Food and Agriculture effort and the literature would be reviewed; and a team of scientists in cooperation with Washington State Department of Health, Department of Ecology, and Department of Agriculture would experiment growing multiple crops using several different types of "recycled" fertilizers and at different application rates. These field and laboratory studies would be performed using different soil types representing the west and east sides of the state under a range of soil conditions. Laboratory studies should be conducted to determine the solubility of contaminants in various products as a function of soil type, pH and time. The intent would be to determine the appropriate standards for regulating fertilizers.

References

[1] AAPFCO. 1997. Commercial Fertilizers. Association of American Plant Food Control Officials.

[2] National Research Council. 1989. Recommended Dietary Allowances, Tenth Edition. National Academy Press.

[3] Campbell, K.B. et al. 1995. Western Fertilizer Handbook, Eighth Edition. Soil Improvement Committee California Fertilizer Assn, Interstate Publishers, Inc., Danville, IL.

[4] USEPA. 1993. Standards For The Use Or Disposal Of Sewage Sludge. Fed. Reg. 58(32): 9248-9415.

[5] Goyer, R.A. 1996. Casarett and Doull's Toxicology, Fifth Edition, Chapter 23. Klaassen, C.D., M.O. Amdur, and J. Doull, eds., McGraw-Hill Publishers.

[6] Wolnik, K.A., F. L. Fricke, S.B. Capar, G.L. Braude, M.W. Meyer, R.D. Satzger, and E. Bonnin. 1983. *Elements in Major Raw Agricultural Crops in the United States. 1.Cadmium and Lead in Lettuce, Peanuts, Potatoes, Soybeans, Sweet Corn, and Wheat.* J. of Ag. Food Chemistry, 31: 1240-1244.

[7] Dorsey, K. 1997. Personal communication. Washington State Department of Ecology.

[8] USEPA. 1992. The Technical Support Document for Land Application of Sewage Sludge. EPA 822/R-93-001a and 001b.

[9] Raven, K.P. and R.H. Loeppert. 1997. *Trace Element Composition Of Fertilizers And Soil Amendments.* J. Environ. Qual. 26:551-557.

[10] SETAC. 1997. ORNL *Evaluates Land Application Of Sewage Sludge*. SETAC News 17(3):22.

[11] Kabata-Pendias, A. and H. Pendias. 1992. Trace Elements in Soils and Plants, Second Edition. CRC Press.

[12] Kuo, S., and J.B. Harsh. 1977. *Physiochemical Characterization of Metals in Soil and Their Plant Availability*. In Adriano, D.C. et al (ed.) Biogeochemistry of Trace Metals. Science Reviews, Northwood, U.K. p.75-120.

[13] McBride, M.B. 1995. *Toxic Metal Accumulation From Agricultural Use Of Sludge; Are USEPA Regulations Protective?* J. Environ. Qual. 24:5-18.

[14] Blair, D. 1997. Personal communication. Fertilizer Section, Canadian Food Inspection Agency.

[15] Agriculture and Agri-Food Canada. 1996. Support Document for Compost Quality Criteria – National Standard of Canada, CAN/BNQ 0413-200

[16] Ontario Ministry of Agriculture and Food. 1981. Guidelines for Sewage Sludge Utilization on Agricultural Lands, Ontario Ministry of the Environment.

[17] Chang, A.C., A.L. Page, and T. Asano. 1995. Developing Human Health-Related Chemical Guidelines for Reclaimed Wastewater and Sewage Sludge Application in Agriculture. World Health Organization, Geneva, Switzerland.

[18] Will, M.E. and G.W. Suter II. 1995. Toxicological Benchmarks For Screening Potential Contaminants Of Concern For Effects On Terrestrial Plants, 1995 Revision. Oak Ridge National Laboratory, TN.

[19] Mortvedt, J.J. 1985. *Plant Uptake Of Heavy Metals In Zinc Fertilizers Made From Industrial By-Products.* J. Environ. Qual. 14:424-427.

[20] Mulla, D.J., A.L. Page, and T.J. Canje. 1980. *Cadmium Accumulations And Bioavailability In Soils From Long-Term Phosphorus Fertilization.* J. Environ. Qual. 9:408-412.

[21] Williams, C.H. and D.J. David. 1973. *The Effect Of Superphosphate On The Cadmium Content Of Soils And Plants.* Aust. J. Soil Res. 11:43-56.

[22] Jinadasa, K.B.P.N., P.J. Milham, C.A. Hawkins, P.S. Cornish, P.A. Williams, C.J. Kaldor, and J.P. Conroy. 1997. *Survey Of Cadmium Levels In Vegetables And Soils Of Greater Sydney, Australia.* J. Environ. Qual. 26:924-933.

[23] Holmgren, G.G.S., M.W. Meyer, R.L. Chaney, and R.B. Daniels. 1993. *Cadmium, Lead, Zinc, Copper, And Nickel In Agricultural Soils Of The United States Of America.* J. Environ. Qual. 22:335-348.

[24] Berti, W.R. and L.W. Jacobs. 1996. *Chemistry And Phytotoxicity Of Soil Trace Elements From Repeated Sewage Sludge Applications.* J. Environ. Qual. 25:1025-1032.

[25] Sloan, J.J., R.H. Dowdy, M.S. Dolan, and D.R. Linden. 1997. *Long-Term Effects Of Biosolid Applications On Heavy Metal Bioavailability In Agricultural Soils.* J. Environ. Qual. 26:966-974.

[26] Lindsay, W.L. 1979. Chemical Equilibrium in Soils. John Wiley & Sons, New York, NY.

[27] San Juan, C. 1994. Natural Background Soil Metals Concentrations in Washington State. Ecology Publication 94-115.

[28] Schmidt, J.P. 1997. *Understanding Phytotoxicity Thresholds For Trace Elements In Land-Applied Sewage Sludge.* J. Environ. Qual. 26:4-10.

[29] Bjerre, G.K. and H.H. Schierup. 1985. *Uptake Of Six Heavy Metals By Oat As Influenced By Soil Type And Additions Of Cadmium, Lead, Zinc, And Copper.* Plant Soil 88:57-69.

[30] Kuo, S., E.J. Jellum, and A.S. Baker. 1985. *Effect Of Soil Type, Liming, And Sludge Application On Zinc And Cadmium Availability To Swiss Chard.* Soil Sci. 139:122-130.

[31] Oliver, D.P., R. Hannam, K.G. Tiller, N.S. Wilhelm, R.H. Merry, and G.D. Cozens. 1994. *The Effects Of Zinc Fertilization On Cadmium Concentration In Wheat Grain.* J. Environ. Qual. 23:705-711.

[32] Dowdy, R.H. and W.E. Larson. 1975. *The Availability Of Sludge-Borne Metals To Various Vegetable Crops.* J. Environ. Qual. 4:278-282.

[33] Kim, S.J., A.C. Chang, A.L. Page, and J.E. Warneke. 1988. *Relative Concentrations Of Cadmium And Zinc In Tissue Of Selected Plants Grown On Sludge-Treated Soils.* J. Environ. Qual. 17:568-573.

Additional References

Agriculture and Agri-Food Canada. 1996. Standards for metals in fertilizers and supplements. Agriculture and Agri-Food Canada, Ontario, Canada.

Anderson, A., and K.O. Nilsson. 1974. *Influence Of Lime And Soil pH On Cd Availability To Plants.* Ambio 3:198-200.

Chang, A.C. 1987. *Long-Term Sludge Applications On Cadmium And Zinc Accumulation In Swiss Chard And Radishes.* J. Environ. Qual. 16:217-221.

Chang, A.C., Hae-nam Hyun, and A.L. Page. 1997. *Cadmium Uptake For Swiss Chard Grown On Composted Sewage Sludge Treated Field Plots: Plateau Or Time Bomb?* J. Environ. Qual. 26:11-19.

Czuba, M. and T.C. Hutchinson. 1980. *Copper And Lead Levels In Crops And Soils Of The Holland Marsh Area - Ontario.* J. Environ. Qual. 9:566-575.

Heckman, J.R., J.S. Angle, and R.L. Chaney. 1987. *Residual Effects Of Sewage Sludge On Soybeans. I. Accumulation Of Heavy Metals.* J. Environ. Qual. 16:113-117.

John, M.K. 1972. *Cadmium Adsorption Maxima Of Soils As Measured By The Langmuir Isotherm.* Can. J. Soil Sci. 52:343-350.

King. L.D. 1988. *Effects Of Selected Soil Properties On Cadmium Content Of Tobacco.* J. Environ. Qual. 17:251-255.

McVickar, M.H. and W.M. Walker. 1978. Using Commercial Fertilizers, Fourth Edition. The Interstate Printers and Publishers, Inc., Danville, IL.

Meister, R.T., 1997. Farm Chemicals Handbook '97, Meister Publishing Company, 37733 Euclid Avenue, Willoughby, OH 44094-5992.

Padmore, J.D., 1996. Official Publication Association Of American Plant Food Control Officials (AAPFCO), #49. Published by AAPFCO, Inc., West Lafayette, IN.

Sims, J.T. 1986. *Soil pH Effects On The Distribution And Plant Availability Of Manganese, Copper, And Zinc.* Soil Sci. Soc. Am. J. 50:367-373.

Sommers, L.E. 1980. *Toxic Metals In Agricultural Crops.* p. 105-140. In G. Bitton et al. (ed.). Sludge-Health Risks Of Land Application. Ann Arbor Sci. Ann Arbor, MI.

Appendices

Appendix A

1995 - 96 Annual Tonnage Report
Commercial Fertilizers including Liming Agents

Washington State Department of Agriculture, Pesticide Management Division, PO Box 42560, Olympia WA. 98504-2560.

	JULY 1 THRU DECEMBER 1995	JANUARY 1 THRU JUNE 1996	1995 - 96 CROP YEAR TOTAL
NITROGEN MATERIALS		Quantities Sold (tons)	
AMMONIA, ANHYDROUS	39,715	41,862	81,577
AMMONIA, AQUA	56,981	77,970	134,951
AMMONIUM NITRATE	18,227	32,862	51,089
AMMONIUM NIT-SULFATE	134	1,037	1,171
AMMONIUM POLYSULFIDE	5,118	7,315	12,433
AMMONIUM SULFATE	13,120	38,491	51,611
AMMONIUM THIOSULFATE	16,400	23,128	39,528
CALCIUM AMMONIUM NITRATE	1,011	1,065	2,076
CALCIUM NITRATE	5,008	8,467	13,475
NITROGEN SOLUTION <28%N	2,632	6,402	9,034
NITROGEN SOLUTION 32%N	58,025	80,586	138,611
UREA	24,039	46,911	70,950
OTHER	11,221	24,543	35,764
TOTAL	**251,631**	**390,639**	**642,270**

PHOSPHATE MATERIALS			
AMMONIUM METAPHOSPHATE	3,277	5,007	8,284
AMMONIUM PHOSPHATE	0	353	353
DIAMMONIUM PHOSPHATE	3,757	6,656	10,413
AMMONIUM POLYPHOSPHATE	3,203	0	3,203
AMMONIUM PHOS SULFATE	11,897	17,681	29,578
MONOAMMONIUM PHOSPHATE	11,587	29,413	41,000
BONE MEAL, STEAMED	168	206	374
NITRIC PHOSPHATE	498	1,896	2,394
PHOSPHATE ROCK	0	39	39
PHOSPHORIC ACID	2,530	557	3,087
LIQUID AMM POLYPHOSPHATE	17,584	20,107	37,691
SUPERPHOSPHATE, TRIPLE	1,964	2,993	4,957
OTHER	2,501	9,378	11,879
TOTAL	**58,966**	**94,286**	**153,252**

POTASH MATERIALS	JULY 1 THRU DECEMBER 1995	JANUARY 1 THRU JUNE 1996	1995 - 96 CROP YEAR TOTAL
	Quantities Sold (tons)		
POTASH SUSPENSIONS	2,414	2,031	4,445
MURIATE OF POTASH 60%	22,462	41,511	63,973
POTASSIUM-MAGNESIUM SULFATE	2,165	6,826	8,991
POTASSIUM NITRATE	40	36	76
POTASSIUM SULFATE	2,270	6,626	8,896
OTHER	11,425	4,328	15,753
TOTAL	**40,776**	**61,358**	**102,134**

SECONDARY/MICRO MATERIALS			
ALUMINUM SULFATE	1,899	19	1,918
BORAX (BORON AS BORAX)	1,152	2,339	3,491
COPPER SULFATE	31	58	89
COPPER CHELATES	7	19	26
FERRIC SULFATE	0	3,493	3,493
FERROUS SULFATE	560	599	1,159
IRON CHELATES	43	113	156
GYPSUM (CALCIUM SULFATE)	12,407	10,106	22,513
MAGNESIUM SULFATE (EPSOM SALT)	388	862	1,250
MAGNESIUM CHELATES	3	32	35
MANGANESE CHELATES	24	81	105
MANGANESE SULFATE	0	250	250
MOLYBDENUM SALTS	0	22	22
SULFUR	2,978	4,177	7,155
ZINC OXIDE	364	0	364
ZINC SULFATE	1,597	1,903	3,500
ZINC CHELATES	227	563	790
OTHER	4,970	4,955	9,925
TOTAL	**26,650**	**29,591**	**56,241**

