Projecting Farm Income Effects of Sewage Sludge Utilization in the Tualatin Basin of Oregon

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INTRODUCTION AND OBJECTIVES

Sewage treatment plants face significant disposal problems resulting from increased volumes of sewage and higher in-stream water quality standards. Substantial quantities of materials which were formerly discharged into streams and rivers are now removed and must be disposed as sludge.

Nutrients and organic matter in processed sewage sludge which cause pollution problems in water can be of benefit when applied on land. The possible benefits of sludge application would show up in the quality and quantity of crop production. Organic materials present in sewage sludge may improve the physical and chemical properties of soil. Some nutrients in the sludge, such as nitrogen in the ammonium form, may be available to plants immediately, while organically bound nutrients will be released with time. While the benefits of improved soil condition are difficult to quantify because they occur over a long period of time, the cost savings due to lower fertilizer requirements and increased crop yields have direct effects on farm income, and can be more readily estimated.

The rationale of this study is to separate two questions. The first is the concern of the sewerage agency as to whether it is less expensive to dispose of sludge by land application rather than some alternate disposal method such as incineration or pyrolysis. The second question is the farmer's concern about his gain in net income if he used sludge in his farm fertilization program. Recent increases in the prices of two key inputs - energy for treatment plants and chemical fertilizers for farmers - have made re-evaluation of alternatives to traditional management practices an important issue for both sewage treatment plants

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and farmers. As the prices of chemical fertilizers increase, sludge may become more attractive as an alternate nutrient source. From the perspective of the sewerage agency, the nutrients may have sufficient value that revenues can be generated to offset some disposal costs. The agency's responsibilities include treating sewage to meet applicable standards, and disposing of by-products at the least cost without jeopardy to the public.

From the farmer's point of view, sewage sludges represent a mixed blessing. The benefits to the farmer may be significant; however, the use of sludge may increase management problems because of the presence of trace elements, possible pathogens, public concerns, and, hence, restrictions on the crops to which it may be applied. Additional cultivation and use of herbicides may be required, and timing of application may need to be scheduled. Thus, the farmer may incur both increased costs and constraints on his management prerogatives to gain the benefits from sludge use.

Several conditions are converging to increase the potential for mutually beneficial agreements between sewerage agencies and farmers regarding the application of sludge and effluent to farmland. The general objective of this research is to analyze the potential benefits and costs derived from the use of sludge on agricultural lands in the Tualatin Valley (Washington County) of Oregon. Costs for delivering and applying the materials to the land are not considered. Factors evaluated in estimating the returns to sludge use include soil characteristics, crop rotations, sludge composition, crop costs and prices, required changes in cultivation practices, and sludge application rates.

The specific objectives of this study are to

1. Estimate the extent to which sewage sludge could be substituted for commercial fertilizers in the production of selected crops grown on selected soils in the Tualatin Valley.
2. Indicate what changes in cultural practices would be required to provide for safe and effective utilization of the sludge.
3. Estimate the impact on farm income when alternative levels of sewage sludge applications are made to agricultural land.

SUMMARY OF FINDINGS

This study analyzes the utilization of sewage sludge and effluent on selected agricultural crops in the Tualatin River Basin of Oregon. The Tualatin Valley is a diverse agricultural area located primarily in Washington County, adjacent to and serving as a bedroom community for Portland. The soil types in the study area were studied and three prominent types - Willamette, Woodburn, and Laurelwood and Kinton combined - were selected for study.

On the selected soil types, sweet corn, bush beans, wheat, tall fescue hay, and barley were selected for analysis. The selection of these crops, especially tall fescue hay, was based, in part, on the availability of data from experiments conducted by the Oregon Agricultural Experiment Station at the North Willamette Experiment Station. Six rotations for these crops were developed for the three soil types. For each rotation, a sludge application and fertilizer use program was specified which would provide the nutrients needed to meet the assumed yields for each crop. Three alternatives were considered, including no sludge use, a low level of sludge application, and a high level of sludge application. Cost budgets were developed for each rotation on each soil type at each level of sludge use. These cost budgets considered the changes in production practices required if sludge were used. Recommended management practices for the use of the sewage sludge are outlined.

The increased return to land and management per acre from the use of sludge, compared to traditional fertilizer sources, ranges from -\$6 to +\$15 per acre, depending on the rotation, previous soil management, soil type, and level of sludge application. These benefits from sludge use accrue from the fertilizer savings after subtracting costs for new production practices. It appears from the analysis that the greatest benefits accruing from the use of sludge occur on the less productive soils (Laurelwood and Kinton) using a rotation of 10 years of tall fescue hay with wheat and bush beans. However, depending on the degree of slope involved, these benefits may be offset at some locations by the costs required for contouring and other runoff control practices. A second rotation evaluated for Laurelwood and Kinton soils, wheat and barley, provided a lower return to the use of sludge, but did offer a higher total net return to land and management.

On the higher quality soils (Willamette and Woodburn), an intensive rotation, including sweet corn, bush beans, and wheat, gave the highest net return to land and management and the largest increase in net return resulting from sludge use. However, the acreages of the vegetable crops in this rotation will be constrained by the availability of contracts from the vegetable processors. Furthermore, the recent closure of the last local vegetable processing plant in the Tualatin Valley area further restricts this alternative. The additional transportation costs for moving the produce to other processing plants was considered in the analysis. However, the distance may present other disadvantages for local growers.

Of the other rotations evaluated on Willamette and Woodburn soils, the two including 10 years of tall fescue grass hay provided sizeable benefits to the substitution of sludge for traditional fertilizer. However, these two rotations had lower total net returns to land and management and, because of their length, would reduce the farm operator's ability to adjust to changes in product prices. On these higher quality soils, it appears that a three-year rotation of wheat, barley, and corn is a good compromise between the returns to sludge use and the overall returns to land and management.

In this study, the sewage sludge was assumed to be available to the farmer, with no cost for application. If the sludge were available to the farmer under this type of agreement, he would need to weigh the potential benefits against any increase in risk or preference against using the sludge. Careful management of application, monitoring of the composition and the effects of the sludge, and, possibly, written agreements between the farmer and the sludge supplier are important to the successful development of an agricultural sludge utilization program.

DESCRIPTION OF TUALATIN VALLEY

Climate

The Tualatin Valley, located primarily in Washington County, Oregon, is subject to a mild marine climate, with warm, dry summers and cool, wet winters. Annual frost-free days average between 165 and 210 days. Temperature averages between 51° and 53° F, and precipitation is 35 to 55 inches annually. Precipitation occurs mainly during November through February, with an average water surplus, in excess of crop demand, of 3.6 to 6.9 inches, occurring in December and January, respectively (Johnsgard, 1963). Soils are dry for prolonged periods during the summer.

Geology and Soils

Soils of the Tualatin Valley were formed from a variety of parent materials including basalt, siltstone, sandstone, shale, old and recent alluvium, and mixed materials dominated by loess. Land forms include flood plains; alluvial fans and lakebeds; stream-cut terraces; broad, valley floor terraces; high, valley-margin terraces; silt-mantled footslopes; and foothills of the Coast Range mountains (State Water Resources Board, 1969).

The preliminary soil survey for Washington County has been completed, and lists the soil series name and areas for the soils in the Tualatin Valley (Appendix Table B-1).

Description of the Agricultural Sector

Approximately 6 percent of the state's farms are located in Washington County, with 4 percent of the state's total agricultural output originating there.[1/] The total number of farms in 1974 was 1,909, of which 954 had sales in excess of $2,500. In 1974, average farm size in the study area was 86 acres. Sixty-two percent of the farms in Washington County have less than 50 acres. Another 27 percent of the farms have between 50 and 180 acres. Of the remaining farms, approximately one-fourth are over 500 acres in size.

1/ Unless otherwise noted, all data were taken from the U.S. Bureau of the Census, 1974 Census of Agriculture: Preliminary Report. Oregon. U.S. Government Printing Office, Washington, D.C., Sept. 1976, Ag 74-P-41-000, and 1974 Census of Agriculture, Preliminary Report, Washington County, Oregon. U.S. Government Printing Office, Washington, D.C., Aug. 1976, AG 74-P-41-067.

In terms of sales, approximately one-half of the farms had gross revenues in excess of $2,500, and 12 percent had sales in excess of $40,000. Of the total revenue associated with agricultural output in 1974, 77 percent was earned by crop production, including nursery products and hay. The leading crops in terms of 1976 value of production were horticultural specialty crops, wheat, and strawberries (Table 1).

The diversity of agriculture in Washington County can be seen from the range of crops grown, and the range in farm size. Fully one-half of the farms are operated on a part-time basis, reflecting the fact that the area has become a bedroom community for Portland. Yet, agriculture produces a variety of crops, ranging from nursery products to small grains, vegetables, hay, tree nuts, and fruit.

While average farm size is small, and the quantity of farmland declining (4 percent decrease between 1969 and 1974), the trend has been toward larger units. This trend toward larger farms may enhance the stability required for long-term contractual arrangements regarding application of sludge to privately owned land.

SELECTION OF SOILS FOR STUDY

Criteria for Selection of Soils Suitable for Sludge Application

The following criteria were used to select the soils on which the economic benefits/losses resulting from sewage sludge additions would be studied:

1. Slope should be less than 9 percent (Table 2).
2. Depth to bedrock should be greater than 60 inches for no limitation, and between 20 and 60 inches for slight limitation.
3. Depth to seasonal high water table should be at least 24 inches, and preferably 60 inches, to avoid ground water contamination.

Table 1: Production and value of agricultural crops, Washington County, 1976

Crop	Unit	Acres harvested	Yield per acre	Total production	Price per unit dollars	Value of production thou. dollars
Wheat.....................	bu.	32,500	72.0	2,332,000	2.70	6,297
Barley....................	bu.	4,000	57.0	228,000	2.21	504
Oats......................	bu.	6,500	62.0	404,600	1.72	694
Rye.......................	bu.	100	42.0	4,200	2.62	11
Alfalfa...................	ton	6,000	3.6	21,730	75.00	1,629
Clover, grass.............	ton	11,500	2.3	26,690	61.20	1,634
Small grain hay...........	ton	1,200	2.1	2,460	54.50	134
Wild & other hay..........	ton	3,000	1.5	4,500	50.00	225
Silage, corn..............	ton	3,000	21.8	65,307	18.20	1,188
Crimson clover seed.......	lbs.	6,510	320.0	2,088,000	0.354	739
Red clover seed...........	lbs.	6,100	240.0	1,444,000	0.792	1,143
Hairy vetch seed..........	lbs.	4,300	550.0	2,868,000	0.255	603
Chewings fescue seed......	lbs.	100	520.0	52,000	0.442	23
Red fescue seed...........	lbs.	100	510.0	51,000	0.431	22
Other Ky. bluegrass seed..	lbs.	100	590.0	59,000	0.542	32
Common vetch seed.........	lbs.	730	696.0	508,000	0.201	102
Austrian peas.............	lbs.	60	733.0	44,000	0.114	5
Potatoes..................	cwt.	600	340.0	204,000	3.66	746
Apples....................	box	—	—	32,000	3.45	110
Tart cherries.............	ton	—	—	310	523.00	162
Sweet cherries............	ton	—	—	840	352.00	296
Peaches...................	box	—	—	35,000	8.25	288
Bartlett pears............	ton	—	—	150	173.30	26
Prunes & plums............	ton	—	—	4,100	102.90	422
Grapes....................	ton	—	—	75	307.00	23
Filberts..................	ton	—	—	1,900	647.00	1,230
Walnuts...................	ton	—	—	290	630.00	185
Strawberries..............	lbs.	1,500	9,380.0	14,069,000	0.286	4,026
Red raspberries...........	lbs.	42	5,000.0	210,000	0.295	62
Black raspberries.........	lbs.	208	1,630.0	338,000	0.494	167
Tame blackberries.........	lbs.	160	8,700.0	1,392,000	0.285	397
Boysen & youngberries.....	lbs.	35	4,510.0	158,000	0.278	44
Loganberries..............	lbs.	10	5,520.0	138,000	0.21	29
Blueberries...............	lbs.	55	7,036.0	387,000	0.393	152
Gooseberries..............	lbs.	15	5,267.0	79,000	0.241	19
Currents..................	lbs.	10	4,600.0	46,000	0.196	9
Dry onions, West..........	cwt.	450	485.0	218,000	2.85	623
Sweet corn, fresh.........	cwt.	25	100.0	2,500	8.40	21
Snapbeans, processed......	ton	700	4.7	3,310	131.70	436
Sweet corn, processed.....	ton	500	7.9	3,950	59.00	233
Broccoli, processed.......	cwt.	100	71.0	7,125	10.10	72
Cucumbers, processed......	ton	435	11.8	5,133	121.95	626
Tomatoes..................	cwt.	10	300.0	3,000	12.00	36
Squash & pumpkin..........	cwt.	10	400.0	4,000	3.00	12
Specialty, horticultural..	XXX	—	—	—	—	9,200
Forest farm products......	XXX	—	—	—	—	600

SOURCE: Stanley Miles, Extension Economics Information Office, Oregon State University, Corvallis.