LIMING MATERIALS	JULY 1 THRU DECEMBER 1995	JANUARY 1 THRU JUNE 1996	1995 - 96 CROP YEAR TOTAL
	Quantities Sold (tons)		
CAL HYDROXIDE (HYDRATE)	1,243	551	1,794
STANDARD DOLOMITE	5,241	8,718	13,959
STANDARD CALCITE	6,909	5,923	12,832
OTHER	33,219	21,486	54,705
TOTAL	**46,612**	**36,678**	**83,290**

NATURAL ORGANIC MATERIALS

BLOOD, DRIED	35	123	158
COMPOST	0	924	924
COTTONSEED MEAL	3	69	72
FISH SCRAP	287	90	377
GUANO	0	2	2
MANURE	4,043	13,427	17,470
OTHER	3,193	8,754	11,947
TOTAL	**7,561**	**23,389**	**30,950**

MISCELLANEOUS MATERIALS

GRADE 6-10-4	9	1,127	1,136
GRADE 8-16-29	38	817	855
GRADE 9-0-0-10S	1,808	1,604	3,412
GRADE 10-20-20	920	364	1,284
GRADE 11-19-23	0	1,094	1,094
GRADE 13-7-20	726	0	726
GRADE 15-2-4	45	363	408
GRADE 20-0-0-24S	124	1,248	1,372
GRADE 16-16-16	357	621	978
GRADE 20-2-5	13	571	584
GRADE 21-3-5	244	2,802	3,046
GRADE 30.5-0-0-6S	0	1,288	1,288
GRADE 33-0-0-12S	0	865	865
MISC PRODUCT	41,863	84,566	126,429
TOTAL	**46,147**	**97,330**	**143,477**

GRAND TOTALS

	JULY 1 THRU DECEMBER 1995	JANUARY 1 THRU JUNE 1996	1995 - 96 CROP YEAR TOTAL
	Quantities Sold (tons)		
PERIOD TOTAL FOR FERTILIZER MATERIALS	431,731	696,593	1,128,324
PERIOD TOTAL FOR LIMING MATERIALS	46,612	36,678	83,290
GRAND TOTALS FOR YEAR	**478,343**	**733,270**	**1,211,614**

Appendix B

Concentrations of Metals in 19 Archive Fertilizer Samples, mg/kg (ppm)*

Material		Metals regulated under EPA Biosolids Rule									Metals not regulated under EPA Biosolids Rule				
		As	Cd	Cu	Pb	Hg	Mo	Ni	Se	Zn	Al	Sb	B	Ba	Be
Fertilizers	**Reported Application Rate, kg/ha**														
Nitro Cal 21-0-0	134	1 U	1 U	2 U	20 U	0.2 U	2 U	10 U	NT	16	708	10 U	11	7	1 U
34-0-0	267	1 U	1 U	7	20 U	0.2 U	2 U	10 U	NT	2	10 U	10 U	10 U	1 U	1 U
CM 39-0-0-6	283	1 U	1 U	2 U	20 U	0.2	2 U	10 U	NT	4	24	10 U	67	1 U	1 U
CM 37-0-0-7	241	1 U	1 U	2 U	20 U	0.2	2 U	10 U	NT	4	20	10 U	2780	1 U	1 U
CM 23-11-13	1149	10	3	4	20 U	0.2 U	3	10 U	NT	2990	2060	10 U	1180	2	1
CM 4-15-34	407	9	6	36	313	0.2 U	4	10 U	NT	6270	2610	10 U	6150	4	2
CM 28-0-7	586	1 U	1 U	2 U	20 U	0.2 U	2 U	10 U	NT	150	240	10 U	1720	1 U	1 U
CM 27-0-14	492	1 U	1 U	2 U	20 U	0.3	2 U	10 U	NT	12	30	10 U	1600	1 U	1 U
CM 31-10-0	N/A	1 U	20	11	20 U	0.3	4	33	NT	972	1700	10 U	6100	1	1
CM 37-0-0	N/A	1 U	1 U	2 U	20 U	0.4	2 U	10 U	NT	12	14	10 U	2910	1 U	1 U
CM 27-0-8	N/A	1 U	1 U	2 U	20 U	0.2 U	2 U	10 U	NT	24	354	10 U	23	1 U	1 U
CM 18-8-0	356	2	25	9	20 U	0.2 U	3	45	NT	366	3070	10 U	47	10	1 U
CM 15-40-0	178	1 U	1	18	20 U	0.2 U	5	20	NT	67	6290	10 U	113	16	1
CM 28-9-9	472	10	1 U	53	20 U	0.2 U	3	10 U	NT	3530	1550	10 U	65	3	1
CM 5.6-21.4-21.5	333	10	4	18	20 U	0.2 U	6	11	NT	6000	3270	13	5110	47	2
16-20-0-14	178	1 U	13	7	24	0.2 U	6	15	NT	5430	1280	10 U	139	4	2
CM 14-15-21	N/A	1 U	34	46	346	0.2 U	4	39	NT	3730	2810	10 U	1320	4	1
CM 10-18-25	1223	2	56	42	300	0.2 U	6	54	NT	3640	3570	10 U	2420	3	2
CM 5-23-23-6	261	4	15	19	20 U	0.2 U	7	17	NT	6800	2520	10 U	8930	29	2

* Collected in 1993 and 1994 as part of the WSDA routine sampling for guaranteed analysis.

N/A: Not applicable

CM: Customer Mix

U: The analyte was not detected at or above the listed numerical value.

NT: Not tested

Concentrations of Metals in 19 Archive Fertilizer Samples, mg/kg (ppm)* - continued

	Metals not regulated under EPA Biosolids Rule														
Material	Ca	Co	Cr	Fe	Mg	Mn	P	K	Ag	Na	Sr	Tl	Ti	V	Sn
Custom Mix															
Nitro Cal 21-0-0	98900	2 U	2	501	6290	20	232	480	2 U	447	512	NT	10	2 U	10 U
34-0-0	41	2 U	2 U	8	9	1 U	28	400 U	2 U	20 U	1 U	NT	2 U	2 U	10 U
CM 39-0-0-6	60	2 U	2 U	30	11	1 U	214	1410	2 U	133	1 U	NT	2 U	2 U	10 U
CM 37-0-0-7	45	2 U	2 U	43	11	1 U	231	5180	2 U	3270	1 U	NT	2 U	2 U	10 U
CM 23-11-13	849	3	97	2260	959	234	48400	115000	2 U	4130	11	NT	16	93	10 U
CM 4-15-34	1940	2 U	132	4710	1040	491	62600	301000	2 U	16500	14	NT	22	96	15
CM 28-0-7	242	2 U	5	212	81	15	2660	67500	2 U	3890	2	NT	2 U	5	10 U
CM 27-0-14	517	2 U	2	37	45	3	646	128000	2 U	2530	2	NT	2 U	3	10 U
CM 31-10-0	946	2 U	106	1550	815	68	47500	1280	2 U	6880	18	NT	16	166	10 U
CM 37-0-0	30	2 U	2 U	26	9	1	348	400 U	2 U	3220	1 U	NT	2 U	2 U	10 U
CM 27-0-8	57	2 U	2 U	41	83	2	289	53600	2 U	319	1 U	NT	2 U	2 U	10 U
CM 18-8-0	119000	2 U	73	1960	8610	44	36100	800	2 U	1610	470	NT	24	176	10 U
CM 15-40-0	5660	2 U	469	3760	9920	91	180000	1800	2 U	2630	49	NT	53	33	14
CM 28-9-9	1310	2 U	84	1920	526	298	44600	62400	2 U	2450	12	NT	12	73	10 U
CM 5.6-21.4-21.5	1210	2 U	147	4180	1520	352	87300	173000	2 U	11200	17	NT	64	119	10 U
16-20-0-14	2780	2 U	90	2820	2650	402	82600	3050	2 U	1780	73	NT	165	30	10 U
CM 14-15-21	3090	2 U	191	4190	3480	269	71100	183000	2 U	3450	31	NT	28	119	14
CM 10-18-25	1820	2 U	235	4860	2320	267	77400	218000	2 U	4090	27	NT	48	350	10 U
CM 5-23-23-6	2540	2 U	138	4230	3370	484	116000	197000	2 U	16200	60	NT	189	67	10 U

* Collected in 1993 and 1994 as part of the WSDA routine sampling for guaranteed analysis.

N/A: Not applicable

CM: Customer Mix

U: The analyte was not detected at or above the listed numerical value.

NT: Not tested

Appendix C

Product Information

AG LIME
Generic Name: Ag lime
Industry Or Common Name: Dical lime
Chemical Characteristics: Product guarantee is 33% calcium, 82.5% calcium carbonate, 2% magnesium and 7% magnesium carbonate. The calcium component of Dical lime is derived from calcium silicate, calcium hydroxides and calcium oxide. The magnesium component is derived from magnesium hydroxide and magnesium oxide. The calcium carbonate equivalent of the product is 94%.
Agronomic Or Horticultural Information: In Eastern Washington, Dical lime is used as a soil amendment and for soil neutralization. Dical lime is incorporated into the soil or topdressed in the spring or fall at an application rate of 2240 to 8960 kg/ha (2000 to 8000 lb/ac).
Sample Number: H2529
Sample Name: Dical lime
State Or Country Of Origin: Washington
By-Product Information: By-product of magnesium ore extraction from dolomite deposits.

AMMONIUM NITRATE
Generic Name: Ammonium nitrate
Industry Or Common Name: Ammonium nitrate
AAPFCO Definition[1]: Ammonium nitrate is chiefly the ammonium salt of nitric acid. It shall contain not less than 33% nitrogen, one half of which is the ammonium form and one half in the nitrate form. (Official 1951)
Chemical Characteristics: Product guarantee is 34.5-0-0.
Manufacturing Information: Ammonium nitrate is manufactured by reacting nitric acid with anhydrous ammonia and removing all of the water. The final product is concentrated, prilled or granulated, and coated to prevent caking.
Agronomic Or Horticultural Information: In Western Washington, ammonium nitrate is applied in the summer *as a sidedress fertilizer for spinach and corn. The application rate is 112 to 168 kg/ha (100 to 150 lb/ac). Ammonium nitrate may also be used on pasture at an application rate of 151 kg/ha (135 lb/ac).
Sample Number: H4771
Sample Name: Ammonium nitrate
State Or Country Of Origin: Washington

AMMONIUM PHOSPHATE SULFATE
Generic Name: Ammonium phosphate-sulfate
Industry Or Common Name: Ammonium phosphate-sulfate
AAPFCO Definition: Ammonium phosphate-sulfate (fertilizer grade) is a product obtained when a mixture of phosphoric acid and sulfuric acid is treated with ammonia. It consists principally of a mixture of ammonium phosphate and ammonium sulfate. The guaranteed percentages of nitrogen and of Available Phosphate shall be stated as a part of the name. (Official 1993)
Chemical Characteristics: Ammonium phosphate-sulfate is a double salt of ammonium phosphate and ammonium sulfate or a mixture of these two salts. It is a free running granular fertilizer; green, light gray or dark gray in color; and readily soluble in water. Product guarantee is 16-20-0-with 14% sulfur. The nitrogen is derived from ammoniacal nitrogen. The phosphoric acid is derived from ammonium phosphate and the sulfur is derived from ammonium sulfate and gypsum.

1) Padmore, J.D. et al, 1997. Official Publication - Association of American Plant Food Control Officials (AAPFCO), #50. Published by AAPFCO, Inc., West Lafayette, IN.