Table 2: Slope and acreage of selected soil series in the Tualatin Valley suitable for sewage sludge application

Soil series	Slope	Area[a/]
	percent	acres
Kinton-Cornelius	2 - 7	7,941
	7 - 12	9,877
		17,718
Laurelwood	2 - 7	6,191
	7 - 12	8,712
		14,803
Woodburn	0 - 3	20,395
	3 - 7	10,877
	7 - 12	2,124
		33,396
Willamette	0 - 3	5,758
	3 - 7	1,666
	7 - 12	293
		7,717

a/ Figures obtained from preliminary Washington County Survey, Soil Conservation Service, Hillsboro, Oregon.

Description of Soils Selected for Study[2/]

Willamette *(Pachic Ultic Argixeroll)*. - Willamette soil is a deep, well-drained silt loam formed in silty alluvium of mixed materials or lacustrine silts. It occurs on broad valley terraces, at elevations from 150 to 450 feet. These soils are suited to a wide variety of crops including vegetables, grasses, and grains.

Woodburn *(Aquultic Argixerolls)*. - Woodburn soil is a moderately well-drained silt loam over heavy silt loam formed in silty alluvial deposits. It occurs on broad valley terraces at elevations from 150 to 400 feet. Soils are suited for cultivation of cannery crops, grain, hay, and pasture.

2/ Detailed soil descriptions are from an unpublished Washington County soil survey report.

Laurelwood *(Ultic Haploxeralf)*. - Laurelwood soil is a well-drained silt loam over silty clay loam formed in loess-like material. It occurs on low uplands at elevations from 200 to 1,500 feet. Soils are suited for cultivation of grain, hay, and pasture.

Cornelius *(Ultic Haploxeroll)*. - Cornelius soil is a moderately well-drained silt loam over silty clay loam formed in silty loess-like material and old silty alluvium of mixed origin. It occurs on the uplands at elevations from 350 to 800 feet. Crops cultivated on these soils include grain, seed crops, hay, and pasture. A fragipan occurs below the argillic horizon (at 38 inches).

Kinton *(Typic Fragiochrept)*. - Kinton soil is similar to Cornelius, except it is formed over old alluvium of mixed origin. Both soils appear as one unit on soil survey maps of the area.

The locations of these selected soil series are indicated in Appendix Figure C-1.

Soil Properties in Relation to Sewage Sludge Application

Most soils contain negatively-charged clay and organic particles which act as sites of attachment for cations (positively-charged ions). The capacity of a soil to retain cations is referred to as the cation exchange capacity (CEC), and is measured in millequivalents per 100 grams (meq/100 g) of air dry soil (Table 3). The ability of a soil to sorb cations is, thus, related to the CEC of the soil. Generally, the higher the positive charge on the cation, the greater the force of attraction to the soil exchange site. Positively charged ions such as zinc and copper may be sorbed on the negatively charged exchange sites in the soil. Upon sorption to soil exchange sites, the mobility of a cation in the soil is markedly reduced.

Texture is also related to the ability of a soil to retain cations. The surface area per unit mass of a given soil increases rapidly with a reduction in particle size. With an increased surface area, large organic molecules which could contain some trace elements of concern - lead, nickel, zinc, cadmium, and copper - are more readily sorbed by the soil.

Table 3: Cation exchange capacity and pH of four Tualatin Valley soils a/

Soil series	Soil texture	CEC	pH
		meq/100 g	
Willamette..............	silt loam	13 - 22	5.4 - 5.9
Woodburn................	silt loam	18.3 - 21.8	5.5 - 5.6
Laurelwood..............	silt loam	10.8 - 26.5	5.2 - 5.9
Kinton..................	silt loam	10.4 - 14.3	5.3 - 5.8

a/ Data from Oregon State University Soil Testing Laboratory, Corvallis.

Although some trace elements are sorbed on exchange sites, most are present in the soil matrix as precipitates. The solubility of these precipitates is related to the pH of the soil. Trace element availability to plants is thus strongly affected by soil pH. As the pH of a soil increases, cations such as zinc, cadmium, nickel, and lead form hydroxides, and are less available for uptake by plants. Other cations, such as manganese (Mn^{2+}), are oxidized to insoluble forms (MnO_2) in the presence of hydroxide ions at higher pH (Leeper, 1972). Numerous experiments have shown that toxic effects of trace elements in sewage sludge may be controlled by maintaining a soil pH above 6.5. For example, oat plants were severely damaged when grown on an acid soil (pH 5.3) treated with 134 metric tons of sludge per hectare, but when the same soil, similarly treated with sludge, was limed to a pH of 6.8, yield was unaffected (Page, 1974).

SLUDGE UTILIZATION AND INCOME EFFECTS

Selection Criteria for Crops Grown on Sludge-Amended Soils

Sweet corn, bush beans, dryland winter wheat, dryland tall fescue hay, and dryland spring barley were selected as the crops to be studied for use in a fertilization program based on application of digested sewage sludge. Suitability to climate and soil types in the Tualatin Valley, as well as the economic realities in the area, were considered in the selection process. Availability of research data from which to extrapolate yield and trace element uptake values was also an important consideration. Research on corn, wheat, and tall fescue is presently underway at the North Willamette Experiment Station (Jackson et al., 1976). Yield data from that project, as well as experiences with management considerations associated with sludge-amended soils, were incorporated into this report. Data are also available in the literature on the response of sewage sludge on corn, snap beans, and five other vegetable crops grown on sludge-amended soils (Dowdy and Larson, 1975).

Plants vary tremendously in uptake of trace elements (Page, 1974). Because they tend to accumulate trace elements, and because of possible microbiological concerns on fresh market produce, leafy vegetables and root crops were not incorporated into this sewage sludge study. In all probability, selected leafy vegetable and root crops could be grown on soils which had received limited sludge treatments in years prior to the growth of the susceptible crop. For purposes of this study, applications of sewage sludge to soils in the fall, prior to spring planting of a vegetable crop such as beans, were considered to provide sufficient time for reduction of trace element availability and elimination of pathogen problems. Several years should lapse before crops for the fresh food market should be planted on sewage sludge treated land (Bauer, 1977). Dowdy et al., (1975) have stated that feed grains or grains in general are less sensitive to trace element uptake. Their studies have shown that grasses are the most tolerant crop to trace elements. Thus, crops such as wheat, corn, barley, and tall fescue are well suited for growth on soils treated with sewage sludge.

Crop rotations were selected (Table 4) on the basis of the crops selected for analysis, and the typical cropping patterns existing in Washington County. The inclusion of tall fescue grass is the only exception. Tall fescue was included because of its ability to utilize sizeable amounts of nitrogen, and its adaptation to the Tualatin Valley climate.

Table 4: Crop rotations assumed for analysis of sludge use, Tualatin Basin, Oregon

Rotation I:

Beans - 1 year; wheat - 1 year; corn - 1 year; wheat - 1 year.

Rotation II:

Tall fescue - 10 years; barley - 1 year; wheat - 1 year.

Rotation III:

Wheat - 1 year; barley - 1 year.

Rotation IV:

Tall fescue - 10 years; wheat - 1 year; beans - 1 year.

Rotation V:

Wheat - 1 year; barley - 1 year; beans - 1 year.

Rotation VI:

Wheat - 1 year; barley - 1 year; corn - 1 year.

Selection of Digested Sewage Sludge

Digested sewage sludge from treatment plants at Aloha, Forest Grove, Hillsboro, Oregon City, and Portland (Table 5) was compared with respect to chemical constituents, especially nitrogen, phosphorus, potassium, lead, cadmium, zinc, nickel, and copper.

Sewage sludge from the Portland area contained higher trace element concentrations than the other sewage sludges. It also contained the lowest nitrogen content. Because of the low total nitrogen content and relatively high trace element content, the Portland sewage sludge was used as a basis to calculate application rates and maximum lifetime loadings for the selected soils and crops.

With the lower total nitrogen content, higher sewage sludge applications would be required to supply a constant amount of nitrogen available to the plant. With this higher rate of sewage sludge application, possible problems with trace elements would be reached sooner.

Table 5: Analyses of sewage sludge from five treatment plants in the Tualatin Valley for 1976

Element	Location				
	Portland[a/]	Forest Grove [b/]	Hillsboro[b/]	Oregon City [b/]	Aloha[a/]
	ppm				
Lead (Pb)......	1,412	147	153	567	231
Cadmium (Cd)...	47	18	20	23	12
Copper (Cu)....	1,154	377	1,662	433	732
Nickel (Ni)....	173	69	72	110	28
Zinc (Zn)......	3,250	1,730	1,808	2,267	2,800
	percent				
Nitrogen (N)...	4.58	4.8	5.85	12.1	7.1
Phosphorus (P).	1.3	1.1	1.5	2.2	2.5
Potassium (K)..	0.47	0.41	0.27	0.53	0.45

a/ Alternative Methods for Disposal of Sewage Solids, City of Portland Department of Public Works, 1976.

b/ Lolita Carter, A Study to Characterize Certain Sewage Treatment Plant Effluents and Sludges in the Portland Metropolitan area, Relative to their Disposal by Land Application. Portland State University, 1976.

Portland sewage sludge also represented the largest volume of output and, therefore, the greatest disposal problem, in the area. Portland has a sewage sludge discharge rate of 285,000 gal./day (Department of Public Works, Portland, Oregon, 1976), as compared to 7,000 gal./day for Hillsboro and 4,000 gal./week for Forest Grove (Carter, 1976).

Nitrogen, Phosphorus, and Potassium Requirements of Selected Crops

Nitrogen, phosphorus, and potassium requirements and expected yields of selected crops have been established (Table 6, Appendix Table B-3). Application rates for sewage sludge were designed to meet the nitrogen requirement of the particular crop. Economic returns from the two levels of sludge application

Table 6: Yields and nitrogen requirement of crops compatible with sludge-amended soils

Crop	Yield	Nitrogen required: Total a/	Band	Broadcast
		pounds per acre		
Barley.......	1.5 t/acre	70	20	50
Beans........	4 t/acre	50	35	15
Corn.........	8 t/acre	120	40	80
Fescue.......	3 t/acre	100	20	80
Wheat........	75 bu/acre	150	20	130

a/ Fertilizer Guides. Oregon State University Extension Service, Corvallis.

were determined. The "high" sewage sludge application rate would supply all the crop nitrogen requirements other than that nitrogen required in a band application at planting time. The second, or "low", rate of sewage sludge application is one-half of the high rate. Nitrogen from sewage sludge was never assumed to meet band requirements for nitrogen at seeding time. Band fertilizer applications are localized applications of fertilizer which assist early seedling growth. The band application requirements of nitrogen would be contributed by commercial fertilizer only. From preliminary results on sweet corn grown on Willamette sandy loam soils, the suggested band fertilization of phosphorus may not be needed after several years of sewage sludge application.

Calculation of Sewage Sludge Required to Satisfy the Nitrogen Requirement of the Selected Crops

Nitrogen generally occurs in two forms in sludge - ammonium and organic nitrogen. Ammonium forms in Portland sewage sludge represented, on an average, 42 percent of the total nitrogen in the sludge. Nitrogen in the organic form made up the remaining 58 percent. Portland sludge averaged 4.58 percent total nitrogen on a dry-weight basis. Since approximately one-half of the ammonium was estimated to be lost due to volatilization of NH_3-N when sludge was surface-applied, only 50 percent of the ammonium forms of nitrogen would be available to the plant during the first year after sludge application. The NH_3 loss may be reduced to 25 percent if sludge is incorporated within a short time period after application. Less sewage sludge would be needed to meet the nitrogen requirement of a particular crop if 75 percent of the ammonium nitrogen, rather than 50 percent, is available to the plant.

To determine the proportion of the nitrogen requirement of a crop met by ammonium forms of nitrogen in the sludge, the following terms may be used:

$$\text{Available } NH_4\text{-N} = 0.5yx_1 \text{ or } (0.5)(0.42)x_1 \text{ or } 0.21x_1 \text{ (for Portland sludge)} \quad (1)$$

with x_1 = total amount of sludge nitrogen needed to meet nitrogen requirements during the cropping year;

y = fraction of total nitrogen represented by ammonium forms (for Portland sludge, $y = 0.42$); and

0.5 = fraction of ammonia lost by volatilization.

The organic nitrogen in sewage sludge becomes available to plants through microbial mineralization of the organic residues. A decay rate was assumed so that decreasing amounts of the residual organic nitrogen were mineralized each year after the initial application. After five years, very little nitrogen is released through mineralization of residual organic nitrogen from a given sludge application. The following decay or mineralization rate for organic nitrogen compounds was estimated for the Tualatin Valley:

0.3 (1st year), 0.15 (2nd year), 0.07 (3rd year), 0.02 (4th and 5th years).

During the first year after the initial sludge application, 30 percent of the organic nitrogen fraction becomes available to the crop through mineralization. Fifteen percent of the remaining organic nitrogen is mineralized during the second year, and 7 percent during the third year. For the fourth and fifth years after initial application, 2 percent of the remaining unmineralized organic nitrogen from that application is mineralized. If the sewage sludge were applied in the fall, the organic nitrogen would not be mineralized rapidly during the cool, wet winter; however, mineralization would accelerate during the spring as temperatures and microbial activity increase. If, therefore, sludge is applied in the fall, most of the initial nitrogen benefit is derived from the ammonium fraction.

The organic nitrogen fraction may be expressed by the following terms:

$$\text{Total Organic Nitrogen } (TON_1) \text{ applied} = (1-y)x_1 \tag{2}$$

where

x_1 = total amount of sludge nitrogen needed to meet plant requirements during the first cropping year;

y = fraction of total nitrogen in sludge represented by ammonium nitrogen (for Portland sludge, $y = 0.42$);

or for Portland sludge,

$$TON_1 = (1-0.42)x_1 \text{ or } 0.58\ x_1. \tag{3}$$

Using the decay rate given above, 30 percent of the organic nitrogen in the applied sludge is mineralized the first year, so that the term for the mineralized organic nitrogen (MN) is:

$$MN_1 = 0.3(1-y)x_1 \tag{4}$$

or, for Portland sludge,

$$MN_1 = 0.3(1-.42)x_1 \text{ or } 0.174x_1. \tag{5}$$

The total amount of nitrogen available for plant growth for the first year then becomes:

$$NR_1 \text{ (nitrogen requirement)} = 0.5yx_1(NH_4\text{-N}) + 0.3(1-y)x_1 \text{ (organic-N)}, \tag{6}$$

or, for the Portland sludge,

$$NR_1 = 0.5(0.42)x_1 + 0.3(1-0.42)x_1 = .384x_1. \tag{7}$$

For the second year of sludge application, contribution to the available nitrogen requirement from the ammonium forms is, again:

$$\text{Available } NH_4 - N = 0.5yx_2, \text{ or } 0.21x_2 \text{ (for Portland sewage sludge)}, \tag{8}$$

with x_2 = sludge nitrogen added during the second year to meet crop requirement, and

y = fraction of total nitrogen represented by ammonium forms (for Portland sludge, $y = 0.42$),

and the contribution from the mineralization of the organic matter from the second year of sludge application is:

$$0.3(1-y)x_2, \text{ or } 0.174x_2 \text{ (for Portland sludge).} \qquad (9)$$

The equation for the nitrogen contributions from the second year of sewage sludge application becomes:

$$\text{Total nitrogen } (TN_2) = NH_4 - N + \text{mineralized organic N,}$$

or, for Portland sludge, substituting terms (8) and (9),

$$TN_2 = 0.21x_2 + 0.174x_2 \qquad (10)$$

$$= 0.384x_2.$$

However, the mineralization of the residual organic nitrogen compounds from the first year of sewage sludge application must be added to the expression. The term for the nitrogen mineralized in the second year from the residual organic nitrogen applied in the first year is:

$$MN_{12} = DR_2\ (TON_1 - MN_1) \qquad (11)$$

where

MN_{12} = organic nitrogen mineralized during the 2nd year from the 1st year sludge application;

DR_2 = Decay rate for 2nd year after application;

MN_1 = organic nitrogen mineralized during the 1st year of application of sewage sludge;

TON_1 = total organic nitrogen present in the 1st year application of sewage sludge.

Substituting terms (2) and (4) for TON_1 and MN_1, we have

$$MN_{12} = 0.15\ [(1-y)x_1 - 0.3(1-y)x_1] \qquad (12)$$

$$= 0.105\ (1-y)x_1,$$

or, for Portland sludge, substituting terms (3) and (5),

$$MN_{12} = 0.15\ (0.58x_1 - 0.174x_1) \qquad (13)$$
$$= 0.06x_1.$$

To obtain the total available nitrogen for the second year, one must sum the available $NH_4 - N$ and the mineralized organic N from both the first and second year sludge application:

$$MN_2 = TN_2 + MN_{12}. \qquad (14)$$

Substituting terms (10) and (13) into the equation for TN_2 and MN_{12},

$$MN_2 = 0.384x_2 + 0.06x_1.$$

For each of the subsequent years of sewage sludge application, mineralization of residual organic N from the four previous years of application is considered to determine the total amount of sewage sludge required for the crop.

For the 3rd year after application, and with a decay rate of 0.07, the expression for mineralized organic nitrogen (MN_{13}) from a given year of application is,

$$MN_{13} = 0.07\ [(1-y)x_1 - 0.3(1-y)x_1 - 0.105(1-y)x_1] \qquad (15)$$
$$= 0.04\ (1-y)x_1.$$

The amount of sludge nitrogen that must be applied in a given year to meet the nitrogen requirement of that cropping year is, therefore, calculated by summing the contributions of ammonium-nitrogen and mineralized organic nitrogen remaining from each of the previous four years of sewage sludge application.

The sewage sludge applications required for each crop in each rotation were calculated (Table 7).[3/] After the first complete crop rotation, sewage sludge application rates for each crop move toward an equilibrium application rate. For example, Rotation 1 (beans, wheat, corn, wheat): After the fourth year, the application rates for each crop have reached their equilibrium rates: beans, 1,310 pounds sludge/acre/year; wheat, 7,736 pounds; corn, 5,349 pounds;

3/ A sample of the calculations for one rotation is presented in Appendix Table B-2.

Table 7: Nitrogen, phosphorus, and potassium additions from sludge applied to meet the N requirement of selected crops in the Tualatin Valley

Rotation	Year	Crop	Sludge N required[a/]	N carry-over	Total sludge applied[a/]	Available P	Available K	Reduction in P requirement, and K saved: Willamette P	Willamette K	Woodburn P	Woodburn K	Laurelwood & Kinton P	Laurelwood & Kinton K
			pounds per acre										
I	1	Beans	130	0	2,845	17	7	7	7	7	7	NA[b/]	NA[b/]
	2	Wheat	370	8	8,074	48	19	0	0	0	0	"	"
	3	Corn	247	25	5,393	33	12	4	12	4	12	"	"
	4	Wheat	330	23	7,211	43	17	0	0	0	0	"	"
	5	Beans	60	27	1,310	8	3	7	3	7	3	"	"
	6	Wheat	354	14	7,736	47	18	0	0	0	0	"	"
	7	Corn	245	26	5,349	32	12	4	12	4	12	"	"
	8	Wheat	330	24	7,205	43	8	0	0	0	0	"	"
II	1	Fescue	260	0	5,681	34	13	0	0	0	0	0	13
	2	"	219	16	4,775	29	12	0	0	0	0	0	12
	3	"	213	18	4,666	28	11	0	0	0	0	0	11
	4	"	211	19	4,605	28	11	0	0	0	0	0	11
	5	"	207	20	4,530	27	11	0	0	0	0	0	11
	6	"	210	20	4,576	27	11	0	0	0	0	0	11
	7-10	"	210	19	4,585	27	11	0	0	0	0	0	11
	11	Barley	131	20	2,866	17	7	0	0	0	0	4	0
	12	Wheat	351	15	7,664	46	18	0	0	0	0	7	7
	13	Fescue	191	27	4,175	25	10	0	0	0	0	0	10
	14	"	203	22	4,430	26	11	0	0	0	0	0	11
	15	"	211	19	4,605	28	11	0	0	0	0	0	11
	16	"	208	20	4,546	27	11	0	0	0	0	0	11
	17-22	"	210	19	4,585	27	11	0	0	0	0	0	11
III	1	Wheat	391	0	8,528	51	20	0	0	0	0	15	17
	2	Barley	120	24	2,620	15	7	0	0	0	0	10	0
	3	Wheat	351	15	7,664	46	18	0	0	0	0	15	17
	4	Barley	115	26	2,511	15	12	0	0	0	0	10	0
	5	Wheat	346	17	7,555	45	18	0	0	0	0	15	17
	6	Barley	115	26	2,511	15	12	0	0	0	0	10	0
	7	Wheat	346	17	7,555	45	18	0	0	0	0	15	17

Footnotes at end of table

(continued)

Table 7: Nitrogen, phosphorous, and potassium additions from sludge applied to meet the N requirement of selected crops in the Tualatin Valley (continued)

Rotation	Year	Crop	Sludge N required[a]	N carry-over	Total sludge applied[a]	Available P	Available K	Reduction in P requirement, and K saved: Willamette P	Willamette K	Woodburn P	Woodburn K	Laurelwood & Kinton P	Laurelwood & Kinton K
			pounds per acre										
IV	1	(See Rotation II for first 10 years)											
	11	Wheat	341	19	7,437	44	17	0	0	0	0	NA[b]	NA[b]
	12	Beans	58	27	1,273	7	3	7	3	7	3	"	"
	13	Fescue	226	13	3,939	29	12	0	0	0	0	"	"
	14	"	213	18	4,644	28	11	0	0	0	0	"	"
	15	"	210	19	4,576	27	11	0	0	0	0	"	"
	16	"	212	18	4,629	28	18	0	0	0	0	"	"
V	1	Wheat	391	0	8,528	51	20	0	0	0	0	"	"
	2	Barley	120	24	2,620	16	6	0	0	0	0	"	"
	3	Beans	90	15	1,974	12	5	7	5	7	6	"	"
	4	Wheat	364	10	7,954	48	19	0	0	0	0	"	"
	5	Barley	113	26	2,467	15	6	0	0	0	0	"	"
	6	Beans	91	15	1,987	12	5	7	5	7	5	"	"
VI	1	Wheat	391	0	8,528	51	20	0	0	0	0	"	"
	2	Barley	120	24	2,620	16	6	0	0	0	0	"	"
	3	Corn	273	15	5,961	36	14	4	14	4	14	"	"
	4	Wheat	336	21	7,336	44	17	0	0	0	0	"	"
	5	Barley	109	28	2,389	15	6	0	0	0	0	"	"
	6	Corn	273	15	5,961	36	14	4	14	4	14	"	"
	7	Wheat	332	22	7,260	44	17	0	0	0	0	"	"
	8	Barley	108	28	2,365	14	6	0	0	0	0	"	"

a/ Dry weight basis, sludge = 4.58% N.

b/ Not applicable.

and wheat, following corn, 7,205 pounds sludge/acre/year. The economic analysis is based on these stabilized sewage sludge application rates.