Manufacturing Information: Ammonium phosphates are produced by reacting phosphoric acid in a preneutralization vessel and further ammoniating the slurry in a rotating ammoniation-granulation unit. Ammonium phosphate consists principally of monoammonium phosphate and/or diammonium phosphate. Additional sulfuric acid is introduced into the ammoniation-granulation unit to make ammonium phosphate-sulfate.
Agronomic Or Horticultural Information: Monoammonium phosphate and ammonium phosphate, components of ammonium phosphate-sulfate, are readily soluble in water. The other components are only slightly soluble in water. In Central and Eastern Washington, ammonium phosphate-sulfate is typically applied to wheat ground with seed as a starter fertilizer at an application rate of 112 kg/ha (100 lb/ac). It may also applied in the fall at an application rate of 224 to 280 kg/ha (200 to 250 lb/ac).
Sample Number: H2532 **State Or Country Of Origin:** Idaho
Sample Name: Ammonium phosphate-sulfate

AMMONIUM PHOSPHATE SUSPENSION

Generic Name: Ammonium phosphate
Industry Or Common Name: Suspension phosphate
AAPFCO Definition: Ammonium Phosphate (fertilizer grade) is a product obtained when phosphoric acid is treated with ammonia (anhydrous or aqueous), and consists principally of monoammonium phosphate and diammonium phosphate or a mixture of these two salts. The guaranteed percentage of nitrogen and of available phosphate shall be stated as part of the name. (Official 1993)
A suspension fertilizer is a fluid containing dissolved and undissolved plant nutrients. The suspension of the undissolved plant nutrients may be inherent with the materials or produced with the aid of a suspending agent of non-fertilizer properties. Mechanical agitation may be necessary in some cases to facilitate uniform suspension of undissolved plant nutrients. (Official 1970)
Chemical Characteristics: Product grade is 10-30-0.
Manufacturing Information: Ammonium phosphate suspension is made by combining an ammonium gas in a reactor with phosphoric acid. The resulting product is mixed with a suspending agent (usually clay).
Agronomic Or Horticultural Information: In Central Washington, ammonium phosphate suspension is spray applied by ground rig on alfalfa and timothy hay at an application rate of 1.5 to 12.3 lit/ha (1 to 8 gal/ac).
Sample Number: H2574 **State Or Country Of Origin:** Washington
Sample Name: Suspension phosphate

AMMONIUM POLYPHOSPHATE

Generic Name: Ammonium polyphosphate
Industry Or Common Name: APP, "10-34"
AAPFCO Definition: Polyphosphates is a general term pertaining to salts of any of a series of polyphosphoric acids, whose molecular structure contain two or more phosphorous atoms linked by oxygen. Solutions may contain several species such as orthophosphates, pyrophosphates, and polyphosphates containing three or more phosphorus atoms, commonly known as tripolyphosphates or tetrapolyphosphates and water. (Official 1976)
Chemical Characteristics: Ammonium polyphosphate is a liquid with a product grade of 10-34-0. Nitrogen is derived from ammonium polyphosphate and phosphorous is derived from phosphoric acid.
Manufacturing Information: Ammonium polyphosphate is manufactured by ammoniation of superphosphoric acid or by thermal dehydration of ammonium orthophosphate.
Agronomic Or Horticultural Information: In Central Washington, soft white winter wheat may require from 45 kg/ha (40 lb/ac) to 269 kg/ha (240 lb/ac) of nitrogen in the spring. Winter wheat requires fall placement at similar rates. The application rates are dependent on wheat variety, previous cropping schedule, rainfall, soil type, organic matter, soil pH, and soil test results. Used as a phosphate source, ammonium polyphosphate is applied at an application rate of 186.6 lit/ha (121.8 gal/ac).
Sample Number: H2546 **State Or Country Of Origin:** Washington
Sample Name: Ammonium polyphosphate

AMMONIUM SULFATE

Generic Name: Sulfate of ammonia

Industry Or Common Name: Ammonium sulfate

AAPFCO Definition: Sulfate of ammonia (ammonium sulfate) is chiefly the ammonium salt of sulfuric acid. It shall contain not less than twenty and five tenths percent (20.5%) nitrogen. (Official 1951)

Chemical Characteristics: Product guarantee is 21-0-0 with 24% sulfur.

Manufacturing Information: Ammonium sulfate is manufactured in a neutralizer-crystallizer unit by reacting anhydrous ammonia with sulfuric acid.

Agronomic Or Horticultural Information: Sulfate of ammonia is one of the oldest forms of solid nitrogen fertilizer. In Western Washington, it is broadcast at an application rate of 224 kg/ha (200 lb/ac) as part of a fertilizer blend for pasture, corn and turf ground.

Sample Number: H4769 **State Or Country Of Origin:** Canada

Sample Name: Ammonium sulfate

AQUA AMMONIA

Generic Name: Anhydrous ammonia dissolved in water

Industry Or Common Name: **Aqua 20-0-0,** ammonia liquor, aqua ammonia

AAPFCO Definition: Aqua ammonia is an aqueous solution of anhydrous ammonia generally containing from 18 to 30 % of ammonia (NH_3) by weight and having a vapor pressure usually varying from 0 to 10 psi at 104 degrees Fahrenheit.

Chemical Characteristics: Product grade is 20-0-0. Under normal temperatures, aqua ammonia has some free ammonia but the vapor pressure is low. To minimize the loss of nitrogen, aqua ammonia should be injected below the soil surface or under the water surface when applied in a water run. The pH value of aqua ammonia is highly alkaline.

Manufacturing Information: Anhydrous ammonia is dissolved in water to form aqua ammonia.

Agronomic Or Horticultural Uses: Aqua ammonia may be stored in non-pressure storage and is compatible with ammonium polysulfide, ammonium thiosulfate, potash solution, pesticides and some micronutrients. Aqua ammonia is applied in the spring on dry land grain crops. The application rates should provide 34 to 67 kg/ha (30 to 60 lb/ac) of nitrogen.

Sample Number: H0752 **State Or Country Of Origin**: Washington

Sample Name: Aqua ammonia

CALCIUM AMMONIUM NITRATE

Generic Name: Calcium ammonium nitrate

Industry or Common Name: CAN 17

Chemical Characteristics: Calcium ammonium nitrate is a clear, aqueous solution of calcium nitrate and ammonium nitrate. Product guarantee is 17-0-0 with 8.8% calcium. The total nitrogen guarantee (17%) is comprised of 5.8% ammoniacal nitrogen and 11.6% nitrate nitrogen.

Manufacturing Information: Calcium ammonium nitrate is produced by the acidulation of limestone with nitric acid. Acidic calcium nitrate liquor is neutralized with ammonia and the nitrogen content is adjusted by the addition of ammonium nitrate.

Agronomic or Horticultural Information: Calcium ammonium nitrate is used as a supplemental source of nitrogen and calcium for fruit, vegetable and field crops. Calcium ammonium nitrate provides a readily available source of calcium and is used extensively in the western United States. In Washington State, calcium ammonium nitrate is applied at an application rate of 17.9 to 23.8 lit/ha (12 to 16 gal/ac).

Sample Number: H1233 **State or Country of Origin:** Washington

Sample Name: Calcium ammonium nitrate

CALCIUM NITRATE
Generic Name: Nitrate of lime
Industry Or Common Name: Calcium nitrate
AAPFCO Definition: Chiefly the calcium salt of nitric acid. It shall contain not less than 15 % nitrate nitrogen. (Official 1951)
Chemical Characteristics: Calcium nitrate is derived from hydrated ammonium calcium nitrate double salt. It is a is a white, hygroscope, granular and water soluble product. Product guarantee is 15.5-0-0 with 19% calcium. The total nitrogen guarantee (15.5%) is comprised of 1% ammoniacal nitrogen and 14.5% nitrate nitrogen.
Manufacturing Information: Calcium nitrate is a co-product resulting from nitric acid being reacted with crushed phosphate ore. The resulting solution is neutralized with ammonia, separated and concentrated through successive evaporation and filtration. The final product is granulated and coated to reduce moisture absorption during storage, handling and application. Calcium nitrate may be used in the manufacture of calcium ammonium nitrate solution.
Agronomic Or Horticultural Information: Calcium nitrate is commonly applied in the spring at an application rate of 56 to 112 kg/ha (50 to 100 lb/ac). In Central Washington, calcium nitrate may be used on all crops except mint and mature alfalfa.
Sample Number: H0754 **State Or Country Of Origin:** Norway
Sample Name: Calcium nitrate

CALCIUM SODIUM BORATE
Generic Name: Calcium sodium borate
Industry Or Common Name: Boronat
Chemical Characteristics: The primary source for calcium sodium borate is dry lake beds as ulexite ore. The boron content of ulexite ores is 9 to 10%. Boron products derived from ulexite ores have gray, granular appearance. Product guarantee is 32% boron oxide. The boron content of boron oxide is 32%, providing a 10% boron equivalency.
Agronomic Or Horticultural Information: Calcium sodium borate may be used as a component in bulk dry blend fertilizer and is applied in the spring at an application rate of 11 to 33 kg/ha (10 to 30 lb/ac). This application rate provides 1.1 to 3.3 kg/ha (1 to 3 lb/ac) of boron. In Eastern Washington, calcium sodium borate is used on potatoes, onions and corn.
Sample Number: H0753 **State or Country of Origin:** Chile
Sample Name: Boronat (micronutrient)

DIAMMONIUM PHOSPHATE
Generic Name: Diammonium phosphate
Industry Or Common Name: DAP
Chemical Characteristics: Diammonium salt tends to be less stable than monoammonium salts. Consequently, diammonium phosphate has an economic advantage over monoammonium phosphate because the same amount of acid reacts with twice as much ammonia. Product grade is 18-46-0.
Manufacturing Information: Fertilizer grade diammonium phosphate is made from wet process phosphoric acid and ammonia. The product is manufactured by reacting ammonia with phosphoric acid in a preneutralization vessel and further ammoniating the slurry in a rotating ammoniation-granulation unit. The material discharged from the unit is dried, screened and cooled before being placed in storage. Substantial quantities of crystalline diammonium phosphate are produced as by-products from the iron and steel industry. For example, using electric furnace phosphoric acid from pickling steel in the manufacture of diammonium phosphate produces a fertilizer product with a grade of 21-53-0.
Agronomic Or Horticultural Information: There are three commercial grades of diammonium phosphate: 21-53-0, 18-46-0 and 16-48-0 (made from green or wet phosphoric acid). In Western Washington, diammonium phosphate is used on corn at a rate of 280 to 336 kg/ha (250 to 300 lb/ac). Diammonium phosphate is also applied to grains (wheat, oats and barley) at planting time and is used in fertilizer blends for pastures.
Sample Number: H4755 **State Or Country Of Origin:** Texas
Sample Name: Diammonium phosphate

DOLOMITE

Generic Name: Double carbonate of calcium and magnesium

Industry Or Common Name: Dolomite

AAPFCO Definition: Dolomite is a material composed chiefly of carbonates of magnesium and calcium in substantially equimolar (1-1.19) proportions. (Official 1950)

Chemical Characteristics: Product guarantee is 22% calcium (55% calcium carbonate) and 11.8% magnesium (41% magnesium carbonate).

Manufacturing Information: Dolomite is a naturally occurring mineral.

Agronomic Or Horticultural Information: Dolomite is used in same manner as limestone. However, when the calcium proportions of limestone and dolomite are compared, one half of the calcium in dolomite has been replaced by magnesium. Dolomite reacts more slowly with acids than high calcic limestone and is much less likely to release ammonia from its salts. In theory, 45.4 kg (100 lb) of dolomite is equal to 49.5 kg (109 lb) of calcium carbonate for neutralizing soil acidity. On western Washington permanent pasture, dolomite is broadcast applied in the late fall at an application rate of 2242 to 3363 kg/ha (2000 to 3000 lb/ac). Application rate for dolomite on cultivated crop land is 2242 to 8968 kg/ha (2000 to 8000 lb/ac).

Sample Number: H2550

Sample Name: Dolomite

State Or Country Of Origin: Washington

GYPSUM

Generic Name: Gypsum

Industry Or Common Name: Land plaster, gypsum

AAPFCO Definition: Gypsum, land plaster or crude calcium sulfate is a product consisting chiefly of calcium sulfate with combined water ([calcium sulfate dihydroxide]) and is incapable of neutralizing soil acidity. It shall contain not less than seventy percent (70%) [calcium sulfate dihydroxide].

Chemical Characteristics: Product guarantee is 85% calcium sulfate. Pure gypsum contains approximately 18.6% sulfur.

Manufacturing Information: Recycled wallboard.

Agronomic Or Horticultural Information: Leaching of the soil is an important step in correcting soils with a high pH due to sodium. Gypsum may reduce the alkalinity of sodic soils by replacing less desirable sodium ions with soluble calcium ions on the soil exchange complex. The sodium replacement improves soil aggregation of small soil particles so there are more large pore-spaces in the soil. Gypsum is applied at an application rate of 112 to 224 kg/ha (100 to 200 lb/ac).

Sample Number: H4766

Sample Name: Gypril lime

State Or Country Of Origin: Oregon

By-Product Information: Recycled clean construction wall board.

KILN DUST

Generic Name: Kiln dust

Industry Or Common Name: Cement kiln dust, kiln dust lime

AAPFCO Definition: Cement flue dust (potash lime) is a by-product from cement manufacture. It contains 4% to 12.8% of potash and averages 30% calcium.

Chemical Characteristics: Product guarantee is 85.5% calcium carbonate and 1.5% magnesium carbonate.

Agronomic Or Horticultural Information: In Western Washington, kiln dust is used as a liming material. It is applied in the spring to crop and forage acreage at an application rate of 4484 to 8968 kg/ha (4000 to 8000 lb/ac).

Sample Number: H4763

Sample Name: Kiln dust lime

State Or Country Of Origin: Washington

By-Product Information: By-product of Portland cement manufacturing process.

LIMESTONE

Generic Name: Ground limestone

Industry Or Common Name: Cal pril lime

AAPFCO Definition: Ground limestone (coarse-ground limestone) is calcic or dolomitic limestone ground sufficiently fine for effective use as a liming material. (Official 1950)
Pulverized limestone (fine-ground limestone) is the product obtained by grinding either calcic or dolomitic limestone so that all material will pass US Standard No. 20 sieve (850 μm opening) and at least 75% will pass a US Standard No. 100 sieve (150 μm opening). (Official 1989)

Chemical Characteristics: This product is a finely ground, prilled (uniform size and coated) calcium carbonate. Product guarantee is 91% calcium carbonate and 1% magnesium carbonate.

Manufacturing Information: Made from mined natural limestone.

Agronomic Or Horticultural Information: Correction of adverse chemical, physical and biological conditions by adding limestone may result in improvements in plant growth. Not only is calcium an essential plant nutrient but the availability of some nutrients may also be increased through the application of limestone. Phosphorous availability is increased at pH values greater than 6.5-7.0. Micronutrient availability is increased at pH values of 5.5-6.5. Biological activity favors pH values of 6.8-7.0 and element toxicity is reduced at pH values of over 6.0. Good soil aggregation and structural development are favor near -neutral or neutral pH values. To change soil reaction 1 pH unit, limestone must be applied at a rate of 1682 to 4484 kg/ha (1500 to 4000 lb/ac) depending on soil type. In Western Washington, limestone is typically applied on a periodic schedule based on yearly soil testing at an application rate of 4484 kg/ha (4000 lb/ac).

Sample Number: H4764 **State Or Country Of Origin:** Washington

Sample Name: Cal pril lime

LIMESTONE

Generic Name: Limestone

Industry Or Common Name: Ground limestone

AAPFCO Definition: A material consisting essentially of calcium carbonate or a combination of calcium carbonate with magnesium carbonate capable of neutralizing soil acidity.

Chemical Characteristics: Limestone is used to change soil acidity. The effectiveness of limestone is dependent on its calcium carbonate equivalent and the fineness of the ground material. The finer limestone is ground, the faster it can change soil acidity. Product guarantee is 96% calcium carbonate equivalent.

Agronomic Or Horticultural Information: Correction of adverse chemical, physical and biological conditions by adding limestone may result in improvements in plant growth. Not only is calcium an essential plant nutrient but the availability of some nutrients may also be increased through the application of limestone. Phosphorous availability is increased at pH values greater than 6.5-7.0. Micronutrient availability is increased at pH values of 5.5-6.5. Biological activity favors pH values of 6.8-7.0 and element toxicity is reduced at pH values of over 6.0. Good soil aggregation and structural development are favor near -neutral or neutral pH values. To change soil reaction 1 pH unit, limestone must be applied at a rate of 1682 to 4484 kg/ha (1500 to 4000 lb/ac) depending on soil type. In Western Washington, limestone is typically applied on a periodic schedule based on yearly soil testing at an application rate of 4484560 kg/ha (4000 lb/ac).

Sample Number: H4759 **State Or Country Of Origin:** Washington

Sample Name: Ground limestone

LIQUID AMMONIUM PHOSPHATE

Generic Name: Liquid ammonium phosphate

Industry Or Common Name: Liquid ammonium phosphate

AAPFCO Definition: Ammonium phosphate (fertilizer grade) is a product obtained when phosphoric acid is treated with ammonia (anhydrous or aqueous), and consists principally of monoammonium phosphate and diammonium phosphate or a mixture of these two salts. The guaranteed percentages of nitrogen and of available phosphate shall be stated as part of the name. (Official 1993)

Chemical Characteristics: Product grade is 11-37-0.
Manufacturing Information: Liquid ammonium phosphate is manufactured by neutralizing wet process superphosphoric acid with ammonia.
Agronomic Or Horticultural Information: In Central Washington, liquid ammonium phosphate is sprayed by ground rig on alfalfa and timothy hay at an application rate of 65.6 to 263.7 lit/ha (44 to 177 gal/ac). This application rate provides 11 to 45kg/ha (10 to 40 lb/ac) of available phosphate.
Sample Number: H2526 **State Or Country Of Origin:** Washington
Sample Name: Liquid ammonium phosphate

MANGANESE SULFATE

Generic Name: Manganese sulfate
Industry Or Common Name: Manganese sulfate
AAPFCO Definition: The term manganese sulfate, when applied to an ingredient of a mixed fertilizer, shall designate anhydrous manganese sulfate ($MnSO_4$). (Official 1950)
Chemical Characteristics: Manganese sulfate has a product guarantee of 29.5% soluble manganese.
Agronomic Or Horticultural Information: Manganese is a metallic micronutrient existing in the soil in several oxidation states of which the manganese ion is the form most commonly absorbed by plants. Manganese sulfate provides a readily available source of manganese. Manganese functions as a catalyst in plant growth processes. Manganese sulfate is used in dry blends in Western Washington. This product is broadcast applied to forage and turf grasses at an application rate of 28 to 56 kg/ha (25 to 50 lb/ac). **Sample Number:** H4753
State or Country of Origin: Mexico
Sample Name: Manganese sulfate **By-Product Information:** Industrial by-product

MICRONUTRIENT MIX No. 1

Generic Name: Micronutrients
Industry Or Common Name: Micronutrient mix
Definition: Micronutrient mixes are mixtures of trace elements necessary for optimum plant growth. The mixes are intended to be micronutrient additives for blended fertilizers.
Chemical Characteristics: Product guarantee is: 1) sulfur (8%) in the form of copper, manganese and zinc sulfates and lignosulfonate. Sulfur is an essential secondary plant nutrient and exists in the soil in a number of oxidation states. Sulfur is absorbed by plants as a sulfate ion; 2) boron (1.5%) as sodium borate. Boron is a an essential non-metallic micronutrient. It is absorbed by plants as boric acid or one of the borate anions. Boron is commonly found as an oxide in combination with sodium or calcium; 3) copper (1.5%) as sulfate of copper. Copper is essential for plant growth and is recognized as one of the micronutrients; 4) manganese (3%) as manganese sulfate. Manganese is a metallic micronutrient existing in the soil in several oxidation states. The manganese ion is the form most commonly absorbed by plants; and 5) zinc (6%) as zinc sulfate. Zinc is a metallic micronutrient and it is adsorbed by plants as a zinc ion.
Agronomic Or Horticultural Information: This particular micronutrient mix is recommended for correction of multiple nutrient deficiencies as determined by foliar and soil testing. The product is applied at seeding time in a band with a starter fertilizer. Sidedressing and broadcast methods are also effective. Application rates for this micronutrient mix range from 8.4 kg/ha (7.5 lb/ac) for mild micronutrient deficiency to 34 kg/ha (30 lb/ac) for severe micronutrient deficiency.
Sample Number: H4772 **State Or Country Of Origin:** Washington
Sample Name: Micronutrient mix No. 1 **By-Product Information:** Some of the micronutrients contained in this mix may be made up of industrial by-products.

MICRONUTRIENT MIX No. 2

Generic Name: Micronutrients

Industry Or Common Name: Micronutrient Mix

Definition: Micronutrient mixes are mixtures of trace elements necessary for optimum plant growth. The mixes are intended to be micronutrient additives for blended fertilizers.

Chemical Characteristics: Product guarantee is: 1) boron (2%) as sodium borate. Boron is a an essential non-metallic micronutrient. It is absorbed by plants as boric acid or one of the borate anions. Boron is commonly found as an oxide in combination with sodium or calcium; 2) iron (10%) as iron oxide and iron sulfate. Iron is responsible for the formation of chlorophyll in plant cells and is taken up by plants a ferrous ions: 3) copper (5%) as copper oxide and copper sulfate. Copper is essential for plant growth and is recognized as one of the micronutrients; 4) cobalt (0.05%); 5) manganese (5%) as manganese oxide and manganese sulfate. Manganese is a metallic micronutrient existing in the soil in several oxidation states.

The manganese ion is the form most commonly absorbed by plants; 6) molybdenum (0.05% as sodium molybdate. Molybdenum is a metallic micronutrient that is absorbed as a molybdate anion and is the micronutrient required in the smallest quantity by plants; and 7) zinc (5%) as zinc oxide and zinc sulfate. Zinc is a metallic micronutrient and it is adsorbed by plants as a zinc ion.

Agronomic Or Horticultural Information: This mix is a general purpose homogenous micronutrient used by bulk blenders for preparing a complete fertilizer suitable to a broad range of crops and soil situations. In Western Washington, the maximum blend rate may be 25 kg of micronutrient per metric ton (50 pounds per ton) of finished blended fertilizer. The finished blended fertilizer is applied by ground broadcast every three years or more at an application rate of 561 kg/ha (500 lb/ac) fertilizer mix. This application rate would provide 14 kg/ha (12.5 lb/ac) of micronutrient mix.

Sample Number: H4756

Sample Name: Micronutrient Mix No. 2

State Or Country Of Origin: Arkansas

By-Product Information: Some of the micronutrients in this mix may be made from industrial by-products.

MIXED FERTILIZER WITH MAGNESIUM

Generic Name: Prilled (mechanically manipulated for uniform size) mixed fertilizer containing magnesium

Industry Or Common Name: High Mag Gro

Description: A "mixed fertilizer" means a fertilizer containing any combination or mixture of fertilizer materials. High Mag Gro is an alkaline based fertilizer containing a combination of primary and secondary plant food nutrients.

Chemical Characteristics: Product guarantee is 1-0-8 with 3.5 % calcium (8.7% calcium carbonate) and 18% magnesium (62% magnesium carbonate). The nitrogen component of Hi Mag Gro is derived from ammonia nitrogen. The calcium is derived from calcium chloride, calcium hydroxide and calcium oxide. The potassium component is derived from muriate of potash and the magnesium component is derived from magnesium chloride, magnesium hydroxide and magnesium oxide. The pH value of Hi Mag Gro is 9.5 with a calcium carbonate equivalent of 82%.

Manufacturing Information: Hi Mag Gro is derived from flux bars which have been remanufactured into fertilizer. Flux is defined as a substance that aids, induces or otherwise actively participates in a flow, e.g., a mineral added to a furnace charge to promote fusing of metals or prevent the formation of oxides.

Agronomic Or Horticultural Information: In Eastern Washington, High Mag Gro is incorporated or topdressed on crops at an application rate of 34 to 536 kg/ha (30 to 300 lb/ac). This application assumes Hi Mag Gro is applied as a fertilizer and provides 0.34 to 3.36 kg/ha (0.3 to 3 lb/ac) of nitrogen, 2.69 to 26.9 kg/ha (2.4 to 24 lb/ac) of potassium, 1.1 to 11.2 kg/ha (1 to 10.5 lb/ac) of calcium and 20.85 to 208.5 kg/ha (18.6 to 186 lb/ac) of magnesium. Hi Mag Gro may also be used as soil amendment and applied at an application rate of 2242 to 4484 kg/ha (2000 to 4000 lb/ac).

Sample Number: H2530

Sample Name: High Mag Gro

State Or Country Of Origin: Washington

By-Product Information: By-product of magnesium ore extraction from dolomite deposits.

MONOAMMONIUM PHOSPHATE

Generic Name: Monoammonium phosphate

Industry Or Common Name: MAP, monoammonium phosphate

AAPFCO Definition: Monoammonium phosphate (fertilizer grade) is a product composed of ammonium phosphates, principally monoammonium phosphate, resulting from the ammoniation of phosphoric acid. The guaranteed percentage of nitrogen and available phosphate shall be stated as part of the name. (Official 1991)

Chemical Characteristics: Ammonium phosphate is a concentrated fertilizer. The dry form of ammonium phosphate is a uniform, hard pellet. Product grade is 11-52-0. Monoammonium phosphate is readily soluble in water. The other components of ammonium phosphate are only slightly soluble. Upwards of 18% of the components of ammonium phosphate will not dissolve in water. One thousand liters of water will dissolve approximately 63 kg of monoammonium phosphate, i.e., one hundred gallons of water will dissolve approximately 200 pounds of monoammonium phosphate.

Manufacturing Information: Monoammonium phosphate is manufactured by allowing ammonia gas to react with wet process phosphoric acid.

Agronomic Or Horticultural Information: In Western Washington, monoammonium phosphate is used primarily in the spring in direct applications on fresh peas and sweet corn. Monoammonium phosphate is applied by sidedressing or may be broadcast as part of a custom blend at an application rate of 224 to 336 kg/ha (200 to 300 lb/ac).

Sample Number: H4754 **State or Country of Origin:** Idaho

Sample Name: Monoammonium phosphate No. 1

MURIATE OF POTASH

Generic Name: Potassium salt of muriatic acid

Industry Or Common Name: Muriate of potash, potassium chloride

AAPFCO Definition: Muriate of potash (commercial potassium chloride) is a potash salt containing 48% to 62% soluble potash, chiefly as chloride. (Official 1951)

Chemical Characteristics: Muriate of potash is the most common source of potash. The crystalline and angular product works well in bulk blending. The fine-sized crystalline product is preferred for liquid suspensions. Product grade is 0-0-62.

Manufacturing Information: Potassium chloride is brought to the surface as the sylvinite ore, the main ore mineral for potash. Sylvinite ore is mined through conventional shaft mining and solution mining in New Mexico, Utah and Canada. California and Michigan recover potash by from natural brine deposits.

Agronomic Or Horticultural Information: Muriate of potash has one of the highest analyses for a potash material fertilizer and it is soluble in water. Muriate of potash may draw moisture and set up under certain storage conditions. It has a high chlorine content and may be injurious to some crops when heavy band applications are made. In Western Washington, muriate of potash may be used alone but is more commonly used in blends on corn forage, fresh green peas and pasture grass. Muriate of potash is broadcast in the spring at an application rate of 224 to 280 kg/ha (200 to 250 lb/ac).