An adjustment in calculations was made if the nitrogen requirement for a given year was met by two applications of sewage sludge. For example, wheat had a nitrogen requirement of 150 pounds nitrogen/acre, where 75 pounds nitrogen/acre is applied in the spring. In calculating the amount of sewage sludge to be applied in the spring, mineralization of organic nitrogen from the preceding sewage sludge application was considered to contribute to the total nitrogen available. The spring sludge nitrogen application was, therefore, composed of nitrogen from the spring application and nitrogen mineralized from residual organic nitrogen.

The equation used to determine the amount of sewage sludge to be applied in the spring is similar to the one used to determine the annual sludge application:

$$NR\ (spring) = 0.5(0.42)x_s + 0.3(0.58)x_s + \text{Mineralized nitrogen (from previous applications).}$$

NR (spring) = Nitrogen requirement of crop (spring);

x_s = Total amount of sludge nitrogen needed to meet spring nitrogen requirement.

The amounts of sewage sludge applied in the fall and spring are totaled to obtain the total sludge application for that year:

$$NR_i = x_f + x_s \qquad (i = \text{year of application}).$$

Phosphorus and potassium requirements for crop growth are based on the nutrient content in the soil, or the soil test value. Soil test values and the phosphorus and potassium recommendations for the crops selected were obtained from fertilizer guides (Appendix Table B-3).4/ If, for example, a soil tested between 75 and 150 ppm for potassium, than 50 to 75 pounds/acre of potassium would be recommended for a bean crop.

4/ Oregon State University Extension Service, Corvallis.

Calculation of Potassium and Phosphorus Required with Sewage Sludge

Greater than 46 percent of the soils in Washington County tested by the Oregon State University Soil Testing Laboratory (1976) contained between 125 and 250 ppm potassium. Woodburn, the soil representing the largest acreage in the county, was assumed to have soil test values for potassium within this range. Twenty-seven percent of the soils in the county had soil test values for potassium greater than 250 ppm. Willamette soils, with their high native fertility, were assumed to have values for potassium within this range. Twenty-two percent of the soils contained between 75 and 124 ppm potassium. Again, the less productive, more highly leached hill soils, Laurelwood and Kinton-Cornelius, were assumed to have values within this lower soil test range for potassium.

Greater than 76 percent of the soils in Washington County tested by the Oregon State University Soil Testing Laboratory (1976) contained greater than 40 ppm of phosphorus. Therefore, Woodburn and Willamette soils, the major agricultural soils in the county, were assumed to have soil test values for phosphorus greater than 40 ppm. Twenty percent of the soils in the county contained between 20 and 39 ppm of phosphorus. Laurelwood and Kinton-Cornelius soils, which occur on foothills and which are not intensively cultivated, were assumed to represent the soils in the county with this lower range of phosphorus values.

Sewage sludge application rates were not calculated to meet the phosphorus and potassium requirements of a crop, but the sewage sludge was considered to contribute these nutrients and to have some value for soils low in these two nutrients. It was estimated that the availability of phosphorus and potassium in sewage sludge was 50 percent for the first year after application. No good data are currently available for the extent of phosphorus and potassium carryover to subsequent cropping years.

The average phosphorus and potassium content of sewage sludge from Portland was calculated from data in the North Willamette Experiment Station project (Table 5).

Phosphorus fertilizers are band applied for the crop selected. Since sewage sludge is broadcast over a field, the phosphorus supplied by the sewage sludge would increase the available phosphorus in the soils and, in turn, reduce the band fertilizer phosphorus application required. For example, the phosphorus fertilizer requirement for beans grown on Woodburn or Willamette soils was assumed to be reduced from 46 pounds/acre to 39 pounds/acre when sewage sludge was applied. Since Laurelwood and Kinton-Cornelius soils contain initial low levels of available phosphorus, the phosphorus band requirement for barley and wheat was lowered by 4 and 6 pounds/acre, respectively (Table 8).

Potassium fertilizers for the selected crops are broadcast. Since the sewage sludge applications are comparable to broadcast applications, the amount of available potassium in the sludge was considered to contribute to broadcast requirements for potassium of the selected crops.

Potassium fertilizer value from the sewage sludge application was related to the soil type on which the crops were grown. Some soils had a range of soil test values that included two recommended rates of application for potassium (Table 9). For example, Woodburn soil test values for potassium ranged from 125 to 250 ppm potassium so that if corn was grown, the potassium fertilizer application rate would range from 0 to 83 pounds/acre. The high requirement (i.e., 83 pounds/acre for corn) and low requirement (i.e., 0 pounds/acre for corn) were averaged to obtain a value on which the potassium required on a soil for a particular crop was based. For example, corn grown on a Woodburn soil required, on the average, 42 pounds/acre of potassium.

Expected Yields for Selected Crops

Yields for the crops which were fertilized with sewage sludge (Table 6) were assumed to be the same as with commercial fertilizers. This was considered a reasonable assumption after repeated sewage sludge applications, in light of yield data obtained from various experiments using the same, or similar, crops used in this study (Jackson *et al.*, 1976).

Table 8: Phosphorus requirement[a/] of crops grown on four Tualatin Valley soils, amended with the high rate of sewage sludge

Crop	Soil type: Willamette[b/]	Soil type: Woodburn[b/]	Soil type: Laurelwood & Kinton-Cornelius [c/]
	---- pounds per acre ----		
Barley (WS)[d/]	18	18	22
" (NS)[e/]	18	18	18
P saved	0	0	4
Beans (WS)	46	46	NA[f/]
" (NS)	40	40	
P saved	6	6	
Corn (WS)	40	40	NA
" (NS)	36	36	
P saved	4	4	
Wheat (WS)	0	0	6
" (NS)	0	0	0
P saved	0	0	6
Fescue	0	0	0

a/ All phosphorus requirements are band applications.

b/ Soil containing at least 40 ppm of phosphorus.

c/ Soil containing between 29 and 39 ppm of phosphorus.

d/ With sludge.

e/ No sludge.

f/ Not applicable.

Table 9: Potassium requirements of selected crops based on soil test values of four Tualatin Valley soils a/

Crop	Soil type: Willamette b/	Woodburn c/	Laurelwood & Kinton-Cornelius d/
	pounds per acre		
Barley	0	0	0
Beans	17	41	NA e/
Corn	17	41	NA
Fescue	0	0	25
Wheat	0	0	17

a/ All potassium applications are broadcast.

b/ Soil contains greater than 250 ppm potassium.

c/ Soil contains between 125 and 249 ppm potassium.

d/ Soil contains between 75 and 124 ppm potassium.

e/ Not applicable.

Trace Element Considerations for Sewage Sludge Application to Land

The accumulation of trace elements in soils, and their subsequent uptake by plants, is of major concern when land application of sewage sludge and effluent is being considered (Dowdy and Larson, 1975). Trace element buildup can lead to reduced plant growth, and may be harmful to humans and animals via the food chain if sufficiently high concentrations occur in plant tissue (Dowdy, et al., 1976). The trace elements, zinc, cadmium, copper, nickel, and lead, appear to present the most serious problem, since they commonly occur in anaerobically digested sewage sludge and have been associated with phytotoxic effects (Dowdy et al., 1976).

Toxicity to a variety of plants (e.g., wheat, oats, and rye) involving zinc, nickel, and copper, has been observed when sewage sludges were applied in large quantities (usually greater than 250 metric tons/hectare) on acid soils (Page and Chang, 1974). In addition to effects on plants, copper poisoning can occur in sheep grazing on pasture forage containing 50 to 60 ppm copper (Sidle *et al.*, 1976). Cadmium is of special concern since chronic exposure to even low cadmium concentrations via intake of cadmium-polluted foodstuffs has resulted in numerous cases of ill health in humans (Bingham *et al.*, 1975). Cadmium-related toxicity symptoms have also been observed in sensitive crops such as swiss chard and spinach when grown on soils containing as low as 5 ppm cadmium (Page and Chang, 1974). Lead, although not related to toxicity in plants at present, has been associated with adverse effects on animals (i.e., lead poisoning). Plant species vary in their tolerance to trace element uptake. Grasses are observed to be less sensitive to trace elements than grains which are, in turn, less sensitive than vegetables (Chaney, 1973).

The problem of trace elements is complicated by the fact that, even for the same soil, applications of sewage sludges having the same trace element concentrations may affect soil properties, water quality, plant growth, and availability to microorganisms and higher plants differently (Page, 1974). Concentrations of trace elements vary widely among sludges (Table 10). This variability, along with incomplete knowledge of the mechanics involved in trace element availability in the soil, makes it difficult to generalize about amounts of sludge that can be applied to soils without permanent deleterious effects. It can be said that, once added, the presence of these elements in the soil is virtually permanent (Purves, 1972), since they are relatively immobile and remain in the top 15 inches of soil (Page, 1974).

Within limits, trace elements may also have beneficial effects associated with their use. Certain trace elements such as zinc and copper are considered essential to the growth of plants (Brady, 1974). In some instances, the presence of competing cations may alter the soil chemistry which, in turn, changes the solubility and mobility of "native" metals. Manganese toxicity in a soil, for example, may be reduced by the presence of zinc or other cations in the sludge which compete more successfully for exchange sites, and displace the Mn^{2+} ions into solution, where they are oxidized to an unavailable form (MnO_2), or leached through the soil (Leeper, 1972).

Although it is important to consider the possible harmful effects of trace elements, these effects can be minimized by careful management of the soils.

Table 10: Range of trace element content in digested sludge[a/]

Element	Observed range	Portland sludge[b/]
	ppm	
Zinc (Zn).....................	500 - 50,000	3,250
Copper (Cu)..................	250 - 17,000	1,154
Nickel (Ni)..................	25 - 8,000	173
Cadmium (Cd).................	5 - 2,000	47
Lead (Pb)....................	100 - 10,000	1,412

a/ Recycling Municipal Wastes and Effluent on Land. Champaign, Ill., July 1973), p. 130.

b/ Lolita Carter, A Study to Characterize Certain Sewage Treatment Plant Effluents and Sludges in the Portland Metropolitan Area, Relative to their Disposal by Land Application. Portland State University, 1976.

As mentioned earlier, if soil pH is maintained between 6.2 and 6.8, availability and, thus, toxic effects of trace elements are reduced. In addition, by establishing maximum amounts of trace elements that may be applied in sewage sludge and effluent to agricultural land, concentrations of these elements in the soil and plants can be maintained within normal ranges (Table 11).

Guidelines for the maximum amount of digested sewage sludge which could be applied to agricultural land have been reported (Table 12). These maximum applications depend on the trace element composition of the sludge, the soil to which it would be applied, and the crop grown on the soil. These rates may be conservative, and some studies have suggested that domestic sludges could be applied to soils for a number of years at a rate of 10 to 20 metric tons per hectare and not cause trace element concentrations uncommon to soils in general (Page, 1974). In addition to following these USDA guidelines, a soil test prior to application may be appropriate to determine levels of the relevant trace elements already present in the soil. If a high concentration of a particular element already exists, a reduction in suggested rates may be advisable for a sewage sludge containing large quantities of the particular element.

Table 11:[a/] Total concentration of trace elements typically found in soils and plants b/

Element	Concentration in soils (μg/g)		Concentration in plants (μg/g)	
	Common	Range	Normal	Toxic c/
As......	6	0.1 - 40	0.1 - 5	-
B.......	10	2 - 100	30 - 75	>75
Cd......	0.06	0.01 - 7	0.2 - 0.8	- 2
Cr......	100	5 - 3000	0.2 - 1.0	-
Co......	8	1 - 400	0.05 - 0.5	-
Cu......	20	2 - 100	4 - 15	>20
Pb......	10	2 - 200	0.1 - 10	-
Mn......	850	100 - 4000	15 - 100	-
Mo......	2	0.2 - 5	1 - 100	-
Ni......	40	10 - 1000	1	>50
Se......	0.5	0.1 - 2.0	0.02 - 2.0	50 - 100
V.......	100	20 - 500	0.1 - 10	>10
Zn......	50	10 - 300	15 - 200	>200

a/ A. L. Page. Fate & Effects of Trace Elements if Sewage Sludge Were Applied to Agricultural Lands. 1974. Project No. EPA 670-2-74-005. U.S. Environmental Protection Agency, Washington, D.C.

b/ From Alloway (1968).

c/ Toxicities listed do not apply to certain accumulator plant species.