Sample Number: H4767 **State or Country of Origin:** Canada

Sample Name: Muriate of potash

NITROSOL

Generic Name: Ammonium polysulfide
Industry or Common Name: Nitrosol
Chemical Characteristics: Nitrosol is a liquid fertilizer product with a product guarantee of 20-0-0 with 40% sulfur.
Agronomic or Horticultural Information: Ammonium polysulfide is usually mixed with aqua ammonia or injected in combination with anhydrous ammonia. Ammonium polysulfide may be maintained in non-pressurized storage and is compatible with aqua ammonia, potash solution and some non-metallic micronutrients. Ammonium polysulfide may be applied at planting time and/or following harvest at an application rate for sulfur of 5.6 to 28 kg/ha (5 to 25 lb/ac). This application rate requires 2 to 10 lit/ha (1.3 to 6.7 gal/ac) of ammonium polysulfide. In Eastern Washington, this product is used on any crop after soil tests have demonstrated a sulfur requirement. Ammonium polysulfide may also be used throughout the planting season.
Sample Number: H1231 **State or Country of Origin:** Washington
Sample Name: Nitrosol

PHOSPHORIC ACID

Generic Name: Phosphoric Acid
Industry Or Common Name: Green acid, wet process acid
Chemical Characteristics: Product grade is 0-68-0.
Manufacturing Information: Wet process acid is manufactured by reacting finely ground phosphate rock with sulfuric acid. The phosphoric acid then is separated from the gypsum "cake" by washing and filtration. This process separates the phosphoric acid from the calcium sulfate formed during the reaction procedure. Wet process acid may be green or black. The product coloration is a result of impurities from aluminum, calcium, fluorine, iron, magnesium and organic matter compounds.
Agronomic Or Horticultural Information: Liquid phosphoric acid is applied in irrigation water, furrow irrigation or applied into the soil. It is most commonly used in the manufacture of combination fertilizers such as ammonium polyphosphate.
Sample Number: H2549 **State Or Country Of Origin:** Wyoming
Sample Name: Phosphoric acid

POTASSIUM NITRATE

Generic Name: Nitrate of potash
Industry Or Common Name: Potassium nitrate, saltpeter
AAPFCO Definition: Nitrate of potash (potassium nitrate) is chiefly the potassium salt of nitric acid. It shall contain not less than twelve percent (12%) nitrogen and forty-four percent (44%) soluble potash.
Chemical Characteristics: Potassium nitrate is the potassium salt of nitric acid and is available in prills or fine grade. Product grade is 13.75-0-46.
Manufacturing Information: Potassium nitrate is manufactured by either direct reaction of potassium chloride with concentrated nitric acid to produce potassium nitrate and chlorine or by the action of nitric acid on caustic potash or carbonate of potash.
Agronomic Or Horticultural Information: In Western Washington, potassium nitrate is injection applied through irrigation systems in the greenhouse and nursery industries. Potassium nitrate may also be used in mixed fertilizer blends. Used on a variety of crops, these mixed fertilizer blends are broadcast at an application rate of 1 to 3.1 kg per square meter (5 to 15 lb per square foot) of row. The application may be completed in one operation or spread every 60 days until the required potassium nitrate has been applied.
Sample Number: H4765 **State Or Country Of Origin:** Tennessee
Sample Name: Potassium nitrate

PRILLED BLEND

Generic Name: Prilled blended fertilizer, prilled mixed fertilizer, prilled blend
Industry Or Common Name: Mixed fertilizer, mechanically manipulated for uniform size (prilled)
AAPFCO Definition: A "mixed fertilizer" means a fertilizer containing any combination or mixture of fertilizer materials.
Chemical Characteristics: This product is a prilled mixture of several fertilizer materials. Product guarantee is 16-15-15 with 2.7% sulfur. The total nitrogen guarantee (16%) is comprised of 10% ammoniacal nitrogen and 6% nitrate nitrogen. Available phosphate is derived from mono- and diammonium phosphates and soluble potash is derived from muriate of potash. Sulfur is derived from ammonium sulfate.
Agronomic Or Horticultural Information: This blended fertilizer was formulated for application on grass-seed crops, turf and pastures. The application rate is 420.3 kg/ha (375 lb/ac) which applies 67.2 kg/ha (60 lb/ac) of nitrogen, 62.7 kg/ha (56 lb/ac) of phosphate and 62.7 kg/ha (56 lb/ac) of potash.
Sample Number: H4762 **State Or Country Of Origin:** Norway
Sample Name: Prilled blend

ROCK PHOSPHATE

Generic Name: Phosphate rock
Industry Or Common Name: Phosphate rock, rock phosphate
AAPFCO Definition: Phosphate rock is a natural rock containing one or more calcium phosphate minerals of sufficient purity and quantity to permit its use, either directly or after concentration, in the manufacture of commercial products. (Official 1952)
Chemical Characteristics: The basic source for all phosphorous fertilizer materials is natural deposits of fluoroapatite or phosphate rock.. The bulk of these ores are sedimentary in origin. The principal world reserves are mined in North Africa, the former Soviet Union and North America. North American deposits are located in Florida, Idaho, Montana, Utah , Wyoming, North Carolina and Tennessee. Product grade is 0-30-0.
Manufacturing Information: Phosphate rock may be treated with strong acids or heat to make available forms of phosphate.
Agronomic Or Horticultural Information: The phosphorous in phosphate rock is slowly available to crops and the effectiveness is dependent on the degree of fineness of the ground product. Finely ground phosphate rock is sometimes used in long-term fertility programs. Best results are obtained when phosphate rock is used on soil high in organic matter and of a relatively strong acidity. In Western Washington, phosphate rock is broadcast applied in the fall or spring at a rate of 784.7 kg/ha (700 lb/ac).
Sample Number: H4757 **State Or Country Of Origin:** Texas
Sample Name: Rock phosphate

SULFATE OF POTASH-MAGNESIA

Generic Name: Sulfate of potash-magnesia
Industry Or Common Name: K-MAG, sulfate of potash-magnesia, Sul-Po-Mag
AAPFCO Definition: Sulfate of potash-magnesia is a potash salt containing not less than twenty five percent soluble potash nor less than twenty five percent sulfate of magnesia and not more than two and one half percent chlorine. Double sulfate of potash and magnesia (langbeinite) is a commercial product containing not less than 21% soluble potash (K_2) nor less than 53% sulfate magnesia and not more than 2.5% chlorine. (Official 1950)
Chemical Characteristics: Product guarantee is 22% potassium, 11% magnesium and 22% sulfur.
Manufacturing Information: The domestic salt is produced from langbeinite and is marketed as 95% langbeinite. Sulfate of potash-magnesia imported from Germany was formerly called double manure salts.
Agronomic Or Horticultural Information: In Western Washington, sulfate of potash-magnesia is broadcast applied on peas and corn in the spring at an application rate of 112.1 to 168.7 kg/ha (100 to 150 lb/ac).
Sample Number: H4768 **State Or Country Of Origin:** New Mexico
Sample Name: K-Mag

THIOSOL
Generic Name: Ammonium thiosulfate
Industry or Common Name: Thiosol
Chemical Characteristics: Ammonium thiosulfate is a slightly ammoniacal liquid fertilizer (60% aqueous solution) containing 12% ammoniacal nitrogen and 26% combined sulfur. Product grade is 12-0-0.
Agronomic or Horticultural Information: Ammonium thiosulfate is stable in storage and is maintained under non-pressurized storage and handling. This product is compatible with many non-pressurized fertilizer solutions and with most micronutrients. Ammonium thiosulfate is also compatible in portion with neutral or alkaline phosphate-containing liquid fertilizers as well as aqueous ammonia and nitrogen solutions. Ammonium thiosulfate may be applied on the surface or sub-surface of the ground. In Eastern Washington, ammonium thiosulfate is typically applied to wheat, peas and other crops at a maximum application rate of 129 kg/ha (115 lb/ac).
Sample Number: H2547 **State or Country of Origin:** Washington
Sample Name: Thiosol

TREBLE SUPERPHOSPHATE
Generic Name: Superphosphate
Industry Or Common Name: Treble or triple superphosphate
AAPFCO Definition: A product obtained when rock phosphate is treated with either sulfuric acid, phosphoric acid, or a mixture of those acids. The guaranteed percentage of available phosphoric acid shall be stated as a part of the name. (Official 1993)
Chemical Characteristics: Treble superphosphate is a granular dry fertilizer. Concentrated superphosphate is also called double, treble, triple or multiple superphosphate, referring to the guarantees of 45 to 48% available phosphate. Treble superphosphate is composed of monocalcium phosphate monohydrate. Product grade is 0-45-0.
Manufacturing Information: Concentrated superphosphates are manufactured by acidulating natural phosphatic material with phosphoric acid.
Agronomic Or Horticultural Information: In Western Washington, treble superphosphate is drilled on freezer peas in the early spring at an application rate of 224.2 kg/ha (200 lb/ac).
Sample Number: H4770 **State Or Country Of Origin:** Idaho
Sample Name: Triple superphosphate

UREA
Generic Name: Urea
Industry Or Common Name: Urea
AAPFCO Definition: Urea is the commercial synthetic acid amide of carbonic acid and it shall contain not less than 45% N. (Official 1966)
Chemical Characteristics: Urea is white, crystalline or granular, and often produced in a uniform prill. Urea has a low salt index and is chemically stabile. It is a synthetic organic with has two amino groups and is normally oxidized by bacterial action to form nitrates. Product grade is 46-0-0.
Manufacturing Information: Synthetic urea made by combining liquid ammonia and liquid carbon dioxide at very high temperatures and pressures. The resulting product is a crystalline urea which is completely soluble.
Agronomic Or Horticultural Uses: Urea is the most concentrated and available form of nitrogen in dry fertilizers. Urea can absorb large amounts of water (hygroscopic). Urea is not compatible with sulfate of ammonia, potash salts, dolomite or ammonium nitrate and under high humidity it is not compatible with treble phosphate. Urea is widely used in liquid and solid fertilizer blends and for direct application. In foliar sprays, urea is applied at an application rate of 1.2 kg /lit (10 lb/gal). Foliar applications of urea are readily absorbed through the leaves of many plants and efficiently utilized as a nitrogen source. In Washington state, urea is used on all area crops except mature alfalfa. Dry urea, alone or as part of a fertilizer blend, is applied in the spring at an application of 56 to 246.6 kg/ha (50 to 220 lb/ac) of actual nitrogen per acre. This application rate requires 122to 536.9 kg/ha (109 to 479 lb/ac) of dry urea.
Sample Number: H0751 **State Or Country Of Origin:** Idaho
Sample Name: Urea

UREA AMMONIUM NITRATE

Generic Name: Urea ammonium nitrate
Industry Or Common Name: UN 32, UAN 32, Solution 32
Chemical Characteristics: Urea ammonium nitrate is a liquid fertilizer. Product grade is 32-0-0. The total nitrogen guarantee (32%) is comprised of 7.75% ammoniacal nitrogen, 7.75% nitrate nitrogen and 16.5% is urea nitrogen.
Manufacturing Information: Urea ammonium nitrate is manufactured by combining liquid ammonium nitrate and urea and combining the resulting liquid with water to adjust the nitrogen level.
Agronomic Or Horticultural Information: Urea ammonium nitrate is a non-pressurized liquid, compatible with most non-pressurized solutions, micronutrients and pesticides. The ammoniacal nitrogen portion of urea ammonium nitrate attaches itself to fine clay particles and humus. The nitrate nitrogen portion is readily available for both shallow and deep feeding while the urea nitrogen is unavailable until converted to nitrate form. Urea ammonium nitrate may be used for nitrogen top-dressing applications on spring grains or applied through irrigation on summer growing crops. This product may be also be applied by sprayer on wheat and barley at a rate of 11 to 23 lit/ha (7 to 15 gal/ac).
Sample Number: H 2538
State Or Country Of Origin: Washington
Sample Name: Urea ammonium nitrate

WOOD ASH

Generic Name: Ash from wood hog fuel
Industry Or Common Name: Nutrilime
Definition: Ash from wood hog fuel is the inorganic and organic residue remaining after the combustion of wood, (clean wood fiber and bark) for electricity and steam production.
Chemical Characteristics: Wood ash is an alkaline material with a pH that ranges from 8 to 13 and contains micro and macro nutrients extracted from the soil during tree growth. Wood ash is substantially different from coal ash. Coal ash has a lower alkalinity but higher silicon, aluminum, iron and heavy metal content. The alkali metal and alkaline earth elements in the wood ash are present mainly in the form of potassium and calcium oxides, hydroxides and potassium and calcium carbonates. Product guarantee is 3% calcium (7.6% calcium carbonate), 0.09% magnesium (1.9% magnesium carbonate) and 1.71% iron. The product guarantees 8.9 % calcium carbonate equivalent.
Manufacturing Information: This product is generated from hog fuel burned for electricity and steam production. The wood waste fuel may be from paper production and is reported to contain no added chlorinated compounds.
Agronomic Or Horticultural Information: Wood ash from hog fuel may be used as a liming agent or soil amendment. Wood ash from hog fuel may be used on any acidic soil that needs pH adjustment. The rate of application is dependent upon soil test results. Application rates, dependent upon soil test results, may be 67260 to 91922 kg/ha (60000 to 82000 lb/ac).
Sample Number: H4775
Sample Name: Wood ash
State Or Country Of Origin: Washington
By-Product Information: Paper industry by-product from combustion of hog fuel.