Table 12: Maximum trace element application of sewage sludge for a given location

Element	Cation exchange capacity, meq/100g					
	kg/ha	lb/acre	kg/ha	lb/acre	kg/ha	lb/acre
	<5		5-15		>15	
Pb	500	446	1,000	892	2,000	1,784
Zn	250	223	500	446	1,000	892
Cu	125	112	250	223	500	446
Ni	50	45	100	89	200	178
Cd	5	4.5	10	8.9	20	18

Limit/yr: Cd - 2 kg/ha (1.8 lb/acre)
N = Available N for plant growth

SOURCE: R. H. Dowdy, R. E. Larson, and E. Epstein. "Sewage Sludge and Effluent Use in Agriculture." 1976. Soil Conserv. Soc. of Amer., Ankeny, Iowa, pp. 138-153.

Other Potential Limits to Sewage Sludge Use

In addition to trace element considerations, sewage sludge salinity may adversely affect growth of salt-sensitive crops where low rainfall conditions exist during summer months (Dowdy *et al.*, 1976). Salt effects from waste applications to soils are highly variable, depending mainly upon the salt content of the sludge. No adverse effects due to salinity have been observed on plots at the North Willamette Experiment Station where sewage sludge has been applied to wheat, sweet corn, and tall fescue.

Pathogens in sludge are currently not viewed as a major problem when anaerobically digested sewage sludge is applied to land. Since considerable literature indicates limited transfer of microbial cells through the soil profile and a reasonably rapid die-back of the pathogens in the soil matrix, the presence of pathogenic microorganisms should not be a factor limiting the applicability of recycling wastes on land (Miller, 1973). If reasonable precautions are taken, pathogen considerations should not limit agricultural use of anaerobically digested sewage sludge. Restrictions on fresh market crops have been previously discussed. The Oregon Department of Environmental Quality is currently developing guidelines and recommendations for land application of sewage sludge.

Sewage sludge may also affect the pH of the soil to which it is applied. Initially, the high pH of the sewage sludge, which averages 7 or greater for most sludges, may have a liming effect on the soil. Over time, however, the oxidation of organic compounds in the sludge releases hydronium ions into the soil solution, which may acidify and, in fact, increase the lime requirement of some soils.

Soil Management Practices Related to Sewage Sludge Application

Of major concern in managing soils for sewage sludge application is maintaining a low level of trace element uptake in the crops produced. Maintaining the pH of the soil at a level above 6.5 is, at present, the most effective way to reduce uptake. Terman and Soileau (1973) have stated that if soils are limed, uptake of zinc by corn, beans, and tall fescue is decreased, and no reduction in yields due to zinc toxicity occurs. Studies done on alkaline soils have shown that trace elements released by the decomposition of sludge are less available for plant uptake. Barley seedlings extracted larger quantities of zinc, lead, nickel, and chromium from sludge-amended acid soil than from similarly treated alkaline soils (Dowdy and Larson, 1975).

A second major consideration in sludge application is the reduction of surface runoff. Since many valley soils are saturated during winter months (November through March), application at these times should be restricted or limited to avoid runoff. As a general practice, sludge application to soils or established grass stands should be made when runoff potential is low. Where slope is involved, contouring or terracing of soils is recommended to reduce overland sludge movement, especially if grass waterways or intermittent streams are near application areas. Common runoff control practices are contour furrows, listing, and strip-cropping. Slope may also affect even distribution of the sludge, and sprinkler or low-rate application may be more efficient in such situations. The use of catch ditches may be necessary to avoid movement of pathogens and trace elements into waterways in some locations. Dense vegetative cover, mulch, and a rough, cloddy surface increases water retention and detention storage. When soils are unable to accept sludge application, storage will be necessary.

Sludge movement into the soil involves several considerations. Soil clogging due to organic matter contained in sludge may reduce the oxygen content due to saturation by water which increases trace element availability. Sealing of the soil resulting from the trapping of solid particles from the sludge by soil pores may cause ponding of the sludge on the surface and, thus, increased volatilization losses of ammonia. Immediate incorporation of sludge should be practiced whenever possible, to avoid ammonia volatilization as well as other odor problems. Chiseling stubble ground ahead of sludge has been practiced to improve intake and reduce sealing effects (Wold, 1976). Deep tillage will also serve to reduce concentration of trace elements in the surface by mixing them with a larger volume of soil (Page, 1974). Plow furrowing and subsurface injection are the most common methods of initial subsurface incorporation of sewage sludge incorporation at present.

For the purposes of this study, as mentioned earlier, the USDA guidelines (Table 12) for maximum loading rate of trace elements were followed as a conservative estimate of soil tolerance to these elements. Using these limits for application, and based on elemental content of the sewage sludge analyzed by this study (City of Portland), zinc was found to be the factor controlling the maximum sewage sludge application (Table 13). Average analyses, 1975 and 1976 data, of Portland sludge for zinc were 3,250 ppm - dry weight basis - or 1.5×10^{-3} kg/lb. of sludge (Jackson _et al_., 1976). The maximum limits of application, based on the USDA guidelines for zinc levels, are 500 kg/hectare for a soil with a CEC of 5 - 15 meq/100g of soil (Laurelwood and Cornelius-Kinton series), and 1,000 kg/hectare for a soil with a CEC greater than 15 meq/100g of soil (Woodburn and Willamette series). Given the zinc content of the sewage sludge and the maximum permissible application levels for zinc, the sludge application can be calculated. For the low and high CEC soils, 136,988 and 274,065 lbs./acre of sewage sludge may be applied before recommended levels for zinc are surpassed. No further application of sludge to these sites would be made under present guidelines.

The number of years in which sewage sludge could be applied for the selected crop rotations, based on total zinc applied (Table 13), was calculated. Persons utilizing sludge must be aware that these rates are subject to change as trace element content of the sludge changes.

Table 13: Number of years of sludge application until maximum trace element levels are reached in the soils

Rotation	Application time: CEC > 15 meq/100g Woodburn & Willamette	CEC = 5 - 15 meq/100g Laurelwood & Kinton-Cornelius
	years	
Beans, wheat, corn, wheat......	50	NA[a/]
Fescue, barley, wheat..........	59	29
Wheat, barley..................	30	17
Fescue, wheat, beans...........	58	NA
Wheat, barley, beans...........	63	NA
Wheat, barley, corn............	62	NA

a/ Not applicable.

Guidelines (Appendix Table B-6) have been suggested, involving public access to, and possible contamination by, pathogens in sludge. Restrictions include the maintenance of certain distances between sewage sludge application sites and residences, wells, rivers, lakes, and areas where there is a high risk of flooding. To avoid pathogenic contamination of foodstuffs, Bauer (1977) has recommended that raw vegetables for human consumption should not be grown on soils until three years after sludge application. For most crops, other than those grown for seed or fiber, sludge application should be discontinued a month prior to harvest. Sludge application should be discontinued two months prior to harvest of fruit and forage, to allow time for die-off of pathogens. Excessive loading rates of wastes which result in runoff and deep percolation and, thus, possible pathogenic contamination of ground and surface water, should be avoided.

Crop Practices, Costs, and Returns Without Sludge

The method of economic analysis employed in this study is different from the methods employed in earlier research. Some research has been conducted on waste water utilization (Young, Nov. 1976; Christensen et al., 1975). These studies employed a simulation approach that evaluated only waste water.

Research on the use of sludge as fertilizer is limited, except for one research effort conducted on the use of sludge to rejuvenate strip-mined land (Seitz, 1974). Here, again, the analytical approach was simulation. The unique problems associated with strip-mined land reduce the value of this analysis for purposes of the present study.

The approach employed in the present study involved the analysis of costs and returns for the crops listed earlier without sludge, and at "low" and "high" application levels. Crop yields were assumed to be constant for all three situations (Table 14). Crop prices assumed were projected normal prices based on future expectations of supply and demand (Table 14). These were used to obtain total revenue per acre for each crop. Net revenue was obtained by deducting total production costs from gross revenue.

For each crop, costs of production were broken down into individual operations. Cost estimates were made by determining the time required to perform each operation and the type and sizes of equipment employed. The prices for materials and other inputs are for the year 1977 (Appendix Table A-11). Custom costs were included for work assumed to be hired from custom equipment operators. The length of time required to perform various operations is available from the Oregon State University Department of Agricultural and Resource Economics through the Enterprise Cost Studies. Unpublished equipment costs were also available from the same source (Table A-12).

The rates of application of other inputs were obtained from soil scientists and Extension agents. These included fertilizer, pesticides, herbicides, and insecticides.

Operating capital interest at 9.5 percent is calculated for all cash costs incurred in production except harvest costs. The length of time for which the charge is assessed depends on the crop cycle. For example, the operating capital interest for wheat is based on 10 months, while for beans the time period is 3 months.

Table 14: Yield and price assumptions for alternate crops in economic analysis of sludge use, Tualatin Basin, Oregon

Crop	Unit	Yield per acre	Projected normal price[a/]
			dollars
Dryland winter wheat........	bu.	75.0	3.00
Dryland spring barley.......	bu.	62.5	2.50
Irrigated sweet corn........	ton	8.0	65.00
Irrigated bush beans........	ton	4.0	160.00
Dryland tall fescue hay.....	ton	3.0	47.00

a/ Projected prices, assuming normal market conditions.

General overhead charges were also based on all cash costs except harvest. These charges varied according to crop, and represent expenses for utilities, accounting, office, and equipment.

An interest charge on the land investment was not included because of the difficulties involved in quantifying land values in the study area due to the influence of urbanization.

The development of the budgets for tall fescue grass hay required an additional step. Establishment costs are required in addition to the costs for the producing years. Estimation of establishment costs for tall fescue was based on the assumption that seeding occurred in the fall. This eliminated the production loss that would occur with seeding in the spring. It also eliminated some costs. For example, the tax charge was covered by the crop harvested immediately prior to seeding, and is not assessed in the establishment costs. The total establishment cost was then amortized over the 10-year life of the stand at 9 percent, and charged to the producing years as an additional cost.

The recent closure of the last local vegetable processing plant necessitated additional analysis of transportation costs associated with beans and sweet corn. The distance from field to processing plant was assumed to be

50 miles. Travel time was set at 3 hours. This includes an allowance for queueing at the processing plant. An additional 3/4 hour was added for time in field.

The estimated production costs and the net returns per acre for each of the crops without sludge use are given in Tables 15 and 16. The average yearly returns for the specified crop rotations were also obtained by summing the net returns (revenue) across each rotation, and then dividing by the number of years in each rotation. These data are listed in the later tables, along with the net returns obtained with the application of sludge.

Changes in Practices, Costs, and Returns with Sludge

The application of sludge involves changes in cultural and cropping practices. Additional management by the farm operator is also required.

Although several alternate contractual arrangements may be employed with respect to land ownership and application methods, this study assumed that the existing arrangements in Washington County will continue to prevail. The sewerage agency was assumed to bear the costs of transportation and spreading, including ownership of the equipment and employment of personnel to operate transportation and spreading equipment.

Under these assumptions, several adjustments were made to the crop budgets discussed in the previous section to reflect the use of sludge. The major changes in cultural practices are additional tillage to eliminate runoff, reduced application of commercial fertilizers, and additional lime required to maintain soil pH at 6.5. Additional field work is also required in the spring because of accelerated weed growth due to nutrients available from the sludge.

Most of the annual precipitation in Washington County occurs during the winter months. Since the sludge is applied in liquid form (5 to 10 percent solids) throughout the year, runoff problems are likely to occur during the winter months. This problem is avoided by breaking up the soil to a greater depth than normal. This practice is called "subsoiling", and increases the total amount of moisture retained by the soil.

Table 15: Estimated production costs (excluding land and management) per acre, by crop and level of sludge application, 1977*

Crop	Soil type		
	Willamette	Woodburn	Laurelwood/Kinton d/
	dollars		
Beans:			
High sludge a/	518.50	523.20	
Low sludge b/	520.79	524.26	
No sludge c/	521.04	524.40	
Corn:			
High sludge.............	367.22	372.56	
Low sludge..............	377.27	381.14	
No sludge...............	393.18	396.78	
Barley:			
High sludge.............	136.40	136.40	136.40
Low sludge..............	141.89	141.89	141.89
No sludge...............	132.15	132.15	133.81
Wheat:			
High sludge.............	134.41	134.41	134.41
Low sludge..............	150.37	150.37	151.60
No sludge...............	157.69	157.69	159.70
Fescue Hay:			
High sludge.............	90.09	90.09	90.61
Low sludge..............	98.57	98.57	101.62
No sludge...............	108.22	108.22	112.21

* Does not include idle land charge (see Appendix Tables A-1 through A-10).