ZINC SULFATE

Generic Name: Granular zinc sulfate
Industry Or Common Name: LHM 18% granular zinc
Definition: The zinc salt of sulfuric acid.
Chemical Characteristics: Zinc sulfate is immediately water soluble. The product granules are hard and do not break down under normal mechanical conveying. The "LHM" product designation results from this product having a higher water solubility and a lower level of contaminants when compared to granular zinc No. 1. Product guarantee is 18% zinc and 9% sulfur.
Agronomic Or Horticultural Information: Granular zinc sulfate is commonly blended into dry fertilizers and applied in the spring and/or fall at an application rate of 1.12 to 11.2 kg/ha (1 to 10 lb/ac) of zinc. This application

rate requires 6.28 to 62.78 kg/ha (5.6 to 56 lb/ac) of granular zinc sulfate. In Eastern Washington, granular zinc sulfate is most commonly used on potatoes, corn and beets.

Sample Number: H1903

Sample Name: Granular zinc No.2 (micronutrient)

State Or Country Of Origin: Washington

By-Product Information: Derived from fly ash produced in the combustion of tires for energy generation.

__ZINC SULFATE__

Generic Name: Granular zinc sulfate

Industry Or Common Name: 18% Granular Zinc

Definition: The zinc salt of sulfuric acid.

Chemical Characteristics: Zinc sulfate is immediately water soluble. The product granules are hard and do not break down under normal mechanical conveying. The product guarantee is 18% zinc and 8% sulfur.

Agronomic Or Horticultural Information: Granular zinc sulfate is commonly blended into dry fertilizers and applied in the spring and/or fall at an application rate of 1.12 to 11.2 kg/ha (1 to 10 lb/ac) of zinc. This application rate requires 6.28 to 62.7 kg/ha (5.6 to 56 lb/ac) of granular zinc sulfate. In Eastern Washington, granular zinc sulfate is most commonly used on potatoes, corn and beets.

Sample Number: H1906

Sample Name: Granular zinc No.1 (micronutrient)

State Or Country Of Origin: Washington

By-Product Information: Zinc component may be derived from zinc oxide fume and zinc oxide fly ash.

Appendix D

Sampling Protocols and Quality Assurance/Quality Control

Sampling Protocols

Samples were collected using standard operating procedures as described in the Washington State Department of Agriculture (WSDA) Investigator's Manual - Pesticide Management Division[1]. (Due to product availability, the collection of sample number 2532 did not meet all the standards established by the Investigator's Manual. However, the sample is considered representative of that product.)

Typically, fertilizers are either dry product or bulk liquid. Dry product comes in small packages, one-ton packages or bulk. Composite samples of dry product were collected with clean stainless steel probes. Ten core samples were taken from different packages or containers comprising a single lot, mixed in a stainless steel pan, and transferred to a clean plastic sample bag. Bulk liquid was sampled by flushing a sample port and collecting the sample directly into a clean polyethylene sample bottle. All samples were labeled with a WSDA seal, the sample number, the sampling date and the investigator's initials. A laboratory sample transmittal sheet was also filled out at the time of sampling. WSDA staff then delivered the samples and their supporting documentation to the Manchester Environmental Laboratory.

All sampling equipment was cleaned at the end of each day and wiped dry. For the 1997 samples, three stainless steel probes were used each day to minimize the need to reuse any of the probes before being washed. After the sample equipment was used, excess material was shaken off; a bottle brush was used to wipe the inside of the sample probes; and the sampling equipment was wiped clean. On occasion, an alcohol swab was used to remove any remaining residue. Although some cross-contamination may have resulted, any error would likely have been small and would have generated a "false-positive" result.

Quality Assurance/Quality Control

1997 Samples

The samples collected in 1997 were analyzed by Manchester Environmental Laboratory using standard U.S. Environmental Protection Agency (EPA) methods. Most metals were analyzed using EPA method 6010, which uses inductively coupled plasma and optical emission detection. Mercury samples were analyzed using EPA method 7471, which uses cold vapor atomic absorption. All holding times were met. Following is a summary of the data quality.

Overall, the data for this project are acceptable for use. However, the diverse matrices and high concentrations of some analytes did present analytical problems. When comparing results for undiluted samples and diluted samples, corrected for dilution, the relative percent difference

(RPD) between the undiluted/diluted corrected results for most analytes was within the allowed able acceptance factor of 10%, except for diammonium phosphate, granular zinc, and individual elements in several other samples. Because of the uncertainty of the results, these samples are qualified "J" or instrument estimation. The dilution problems did not appear to be general to all samples of different matrices.

The precision of aluminum, chromium, and manganese duplicate results were low. Data for these elements in granular zinc are qualified "J" as estimated. Mercury results are also qualified on this sample due to possible interference by manganese.

The reported detection levels of aluminum, calcium, iron, zinc, and magnesium for the solid samples were raised due to carryover from high concentrations in some of the samples. Zinc and manganese were detected in the procedure blank run with the solid samples, and sodium was detected in the liquid procedure blank. Data for these elements in samples associated with these blanks at levels less than 10 times the blank level have been qualified "J" as estimated.

Duplicates and Spikes

All spike recoveries, except those for molybdenum from both liquid and spiked solid samples and tin from the spiked solid sample, are within the EPA Contract Laboratory Program (CLP) acceptance limits of +/- 25%. The results of spiked and duplicate spiked samples and of duplicate samples are used to evaluate precision. The RPD for all analytes, except silver in the spiked solid sample, are within the 20% CLP acceptance window for duplicate analyses. The laboratory control samples were within the window established for each parameter, with the following exceptions: The recovery of antimony was low in the solid samples, and molybdenum recovery was low in the liquid samples. Data for all these elements are qualified "J" as estimated. No other significant quality assurance issues were noted with the data.

Archive Samples

The WSDA archive samples were submitted to Columbia Analytical Services Laboratory on April 25, 1997. Most metals were analyzed using EPA method 6010, with mercury being analyzed using EPA method 7471. Since these samples have been in storage since 1993 and 1994, they have exceeded the CLP holding times for metals analysis (28 days for mercury, 180 days for all other metals). No analytes were detected in the method blank associated with these samples

Reference

1) WSDA, 1991. Chapter 2.

Appendix E

Cadmium and Lead in Potatoes

Results of Analysis – Cadmium in Potatoes

Samples collected on April 28, 1997

NO	SAMPLE COLLECTION NUMBER	NATURE OF PRODUCT	AREA OBTAINED FROM	CADMIUM PPB*
1	WARJU0010	fresh, raw, unpeeled	Quincy	35
2	WARJU0011	fresh, raw, unpeeled	Quincy	19
3	WARJU0012	fresh, raw, unpeeled	Quincy	23
4	WARJU0013	fresh, raw, unpeeled	Quincy	39
5	WAGLR0009	fresh, raw, unpeeled	Tri-Cities	34
6	WAGLR0011	fresh, raw, unpeeled	Tri-Cities	44
7	WAGLR0012	fresh, raw, unpeeled	Tri-Cities	42
8	WARTW0001	fresh, raw, unpeeled	Grays Harbor Co	46
9	WALMS0006	fresh, raw, unpeeled	Mattawa	34
10	WALMS0007	fresh, raw, unpeeled	Pasco	39
11	WAJFF025	fresh, raw, unpeeled	Quincy	28
12	WAJFF026	fresh, raw, unpeeled	Quincy	27
13	WAJFF027	fresh, raw, unpeeled	Mt. Vernon	49
14	WAJFF028	fresh, raw, unpeeled	Royal City	26
15	WAJFF029	fresh, raw, unpeeled	Pasco	27
8	WARO0001	fresh, raw, unpeeled	Quincy	26
9	WARO0002	fresh, raw, unpeeled	Quincy	55
10	WARO0003	fresh, raw, unpeeled	Royal	38
11	WARLB0010	fresh, raw, unpeeled	Skagit Co	52
12	WARLB0011	fresh, raw, unpeeled	Skagit Co	16
13	WARLB0013	fresh, raw, unpeeled	Yakima	32
14	WARLB0014	fresh, raw, unpeeled	Skagit Co	59
15	WARLB0015	fresh, raw, unpeeled	Quincy	36
16	WARLB0016	fresh, raw, unpeeled	Moses Lake	36
17	WAMT0001	fresh, raw, unpeeled	Skagit Co	68
18	WAMT0002	fresh, raw, unpeeled	Skagit Co	28
19	WAMT0003	fresh, raw, unpeeled	Skagit Co	11
28	WASIS18	fresh, raw, unpeeled	Mattawa	15
29	WASIS19	fresh, raw, unpeeled	Royal City	22
30	WASIS20	fresh, raw, unpeeled	Royal City	38
31	WASIS21	fresh, raw, unpeeled	Pasco	16

32	WASIS22	fresh, raw, unpeeled	Othello	57
33	WASIS23	fresh, raw, unpeeled	Royal Slope	26
34	WASIS25	fresh, raw, unpeeled	Othello	51
35	WASIS26	fresh, raw, unpeeled	Othello	54
36	WASIS27	fresh, raw, unpeeled	Othello	57
37	WAFDB22	fresh, raw, unpeeled	Colville	20
38	WAFDB23	fresh, raw, unpeeled	Mattawa	20
39	WAFDB24	fresh, raw, unpeeled	Pasco	26
40	WAFDB25	fresh, raw, unpeeled	Kennewick	29
41	WAFDB26	fresh, raw, unpeeled	Quincy	22
42	WAFDB27	fresh, raw, unpeeled	Moses Lake	21
43	WAFDB28	fresh, raw, unpeeled	Green Bluff	6
44	WAFDB29	fresh, raw, unpeeled	Quincy	28

*PPB=PARTS PER BILLION; 1,000 ppb = 1 ppm

These levels would be considered background levels or naturally occurring levels for these products. The average for the samples collected so far is 33.6 parts per billion cadmium (or about 0.03 ppm cadmium). These are low levels for any product. At these levels the average person would need to consume a five-pound bag of potatoes a day to reach the Tolerable Daily Intake Levels of 60 micrograms per day established by the U.S. Food and Drug Administration (FDA) for cadmium, and 40 pounds of potatoes at one sitting to approach toxicity levels established for cadmium in other foods. Biochemists and other technical experts at FDA, toxicologists with the state Department of Health, and scientific researchers in the area of lead and cadmium levels in food have stated that the cadmium levels shown in these samples are not of public health concern.

Results of Analysis – Lead in Potatoes

Samples collected on April 28, 1997

NO	SAMPLE COLLECTION NUMBER	NATURE OF PRODUCT	AREA OBTAINED FROM	LEAD PPB*
1	WARJU0010	fresh, raw, unpeeled	Quincy	9
2	WARJU0011	fresh, raw, unpeeled	Quincy	9
3	WARJU0012	fresh, raw, unpeeled	Royal City	7
4	WARJU0013	fresh, raw, unpeeled	Quincy	11
5	WAGLR0009	fresh, raw, unpeeled	Tri-Cities	16
6	WAGLR0011	fresh, raw, unpeeled	Tri-Cities	17
7	WAGLR0012	fresh, raw, unpeeled	Tri-Cities	13
8	WARTW0001	fresh, raw, unpeeled	Grays Harbor Co	14
9	WALMS0006	fresh, raw, unpeeled	Mattawa	21
10	WALMS0007	fresh, raw, unpeeled	Pasco	23
11	WAJFF025	fresh, raw, unpeeled	Quincy	26
12	WAJFF026	fresh, raw, unpeeled	Quincy	22
13	WAJFF027	fresh, raw, unpeeled	Mt. Vernon	13
14	WAJFF028	fresh, raw, unpeeled	Royal City	13
15	WAJFF029	fresh, raw, unpeeled	Pasco	12
16	WARO0001	fresh, raw, unpeeled	Quincy	46
17	WARO0002	fresh, raw, unpeeled	Quincy	6
18	WARO0003	fresh, raw, unpeeled	Royal	12
19	WARLB0010	fresh, raw, unpeeled	Skagit Co	34
20	WARLB0011	fresh, raw, unpeeled	Skagit Co	7
21	WARLB0013	fresh, raw, unpeeled	Yakima	26
22	WARLB0014	fresh, raw, unpeeled	Skagit Co	10
23	WARLB0015	fresh, raw, unpeeled	Quincy	12
24	WARLB0016	fresh, raw, unpeeled	Moses Lake	12
25	WAMT0001	fresh, raw, unpeeled	Skagit Co	8
26	WAMT0002	fresh, raw, unpeeled	Skagit Co	Trace
27	WAMT0003	fresh, raw, unpeeled	Skagit Co	6
28	WASIS18	fresh, raw, unpeeled	Mattawa	20
29	WASIS19	fresh, raw, unpeeled	Royal City	13
30	WASIS20	fresh, raw, unpeeled	Royal City	8
31	WASIS21	fresh, raw, unpeeled	Pasco	13
32	WASIS22	fresh, raw, unpeeled	Othello	12
33	WASIS23	fresh, raw, unpeeled	Royal Slope	6
34	WASIS25	fresh, raw, unpeeled	Othello	29
35	WASIS26	fresh, raw, unpeeled	Othello	11

36	WASIS27	fresh, raw, unpeeled	Othello	3
37	WAFDB22	fresh, raw, unpeeled	Colville	12
38	WAFDB23	fresh, raw, unpeeled	Mattawa	8
39	WAFDB24	fresh, raw, unpeeled	Pasco	10
40	WAFDB25	fresh, raw, unpeeled	Kennewick	4
41	WAFDB26	fresh, raw, unpeeled	Quincy	8
42	WAFDB27	fresh, raw, unpeeled	Moses Lake	17
43	WAFDB28	fresh, raw, unpeeled	Green Bluff	7
44	WAFDB29	fresh, raw, unpeeled	Quincy	7

*PPB=PARTS PER BILLION

These levels would be considered background levels or naturally occurring levels for these products. The average for the samples collected so far is 13.8 parts per billion lead. These are extremely low levels for any product. At these levels the average person would need to consume 31 pounds of potatoes a day to reach the Tolerable Daily Intake Levels of 216 micrograms per day established by the FDA for lead. Biochemists and other technical experts at FDA, toxicologists with the state Department of Health, and scientific researchers in the area of lead and cadmium levels in food have stated that the lead levels shown in these samples are not of public health concern.