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Estimated costs without sludge application.

d/ Refers to Laurelwood and Kinton-Cornelius soils.

Table 16: Estimated net returns to land and management, per acre, by crop and sludge application, projected normal crop price*

Crop	Soil type: Willamette	Woodburn	Laurelwood/Kinton
	dollars		
Beans:			
High sludge[a/]	111.99	107.46	
Low sludge[b/]	114.45	111.07	
No sludge[c/]	118.96	115.60	
Corn:			
High sludge	143.27	138.10	
Low sludge	137.97	134.19	
No sludge	126.82	123.22	
Barley:			
High sludge	10.34	10.51	15.19
Low sludge	9.60	9.69	12.03
No sludge	24.10	24.10	22.44
Wheat:			
High sludge	81.08	81.25	85.93
Low sludge	69.87	69.96	71.07
No sludge	67.31	67.31	65.30
Fescue Hay:			
High sludge	41.40	41.57	45.73
Low sludge	37.67	37.76	37.05
No sludge	32.78	32.78	28.79

* Including idle land charge.

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Estimated returns without sludge application.

The pattern of availability of plant nutrients contained in the sludge, particularly nitrogen, enhances weed growth in the early spring. This additional growth makes it necessary to disc more times prior to seeding of spring crops.

Another additional cost associated with sewage sludge is control by the farm operator of application sites and rates. Supervision by the farm operator is required to ensure optimal application with respect to both the rate of application and the uniform distribution of application. Selection of application sites also requires a time input by the farm operator. In the crop budgets, this time charge for management was entered as operator's labor.

Two rates of sludge application were evaluated. The high rate of application provided the amount of nitrogen required for the assumed level of crop production. The low rate of application met half of the nitrogen requirements. Of the three major nutrients, nitrogen, phosphorus, and potassium, nitrogen is most abundant in sewage sludge, and was used as the constraint on the amount of sludge applied. The average sludge application per acre for each level of sludge use, by rotation and soil type, is summarized in Table 17.

Other plant nutrients contained in the sludge partially offset the amounts of commercial nutrients required. The application rates of phosphorus and potassium were lowered to reflect the requirements satisfied through sludge application.

Application of sludge also increases the acidity of the soil, over time. Increased applications of lime are required to offset this problem. For the high sludge application, an 18 percent increase in lime applied was charged to the crops. A 9 percent increase in lime was assessed for the low sludge application rate.

The crop production costs for 1977 with sludge use are presented (Table 15). One additional cost associated with the application of sludge has not been included in these detailed budgets. Under the current arrangements, land must be available for land application throughout the year. This includes the critical growing stages of the plants. Therefore, some land must be left idle each year

Table 17. Average quantity of sludge applied per acre per year by rotation

Rotation[a]/sludge level	Pounds/year dry weight	Gallons/year	Acre-inches/year
Rotation I:			
High rate........	5,400	16,177	.60
Low rate.........	2,700	8,088	.30
Rotation II:			
High rate........	4,650	13,930	.52
Low rate.........	2,325	6,965	.26
Rotation III:			
High rate........	5,033	15,077	.56
Low rate.........	2,517	7,539	.28
Rotation IV:			
High rate........	4,584	13,732	.50
Low rate.........	2,292	6,866	.25
Rotation V:			
High rate........	4,136	12,390	.46
Low rate.........	2,068	6,195	.23
Rotation VI:			
High rate........	5,196	15,566	.58
Low rate.........	2,598	7,783	.29

a/ Rotation I: Beans, wheat, corn, wheat.
Rotation II: Tall fescue - 10 years; barley, wheat.
Rotation III: Wheat, barley.
Rotation IV: Tall fescue - 10 years; wheat, beans.
Rotation V: Wheat, barley, beans.
Rotation VI: Wheat, barley, corn.

to accommodate the sludge when crop application is not possible. In Washington County, land is typically cropped every year. Under high application rates, approximately 10 percent of the cropland must remain fallow. The low sludge application rate was assumed to require 5 percent fallow land.

The idle land charge was obtained by estimating the average yearly returns to land for each rotation and soil type. The highest average return without sludge was selected for each soil type, and 5 and 10 percent of this highest value for each soil type was used as the idle land charges for low and high levels of sludge use, respectively (Table 18).

Table 18: Idle land charges

	Soil type		
Sludge level	Willamette	Woodburn	Laurelwood/Kinton
	dollars per acre		
High sludge...........	9.51	9.34	4.66
Low sludge............	4.76	4.67	2.33

Net returns per crop, and rotation under varying rates of sludge application, are contained in Table 19. These values have been adjusted for the idle land charge.

Analysis of Results for Sludge Use

Under the current input price structure, sludge application has positive net benefits only for those crop rotations requiring relatively large amounts of nitrogen. For Rotations III (wheat, barley) and V (wheat, barley, beans), the net returns to land and management per acre are lower with sludge use than when no sludge is applied (Table 19). The reduction in the cost of fertilizer is more than offset by the increase in costs associated with sludge use.

Soil type influences the magnitude of the returns associated with sludge application. Production costs vary across soils because of differences in native

Table 19: Average net returns to land and management per acre by rotation and level of sludge application, projected normal crop prices

Rotation/sludge level[a/][b/]	Soil type		
	Willamette	Woodburn	Laurelwood/Kinton
	dollars		
I. High sludge........	104.36	102.02	
Low sludge.........	98.04	96.30	
No sludge..........	95.10	93.36	
II. High sludge........	42.12	42.29	46.54
Low sludge.........	38.01	38.10	37.80
No sludge..........	34.93	34.93	31.30
III. High sludge........	45.71	45.88	50.56
Low sludge.........	39.74	39.83	41.55
No sludge..........	45.71	45.71	43.87
IV. High sludge........	50.59	50.37	
Low sludge.........	46.75	46.55	
No sludge..........	42.84	42.56	
V. High sludge........	67.80	66.41	
Low sludge.........	64.64	63.57	
No sludge..........	70.16	69.00	
VI. High sludge........	78.23	76.62	
Low sludge.........	72.48	71.28	
No sludge..........	72.74	71.54	

a/ See Table 18 for definition of sludge application rates.

b/ Rotation I: Beans, wheat, corn, wheat.
Rotation II: Tall fescue - 10 years; barley, wheat.
Rotation III: Wheat, barley.
Rotation IV: Tall fescue - 10 years; wheat, beans.
Rotation V: Wheat, barley, beans.
Rotation VI: Wheat, barley, corn.

fertility. Generally, greater cost savings may be realized as a result of using the plant nutrients from sludge on less productive soils. However, if other investments, such as contouring, are required, or if output declines, the additional benefits may be quickly offset.

The greatest benefits accruing from the use of sludge on the Laurelwood/Kinton soils were for the rotation of 10 years of tall fescue hay with wheat and bush beans (II). High sludge use increased net returns about $15 per acre, and the lower application rate resulted in a $6 increase (Table 19). However, depending on the degree of slope involved, these benefits may be offset at some locations by the costs required for contouring and other runoff control practices. The second rotation (III) evaluated for Laurelwood/Kinton soils, wheat and barley, provided a lower return to the use of sludge. The high sludge application rate decreased returns by $2 (Table 19). However, the total net returns to land and management per acre were at higher levels for this rotation (III) compared to Rotation II (Figure 1).

On the Willamette and Woodburn soils, Rotation I (beans, wheat, corn, wheat) is preferable from both points of view: highest net return to land and management and the largest increase in net return resulting from sludge use, about $9 per acre (Table 19). However, the acreages of the vegetable crops in this rotation will be constrained by the availability of contracts from the vegetable processors. Vegetables grown for processing are typically contracted prior to planting. Acres contracted will vary from year to year. The recent closure of the last local vegetable processing plant in the Tualatin Valley area further restricts this alternative. The additional transportation costs for moving the produce to other processing plants were considered in the analysis. However, the distance may present other disadvantages for local growers. In addition, sludge application to land for vegetable crops may be discouraged or constrained by the processors until they have a better understanding of how it can be safely managed.

Of the other rotations evaluated on Willamette and Woodburn soils, the two including 10 years of tall fescue grass hay (II and IV) provided sizeable benefits to the use of sludge (Table 19). However, these two rotations had lower net returns to land and management and, because of their length, would

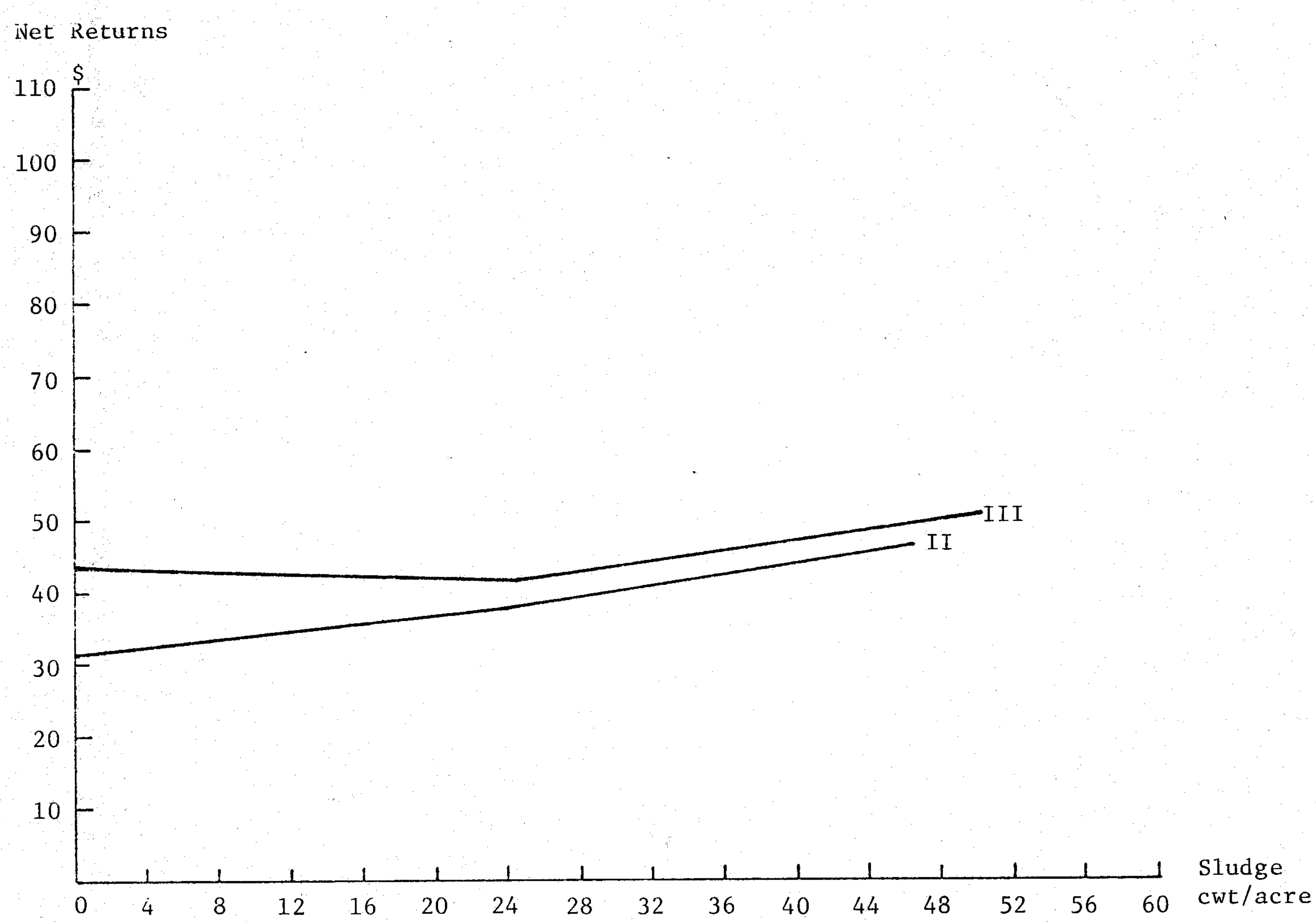

Figure 1. Relationship between net returns and average sludge application (dry weight basis) per year by rotation. Laurelwood/Kinton soils. Projected normal prices.

reduce the farm operator's ability to adjust to changes in product prices. On these Willamette and Woodburn soils, it appears that a 3-year rotation of wheat, barley, and corn (VI) may be a good choice, considering the returns to sludge use and the overall returns to land and management if the processing contracts for the sweet corn can be obtained.