Appendix F

Laws and Regulations on Fertilizers

Fertilizer manufacturers are required to get an annual registration for packaged fertilizers or an annual license to distribute bulk products from the Washington State Department of Agriculture (WSDA). This process includes approval of labels. WSDA conducts random sampling but usually tests only for the nutrients that are guaranteed on the label such as total nitrogen, available phosphoric acid, soluble potash and, when claimed, some of the trace elements and micronutrients. Penalties are assessed if the analysis of any fertilizer falls below certain levels of guarantees in any one-plant nutrient. In addition, it is illegal to mislabel or adulterate any fertilizer. Adulteration is defined as *injurious to beneficial plant life, or composition differs from the label or the product contains unwanted viable seed* (15.54.414 RCW). This law was adopted in the 1950s, so other contaminants were not considered. Soil amendments are not required to get a license or register with WSDA.

The procedure for someone marketing a waste product as a fertilizer is similar. An exception is "woody waste" products under a new law (Senate Bill 5701) passed in 1997. The law creates an optional procedure for distributors to request that Ecology determine if a product is safe for human health and the environment (70.95.830 RCW). Even if this option is not used, the company selling the fertilizer must follow applicable solid and/or hazardous waste laws as well as register the product with WSDA. Also, WSDA frequently checks with Ecology to determine if applicable environmental laws have been followed.

Examples of solid wastes that have been used in fertilizers include gypsum, some waste sludges, and boiler ashes. Biosolids are no longer considered a solid waste and are regulated separately. Solid wastes sold as fertilizer must get a local health department permit for each site the material is to be applied. The local health department regulations must be as strict as state regulations.

Designating a Waste as a Hazardous Waste

A waste is designated a hazardous waste if it fails certain toxicity tests (such as a fish toxicity test), or if it is declared a hazardous waste under the Resource Conservation and Recovery Act (RCRA) or under the state *Dangerous Waste Regulations* (WAC 173-303). Some examples of hazardous wastes that are used as fertilizers are cement kiln dust, electric arc furnace dust, and certain industrial sludges or residues. Generally, companies self-certify that the hazardous waste constituents do not exceed the standards specified in the "Land Disposal Restriction" portion of the Ecology *Dangerous Waste Regulations* (WAC-173-303-140).

Waste-Derived Fertilizers and Applicable Standards

Fertilizer products that are derived from certain hazardous waste as defined by the Dangerous Waste Regulations (WAC 173-303) are subject to the concentration based standards in the table below.

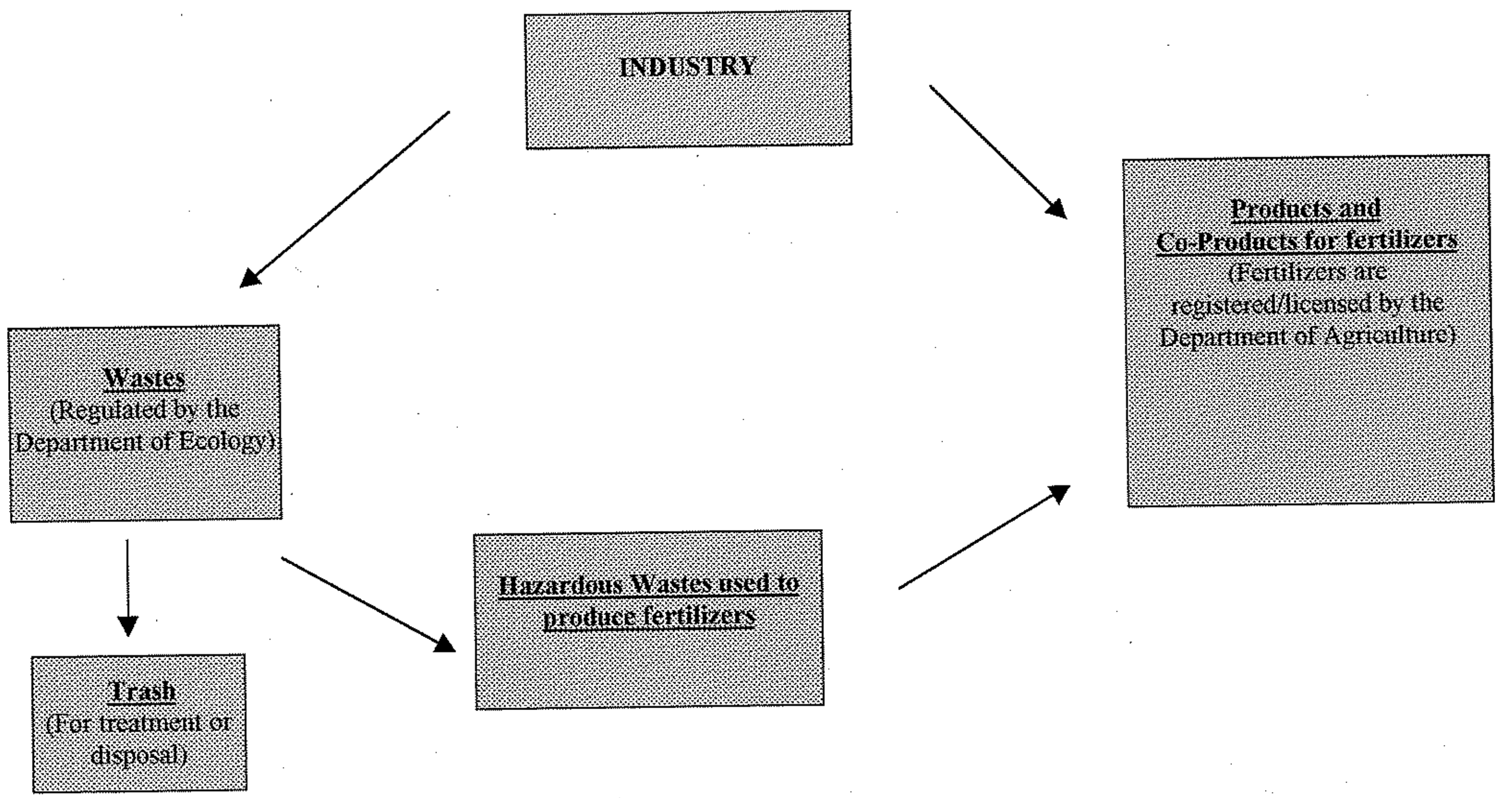
Contaminant	**Limit*** (ppm)
Arsenic	5.0
Cadmium	1.0
Chromium	5.0
Lead	5.0
Mercury	0.2
Selenium	1.0
Barium	100.0
Silver	5.0

* Limit is based on concentration of metal in an extract rather than the actual concentration in product.

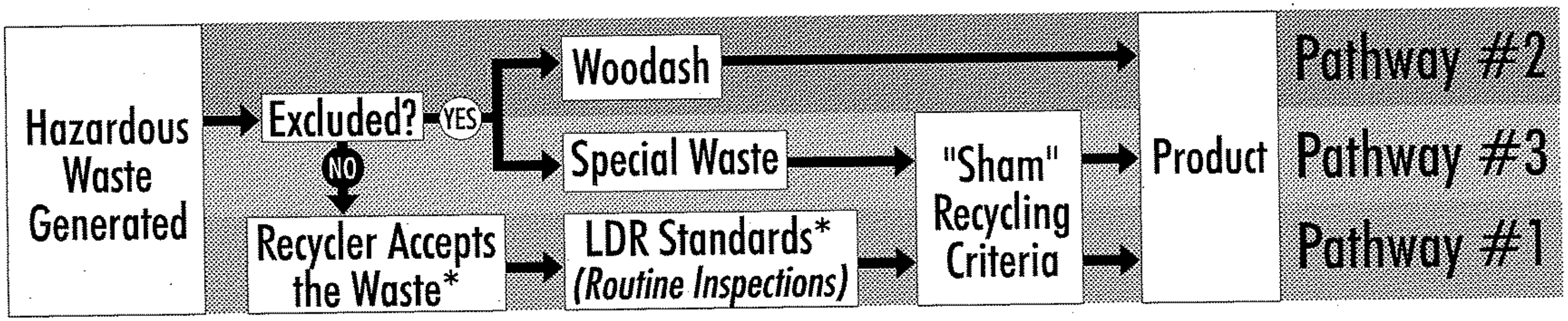
Producing Fertilizer Using Industrial By-Products

The following pages were prepared to explain as simply as possible how fertilizer ingredients are regulated by the state of Washington. In doing so, oversimplification was difficult to avoid. This process is complicated and does not lend itself to quick explanation.

This is a general overview of the process:



Producing Fertilizer Using Hazardous Waste



* Self Implemented Requirements Imposed by Rule

Department of Ecology *Pathway # 1*

Hazardous Waste Generated

- Company must notify Ecology and obtain an ID number.
- Each shipment of hazardous waste sent to a recycler must be accompanied by a hazardous waste manifest. The manifest includes what the shipment contains, the quantity, when it was shipped, from where it came, etc. The original copy of the manifest is signed by the recycler and returned to the generator to document that the shipment arrived at the intended destination. The generator keeps the manifest copies available for inspection.
- The generator submits to Ecology an annual report of the quantity of waste generated.

Recycler Accepts the Waste to Develop into a Product

- The recycler must notify Ecology about that activity and obtain an ID#.
- The recycler's name and ID# are recorded on the manifests for each shipment of hazardous wastes received. The recycler keeps copies available for inspection.
- The recycler must have a permit to store hazardous waste on its property.
- The recycler submits an annual report to Ecology.
- The recycler must keep records of who receives the product.

Land Disposal Restrictions (LDR)

At this time, Ecology will make sure the product meets two standards:

- First, the product has been tested for concentrations of hazardous constituents. Which constituents depend on the type of hazardous wastes used to make the product. Those constituents ***must not exceed*** the standards specified in the "Land Disposal Restriction" portion of Ecology's dangerous waste regulations.
- Second, a packaged product must be registered and a bulk product must be licensed with the Washington State Department of Agriculture WSDA).

Ecology Inspectors May Apply The "Sham Recycling Criteria"

Inspectors can use the "sham recycling criteria" to test for a variety of parameters to ensure the product does not harm human health or the environment. Ecology applies this criteria to make sure the waste is being legitimately recycled. It is written as guidance and has been supported by several court cases. The generator of a waste is required to use this criteria to interpret the dangerous waste rules and determine if the rules apply.

EXCLUSIONS

Department of Ecology *Pathway # 2*

Wood Ash and Treated Wood

For some wastes, the generator and recycler do not need to contact Ecology for prior approval. Some kinds of wastes are excluded from the requirements because they don't threaten public health or the environment to the degree that regulation under the dangerous waste rules is warranted. Others are excluded because they are *recycled* in ways that do not threaten public health or the environment. Some of the wastes could be used as fertilizers or soil amendments because the language of the exclusion does not preclude those uses. An example of this pathway is wood ash from pulp mill burners. Wood ash is designated as hazardous only because of its pH (or base) value. (These exclusions rely on the generators to correctly designate their wastes, in order to screen out the wastes that should use Pathway #1.) Generators are not required to notify Ecology, so the agency's knowledge is limited about some recycling activities.

Department of Ecology *Pathway # 3*

"Special Waste"

An example of a special waste is cement kiln dust that is used as a commercial fertilizer. As such it is registered with the WSDA. This use is not regulated by state dangerous waste laws. The generator of the cement kiln dust must notify Ecology about the existence of the waste, but does not need to get prior approval from Ecology to recycle it into a fertilizer. Ecology can, however, apply the "sham recycling criteria" to make sure the waste is being legitimately recycled.

WSDA's Authority to Regulate Fertilizer

Fertilizer manufacturers are required to get annual registration for packaged fertilizers and/or an annual license to distribute bulk products. To register packaged fertilizers, the applicant must submit the following to the WSDA:

- A completed application form. (WSDA may require the applicant to submit data to substantiate labeling claims.)
- A copy of the label for each commercial fertilizer to be registered.
- A registration fee of $25 for the first products and $10 for each additional product.

The applicant must file a bulk fertilizer license application for each physical location of the product. The application forms are provided by the Master License System of the Department of Licensing. An annual fee of $25 is required for each location.

WSDA Has Strict Labelling Requirements

When WSDA reviews and approves the labels for packaged fertilizers, the inspectors are looking at specific requirements including but not limited to: net weight, brand name, grade (if claimed to provide primary nutrients), guaranteed analysis (guarantee of the concentration of plant nutrients), the list of sources of nutrients and the name and address of the registrant or licensee. The same information is required for bulk fertilizers. Labels of bulk fertilizers are reviewed in the field. Fertilizers with organic and slow release claims have additional labeling requirements. WSDA usually tests only for the nutrients that are guaranteed on the label such as total nitrogen, available phosphoric acid, soluble potash and some of the trace elements and micronutrients, when claimed.