The results for Rotation III (wheat, barley) are ambiguous on Willamette and Woodburn soils, showing little or no economic benefit associated with sludge application. Use of sludge on Rotation V (wheat, barley, beans) reduces net returns because of the low nitrogen requirement for bush beans.

The results of the analysis by rotation are illustrated in Figures 1 through 3. In these figures, the curves extending farther to the right represent rotations that may be preferred by the sewerage agency, due to the high application of sludge per acre. Curves located higher in the figures will be preferred by farm operators, because they represent greater net returns per acre. However, they would not consider those that slope downward to the right.

Sewerage agencies sometimes acquire land through fee simple acquisition for sludge disposal. The results may be employed by sewerage agencies to determine the rate of return to their use of this land. The rate of return can then be utilized in the allocation of financial resources.

While output has been held constant in this study, the farm operator may find it advantageous to increase the application rate per acre of sludge above the rates suggested here, assuming sludge is available at no cost. Yields will be greater, and the returns to land and management will increase. The economically optimal application rate will depend on the cost of sludge.

Widespread use of sewage sludge for agricultural land treatment in the Tualatin Basin may result in shifts in cropping patterns, and influence the prices and net returns of some crops. These aspects were not considered in this study.

Discussion of Implications

The soil management practices listed above will affect production costs. Changes required in cultural practices will vary across soil types. Returns to sludge will also vary across soil type and across rotation.

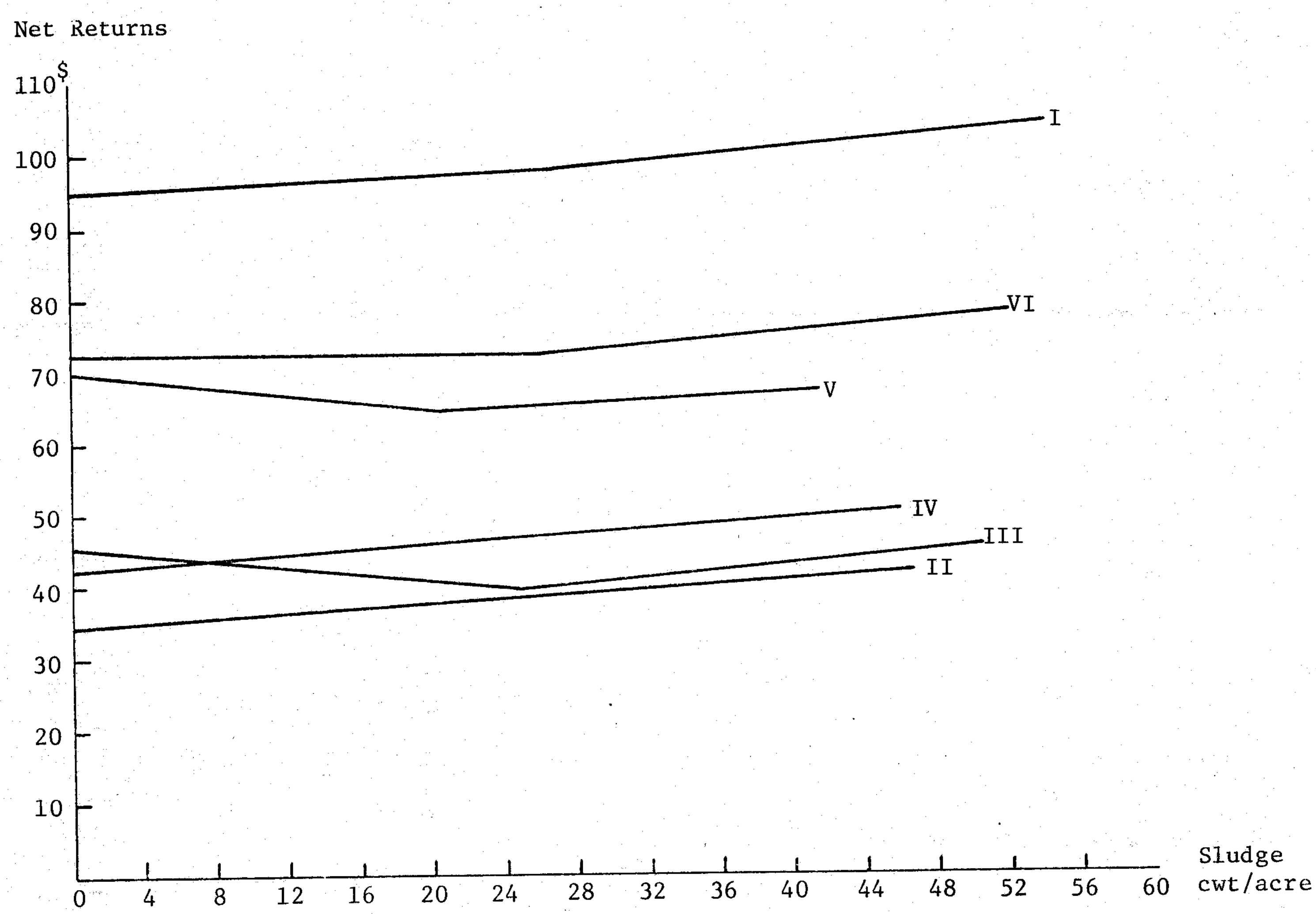

Figure 2. Relationship between net returns and average sludge application (dry weight basis) per year by rotation. Willamette soil. Projected normal prices.

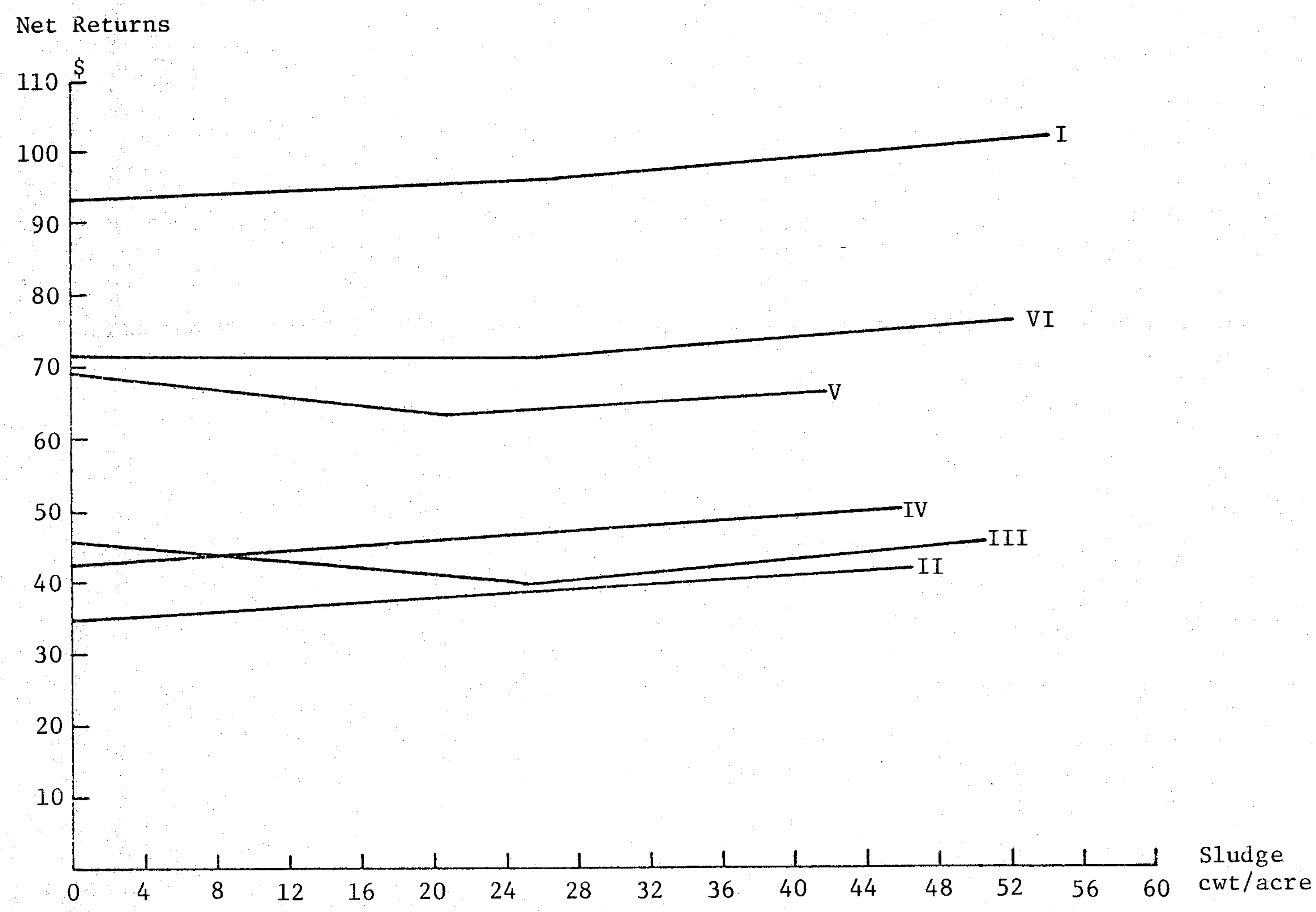

Figure 3. Relationship between net returns and average sludge application (dry weight basis) per year by rotation. Woodburn soil. Projected normal prices.

While some rotations indicate cost reductions associated with sludge applications, it is essential that application procedures and rates be closely monitored. Over-application and uneven distribution of application will reduce net returns to the farm operator, and could result in crop losses or damage claims resulting from runoff. In the present analysis these responsibilities are assumed to belong to the sewerage agency.

Careful management by both the farm operator and the cooperating agency will enhance the cost reductions and minimize the public nuisance potential associated with land application. Written contractual agreements containing the specific rights and responsibilities of both parties are important for proper management.

Length of contract is also important. Longer term arrangements provide the farm operator the opportunity to manage sludge application more effectively and increase his willingness to make investments that may be required.

Wherever possible, the flexibility of the farm operator should be maximized. Reductions in the farmer's flexibility to alter crops, in response to changing prices as a result of the sludge application program, may result in reduced farm returns over time. Income losses associated with sludge because of inflexibility problems will reduce the potential number of farm cooperators.

Sludge Application to Long-Term Tall Fescue Rotations

The rotation selected for higher rates of sewage sludge application was 10 years for fescue and one year for barley. With fescue grown for seed, a maximum rate of 600 pounds of available nitrogen from yearly sewage sludge applications was considered. The requirement may be met by application of sewage sludge several times (3 to 6) during the year. As rates of application increase, runoff problems and ground water contamination problems may also increase. Monitoring ground water for nitrogen levels may also be necessary at higher levels. The maximum sewage sludge application for a given piece of land would still be governed by the total trace element application.

Unlike other crop rotations studied, the maximum yearly rate of cadmium application recommended by USDA of 1.8 pounds Cd/acre (Table 12) may be a limiting factor when heavy applications of sewage sludge are planned. Cadmium was not a limiting factor in the use of Portland sewage sludge at a rate of 600 pounds of available nitrogen per acre, although variations in cadmium content may occur at some future time that would result in a limitation. Careful monitoring of the cadmium content of the sewage sludge is recommended to prevent cadmium applications that exceed recommended rates.

Evidence in the literature is inconclusive regarding phosphorus toxicity to plants at high levels of sludge application (Frank, 1975). It is recommended that plants be monitored to avoid toxicity problems due to high rates of sewage sludge application, after the soil test value for phosphorus exceeds 800 pounds per acre (Bray P_1 test). No phosphorus toxicity problems have ever been observed for crops grown in the Willamette Valley. Future studies may determine the nature and availability of sludge phosphorus in the soil such that higher levels of phosphorus application may be possible. In addition to plant toxicity problems, phosphorus contamination of surface water should be avoided by careful management of the soil to minimize runoff.