The manufacturer is required to provide confidential reports on tonnage sold in Washington State. The manufacturer or distributors pay an inspection fee based on the tonnage distributed in the state (usually semi-annually) to support the fertilizer testing and inspection.

WSDA Conducts Random Sampling

Penalties are assessed if the analysis of any fertilizer falls below certain levels of guarantees in any one plant nutrient (nitrogen, available phosphate, soluble potash or 12 other nutrients specified in state rules) or in total nutrients.

It Is Illegal To Misbrand Or Adulterate Any Fertilizer

Adulteration is defined as:

- A product that contains a substance that can injure beneficial plant life.
- A product with a different composition than is specified on the label.
- A product that contains unwanted viable seed.

Appendix G

Biosolids Risk Assessment and the Applicability of the Biosolids Rule to Fertilizers

Risk Assessment in the EPA Biosolids Rule

Risk assessment was used to develop Biosolids standards in order to ensure that the standards protect human and ecological health. Some of the numeric criteria for the seven metals in the Biosolids Rule are based on risk assessment, e.g., the Cumulative Loading Rates and Pollutant Concentrations.

Risk assessment is a procedure used to characterize potential adverse health effects resulting from exposures to hazardous agents[1]. Risk assessment is made up of four main components:

1. Identifying potential hazardous agents (hazard identification)
2. Gathering and evaluating information about the toxicity of the hazardous agents, i.e., how much could be harmful, and identifying the possible types of health effects (dose-response assessment)
3. Estimating the amount of exposure to people or other organisms in the situation of interest (exposure analysis)
4. Integrating steps 2 and 3 to determine if exposures are high enough to cause harmful effects (risk characterization[2]

The following summarizes some of the risk assessment assumptions used in the Biosolids Rule development. This summary is based mainly on two EPA documents: *The Technical Support Document for Land Application of Sewage Sludge*[3] and *A Guide to the Biosolids Risk Assessment for the EPA Part 503 Rule*[4].

Biosolids Exposure Pathways

In developing the Biosolids Rule, the EPA evaluated multiple ways or "pathways" in which people and other organisms might be exposed to metals from biosolids. A total of fourteen pathways were evaluated. Nine pathways evaluated impacts to people, two pathways evaluated impacts to animals (livestock), and one pathway each evaluated impacts to soil organisms (earthworms), predators of soil organisms, and plants (see Table in this appendix). Examples of human exposure pathways evaluated include eating crops grown on biosolids amended soils, directly ingesting biosolids, or being exposed to biosolids as dust in the air. The pathway which gave the highest risk for each metal (thus requiring the lowest protective concentration in biosolids) was determined to be the limiting pathway for that metal. Allowable biosolids concentrations for the nine metals were set based on the limiting pathway for each metal.

Not every metal was evaluated for each pathway. Many contaminants were screened out of pathways due to low concern based on an earlier EPA study[5]. In at least one instance, a metal was screened out of pathways for other reasons. For example, lead was evaluated in Pathway 3 (child eating biosolids), but was not evaluated in Pathways 1 and 2 due to lack of a toxicity comparison value for lead. Therefore, it is not possible to compare exposures to metals between all of the pathways.

Several organic contaminants were evaluated in the Biosolids risk assessment, but were not included in the final Biosolids Rule. Examples of organic contaminants evaluated in the risk assessment include PCBs, pesticides, and volatile organic compounds. Organic contaminants were excluded because they met one of the following criteria: pollutant had been banned or restricted for use or was no longer manufactured in the U.S., pollutant had been infrequently detected in biosolids, or pollutant was not expected to be present in biosolids above limit identified in biosolids risk assessment[4]. Chromium was also evaluated in the biosolids risk assessment, but was excluded from the final rule.

Biosolids Risk Assessment Assumptions

As part of the Biosolids risk assessment, several assumptions were made to estimate exposures from each of the 14 pathways. For example, Pathway 3 assumes that a child eats 200 milligrams of biosolids per day. This assumption is based on information about the amount of soil children eat incidentally during a day, e.g., from playing outdoors. Appendix F also lists a subset of assumptions used in the Biosolids risk assessment.

Biosolids risk assessment assumptions generally incorporate the upper range of possible exposure values to predict "high-end" exposures. For example, the risk assessment assumes 100% absorption from the gastrointestinal tract for most ingestion pathways, a 70-year lifetime exposure for pathways pertaining to adults, and a maximum allowable amount of each pollutant is applied to soil for 100 years. Many of the pathways account for general background exposures from other sources such as diet, air, and water.

While the Biosolids risk assessment includes many "high-end" exposure assumptions, it also includes some assumptions which are less protective. For example, the risk assessment evaluates exposure pathways independently, i.e., exposures are not added across pathways. Additionally, arsenic and cadmium were not evaluated as carcinogens, even though EPA classifies them as carcinogens for some pathways[6].

The EPA Reference Doses (RfD) were used to evaluate toxicity of metals for many of the human exposure pathways. The RfD is a threshold below which non-cancer effects are unlikely to occur in people, based on human and animal studies. The Biosolids standards were set by allowing exposures equal to the RfD and solving for the metal concentration in biosolids. This ensures that exposures from biosolids are below a level that could impact health. In addition, the risk assessment assumes that metals are in certain forms, e.g., arsenic in its more toxic inorganic form, since the toxicity of many metals depends on their forms. Toxicity to other organisms (plants and animals) was evaluated based on toxicity studies in the scientific literature.

Elements Not Regulated Under the EPA Biosolids Rule

Currently, there are no existing standards similar to the Biosolids standards with which to evaluate potential health or environmental impacts of the 17 non-Biosolids elements in fertilizers. In order to evaluate potential toxicity of these elements, a detailed analysis or risk assessment would be needed to estimate exposures. This might include estimating exposures to these elements from the food chain (e.g., uptake into crops). The fertilizer test results for these 17 elements represent an initial screening of the various fertilizer products. Due to the limited scope of this fertilizer sampling effort, a complex risk assessment estimating exposures to these elements is not possible at this time. The fertilizer test results for these elements may be used in combination with future fertilizer sampling to estimate potential exposures and health impacts. However, several of these elements – such as calcium, sodium, iron, and magnesium – would likely be dropped from further exposure assessment due to their low toxicity.

Ecological Risk Assessment of Fertilizer Application

In order to more broadly evaluate the risk of contaminants in fertilizers, an ecological risk assessment should be performed which include steps in problem formulation, analysis, and risk characterization[7,8]. In the problem formulation phase, a conceptual model is developed, and assessment and measurement endpoints are selected. In the analysis phase, exposure and ecological effects are characterized. The spatial and temporal distribution of chemical and physical stressors is addressed, and their impact on individuals, populations, and communities is quantified. The risk characterization phase uses input from the analysis phase to determine the likelihood of exposure to chemical or physical stresssors resulting in adverse ecological effects. A tiered approach is often employed to characterize the risk with an acceptable degree of uncertainty.

In the EPA Biosolids Rule, five of the 14 exposure pathways for application of biosolids to agricultural land focused on ecological receptors. These receptors included herbivorous livestock (e.g., cattle, sheep), plants (crop species), soil organisms (earthworms), and predators of soil organisms (insectivorous mammals, birds). These represent a relatively limited suite of exposure pathways and receptors in terms of ecological risk assessment. Other important ecological receptors on agricultural land may include soil microorganisms, soil invertebrates (other than earthworms), and mobile species, e.g., deer, whose foraging range overlaps with agricultural land. Because contaminants may also be transported off-site to nearby non-agricultural land, additional receptors may include non-crop plants, terrestrial wildlife species (e.g., mammals other than livestock, birds other than chickens, reptiles, amphibians), and aquatic biota in nearby wetlands and surface waters (e.g., macrophytes, phytoplankton, zooplankton, fish).

References

1) Faustman, E.M. and G.S. Omenn, 1996. Casarett and Doull's Toxicology, Fifth Edition, Chapter 4. Klaassen, C.D., Amdur, M.O. and Doull J., eds., McGraw-Hill Publishers.

2) National Research Council, 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington DC.

3) USEPA, 1992. The Technical Support Document for Land Application of Sewage Sludge. EPA 822/R-93-001a and 001b.

4) USEPA, 1995. A Guide to the Biosolids Risk Assessment for the EPA Part 503 Rule. EPA 832-B-93-005.

5) USEPA, 1985. Summary of Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Methods and Results. Office of Water Regulations and Standards, Wastewater Criteria Branch, Washington, D.C.

6) Southworth, R.M., 1995. The Part 503 Land Application Pollutant Limits for Arsenic. EPA technical paper.

7) Wentzel, R.S., T.W. LaPoint, M. Simini, R.T. Checkai, D. Ludwig, and L.W. Brewer, 1996. Tri-Service Procedural Guidelines For Ecological Risk Assessment. Vol. 1. ADA314323.

8) USEPA, 1996. Proposed Ecological Guidelines For Ecological Risk Assessment. Fed. Reg. 61(175): 47551-47631.

Exposure Pathways and Assumptions Used in Biosolids Risk Assessment

Pathway	Description	Metals evaluated	Risk assessment assumptions[1]
1	Person ingesting crops grown on biosolids-amended soils (commercial consumer).	As, Cd, Hg, Ni, Se, Zn	• 2.5% of vegs./fruits grown on sludge amended soils, • plant uptake estimated mainly from biosolids studies by group (garden fruits, grains/cereals, leafy vegs., legumes, potatoes, and root vegs.).
2	Home gardener ingesting crops grown in biosolids-amended soils.	As, Cd, Hg, Ni, Se, Zn	• 37-59% of vegetables grown on sludge amended soils, • plant uptake estimated same as for Pathway 1.
3	Child eating undiluted biosolids. Limiting pathway for As, Cd, Pb, Hg and Se.	As, Cd, Cu, Pb, Hg, Mo, Ni, Se, Zn	• EPA's Biokinetic Model used to estimate blood leads, • children age 1-6 yrs with bodyweight of 16 kg, • 200 mg/day biosolids ingestion rate for children.
4	Person ingesting animal products where animals are raised on forage grown on biosolids-amended soil (farm household).	Cd, Hg, Se, Zn	• metals uptake into animal tissues from forage, • uptake into forage same as for Pathway 1, • 11% poultry, 10% beef, beef liver, lamb, and pork, 3% dairy products, and 8% eggs of an adult's diet from biosolids affected sources.
5	Person ingesting animal products where animals ingest biosolids directly.	Cd, Hg, Se, Zn	• includes foods from grazing animals: beef, beef liver, lamb, and dairy products, • animal uptake slopes from soil taken from literature, • assumed 1.5% of animal's diet is sewage sludge, • 10% beef/lamb and 3% dairy products of an adult's diet from biosolids affected sources.
6	Animal ingesting plants (forage and grain) grown on biosolid-amended soils. Limiting pathway for Mo.	As, Cd, Cu, Pb, Mo, Ni, Se, Zn	• based on most sensitive/most exposed herbivorous livestock.
7	Animal toxicity from ingesting biosolids (herbivorous livestock).	As, Cd, Cu, Pb, Mo, Ni, Se, Zn	• accounts for background metal soil concentrations, • assumed 1.5% of livestock's diet is sewage sludge.

8	Plant toxicity due to uptake of pollutants when grown in biosolids-amended soils. Limiting pathway for Cu, Ni and Zn.	Cu, Ni, Zn	• used lowest value of either plant growth retardation values or threshold phytotoxic concentrations, • considered relative sensitivity of different crops, • used same plant uptake factors as in Pathways 1 & 2.
9	Soil organism ingesting biosolids/soil mixture (toxicity to soil organisms).	Cu	• based on impacts to earthworms.
10	Predator of soil organisms that have been exposed to biosolids-amended soils.	Cd, Pb	• based on impacts to insectivorous small mammals (shrews and moles).
11	Person inhaling particles (dust) from occupational exposure (e.g., tractor driver tilling a field).	As, Cd, Pb, Hg, Ni	• used occupational standards (NIOSH[2]) for metals to evaluate safety (TWA-10 hr. exposures), • 10 mg/m^3 max. dust concentration (ACGIH[2] standard), • distance from driver to soil surface = 1 m, • sewage sludge incorporated in soil to depth of 15 cm.
12	Person drinking surface water and eating fish containing pollutants in biosolids.	As, Cd, Cu, Pb, Hg, Ni	• 2 liters/day drinking water consumption, • 40 gm fish/day fish consumption, • assumed rates of soil erosion.
13	Person inhaling of biosolid pollutants volatilized to air.	none[3]	--
14	Person drinking well water containing pollutants from biosolids that leached from soil to ground water.	As, Cd, Cu, Pb, Hg, Ni	• sewage sludge assumed to be applied for 20 years.

[1] A subset of biosolids risk assessment assumptions are provided. Please consult EPA, 1992 and EPA, 1995 for further assumptions.
[2] NIOSH: National Institute for Occupational Safety and Health, ACGIH: American Conference of Government Industrial Hygienists.
[3] Note: Organic contaminants were included in many of the biosolids risk assessment pathways.