Based on trace element content of sewage sludge from Portland, Oregon (Appendix Table B-4), high rates of sewage sludge application (approximately 28,000 pounds sludge/acre/year, dry weight basis) to tall fescue grown on low CEC soils would continue until the 4th year of the rotation (Table 20). By the 5th year, only 18,721.6 more pounds sludge/acre could be applied before zinc levels exceed recommended levels. For higher CEC soils, the same rate of sewage sludge application could continue until the 9th year of the rotation.

The final consideration related to high rates of sewage sludge application is that it necessitates multiple applications so that soil intake rates are not surpassed. Problems caused by slope and fineness of soil texture, such as uneven application and runoff, will also increase with higher rates of application. Surface sealing of the soil by sewage sludge solids may be more of a problem than with lower application rates. With tall fescue, incorporation difficulties increase due to the fact that machinery cannot be used on established grasses.

Table 20. Maximum yearly sludge application to a rotation of 10 years of tall fescue, 1 year barley, 1 year wheat

Year	Crop	Maximum N tolerance	Sludge N to meet maximum N (dry weight)	N carryover (due to mineralization from sludge)	Total sludge (dry weight)	P from sludge	K from sludge
		pounds per acre					
1	Fescue	600	1,562	0	34,116	200	81
2	"	600	1,314	95	28,696	172	68
3	"	600	1,272	111	27,282	167	66
4	"	600	1,267	113	27,672	166	66
5	"	600	1,250	120	27,288	164	65
6	"	600	1,233	126	26,928	161	64
7	"	600	1,241	123	27,105	163	64
8	"	600	1,242	123	27,116	163	64
9	"	600	1,242	123	27,116	163	64
10	"	600	1,242	123	27,122	163	64
11	Barley	70	0	123	0	0	0

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APPENDIX A

Table A-1. Estimated production cost, bush beans, Willamette soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	64.00	64.00	64.00
Fertilizer[c/]	35.13	28.48	21.84
Lime[c/]	22.00	23.83	25.67
Chemicals[c/]	78.87	78.87	78.87
Machinery & equipment[d/]	94.64	97.33	98.76
Custom hire	146.00	146.00	146.00
Land taxes[e/]	12.00	12.00	12.00
Operating capital interest	6.40	6.30	6.20
General overhead	18.85	18.58	18.26
Labor[f/]	43.15	45.40	46.90
TOTAL COST[g/]	521.04	520.79	518.50

See Table 2 for footnotes.

Table A-2. Estimated production cost, bush beans, Woodburn soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	64.00	64.00	64.00
Fertilizer[c/]	38.22	31.57	24.93
Lime[c/]	22.00	23.83	25.67
Chemicals[c/]	78.87	78.87	78.87
Machinery & equipment[d/]	94.64	97.33	100.02
Custom hire	146.00	146.00	146.00
Land taxes[e/]	12.00	12.00	12.00
Operating capital interest	6.47	6.40	6.10
General overhead	19.05	18.86	17.96
Labor[f/]	43.15	45.40	47.65
TOTAL COST[g/]	524.40	524.26	523.20

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Includes custom application costs.

d/ Includes irrigation pumping cost.

e/ Based on farm use value.

f/ Includes both operator and hired labor.

g/ Excludes interest on land investment.

Table A-3. Estimated production cost, sweet corn, Willamette soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	13.50	13.50	13.50
Fertilizer[c/]	57.06	39.42	25.55
Lime[c/]	22.00	23.83	25.67
Chemicals[c/]	28.28	28.28	28.28
Machinery & equipment[d/]	93.24	93.24	93.24
Custom hire	113.00	113.00	113.00
Land taxes[e/]	12.00	12.00	12.00
Operating capital interest	4.50	4.15	3.90
General overhead	13.20	12.20	11.50
Labor[f/]	36.40	37.65	39.15
TOTAL COST[g/]	393.18	377.27	367.22

See Table 4 for footnotes.

Table A-4. Estimated production cost, sweet corn, Woodburn soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	13.50	13.50	13.50
Fertilizer[c/]	60.15	42.88	28.61
Lime[c/]	22.00	23.83	25.67
Chemicals[c/]	28.28	28.28	28.28
Machinery & equipment[d/]	93.24	93.24	95.93
Custom hire	113.00	113.00	113.00
Land taxes[e/]	12.00	12.00	12.00
Operating capital interest	4.61	4.25	3.97
General overhead	13.60	12.51	11.70
Labor[f/]	36.40	37.65	39.90
TOTAL COST[g/]	396.78	381.14	372.56

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Includes custom application costs.

d/ Includes irrigation pumping cost.

e/ Based on farm use value.

f/ Includes both operator and hired labor.

g/ Excludes interest on land investment.

Table A-5. Estimated production cost, spring barley, Willamette and Woodburn soil types, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	13.60	13.60	13.60
Fertilizer[c/]	14.88	9.55	4.25
Lime[c/]	5.50	6.30	7.33
Chemicals[c/]	12.85	12.85	12.85
Machinery & equipment[d/]	54.53	64.23	62.87
Custom hire	0.00	0.00	0.00
Land taxes[e/]	10.00	10.00	10.00
Operating capital interest	2.24	2.20	2.00
General overhead	4.95	4.81	4.40
Labor[f/]	13.60	18.35	19.10
TOTAL COST[g/]	132.15	141.89	136.40

See Table 6 for footnotes.

Table A-6. Estimated production cost, spring barley, Laurelwood/Kinton soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	13.60	13.60	13.60
Fertilizer[c/]	16.38	9.55	4.25
Lime[c/]	5.50	6.30	7.33
Chemicals[c/]	12.85	12.85	12.85
Machinery & equipment[d/]	54.53	64.23	62.87
Custom hire	0.00	0.00	0.00
Land taxes[e/]	10.00	10.00	10.00
Operating capital interest	2.30	2.20	2.00
General overhead	5.05	4.81	4.40
Labor[f/]	13.60	18.35	19.10
TOTAL COST[g/]	133.81	141.89	136.40

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Includes custom application costs.

d/ Includes irrigation pumping cost.

e/ Based on farm use value.

f/ Includes both operator and hired labor.

g/ Excludes interest on land investment.

Table A-7. Estimated production cost, winter wheat, Willamette and Woodburn soil types, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	11.00	11.00	11.00
Fertilizer[c/]	32.75	20.00	4.25
Lime[c/]	5.50	6.30	7.33
Chemicals[c/]	20.21	20.21	20.21
Machinery & equipment[d/]	50.08	54.41	54.41
Custom hire	0.00	0.00	0.00
Land taxes[e/]	11.00	11.00	11.00
Operating capital interest	7.81	7.00	5.83
General overhead	9.59	7.95	6.63
Labor[f/]	9.75	12.50	13.75
TOTAL COST[g/]	157.69	150.37	134.41

See Table 8 for footnotes.

Table A-8. Estimated production cost, winter wheat, Laurelwood/Kinton soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	11.00	11.00	11.00
Fertilizer[c/]	35.06	21.03	4.25
Lime[c/]	5.50	6.30	7.33
Chemicals[c/]	20.21	20.21	20.21
Machinery & equipment[d/]	50.08	54.41	54.41
Custom hire	0.00	0.00	0.00
Land taxes[e/]	11,00	11.00	11.00
Operating capital interest	8.00	7.10	5.83
General overhead	9.10	8.05	6.63
Labor[f/]	9.75	12.50	13.75
TOTAL COST[g/]	159.70	151.60	134.41

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ One-half of the high application rate.

c/ Includes custom application costs.

d/ Includes irrigation pumping cost.

e/ Based on farm use value.

f/ Includes both operator and hired labor.

g/ Excludes interest on land investment.

Table A-9. Estimated production cost, tall fescue hay, Willamette and Woodburn soil types, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	0.00	0.00	0.00
Fertilizer[c/]	21.25	10.63	1.55
Lime[c/]	0.00	0.00	0.00
Chemicals[c/]	4.55	4.55	4.55
Machinery & equipment[d/]	6.91	5.89	5.89
Custom hire	41.00	41.00	41.00
Land taxes[e/]	10.00	10.00	10.00
Operating capital interest	2.10	1.60	1.05
General overhead[f/]	17.66	19.40	19.30
Labor[g/]	4.75	5.50	6.75
TOTAL COST[h/]	108.22	98.57	90.09

See Table 10 for footnotes.

Table A-10. Estimated production cost, tall fescue hay, Laurelwood/Kinton soil type, by level of sludge use, 1977

	Level of sludge use		
	None	Low[b/]	High[a/]
	dollars		
Seed	0.00	0.00	0.00
Fertilizer[c/]	24.34	12.95	1.55
Lime[c/]	0.00	0.00	0.00
Chemicals[c/]	4.55	4.55	4.55
Machinery & equipment[d/]	6.91	5.89	5.89
Custom hire	41.00	41.00	41.00
Land taxes[e/]	10.00	10.00	10.00
Operating capital interest	2.25	1.70	1.15
General overhead[f/]	18.41	20.02	19.72
Labor[g/]	4.75	5.50	6.75
TOTAL COST[h/]	112.21	101.61	90.61

a/ Sufficient sludge is applied to cover all crop requirements for nitrogen except that banded at seeding.

b/ one-half of the high application rate.

c/ Includes custom application costs.

d/ Includes irrigation pumping cost.

e/ Based on farm use value.

f/ Includes establishment costs amortized over 10 years @ 9 percent interest.

g/ Includes both operator and hired labor.

h/ Excludes interest on land investment.

Table A-11. Fertilizer and chemical price assumptions for economic analysis of sludge use, Tualatin Basin, Oregon

Material	Unit	Price
		dollars
Nitrogen......................	lb.	.2125
Phosphorus....................	lb.	.34
Potassium.....................	lb.	.123
2-4-D (amine).................	gal.	6.18
Eptam.........................	gal.	20.25
Dyfonate......................	gal.	22.75
Sevin.........................	lb.	1.63
Benlate.......................	lb.	9.70
Cygon.........................	gal.	19.30
Lime..........................	ton	22.00
Eradicane.....................	gal.	25.00
Diasinon......................	lb.	3.00
Atrazine......................	lb.	2.52
Oil...........................	gal.	1.83
Avadex........................	gal.	19.48
Barban........................	gal.	15.55
Treflan.......................	gal.	30.50
Dinitro.......................	gal.	7.60

Table A-12. Machinery cost assumptions for economic analysis of sludge use, Tualatin Basin, Oregon

Machine description	Cost per hour[a]
	dollars
Tractor, 35-45 hp, D[b]	7.00
Tractor, 50-60 hp. D	8.03
Tractor, 100-110 hp, D	11.48
Tractor, 120-135 hp. D	12.94
Combine, SP 16'-18'	51.14
Truck, 2-ton	13.15
Truck, 3/4 ton	4.95
Spike harrow	0.77
Roller	2.12
Subsoiler	2.95
Broadcast spreader	2.12
Springtooth	4.33
Grain drill, 12', with fertilizer attachment	2.38
Plow, 4-16	1.70
Plow, 5-16	1.93
Plow, 6-16	2.19
Tandem disc, 12'	1.95
G-C Field cultivator, 12'	1.00
Cultimulcher, 12'	2.83
Wagon, hauling, 200 bushels	6.57
Corn picker, 2-row	15.00
Row planter, 4-36"	4.94
Side delivery rake, 9'	1.54
Mower-conditioner, 9'	5.05
Springtooth harrow, 20'	3.78
Spike harrow, 20'	1.25
4-row cultivator, 36"	2.13
Rotary trailer chopper, 9'	3.74

a/ Total cost includes depreciation, repairs, interest, taxes, insurance, fuel, and lubrication.

b/ D indicates diesel fuel; G is gasoline.

APPENDIX B

Table B-1. Soil mapped in Washington County

Soil name	Range of slope	Area
	percent	acres
Aloha silt loam......................	0	28,901
Amity silt loam......................	0	6,092
Astoria silt loam....................	5 - 80	3,861
Bellpine silty clay loam.............	2 - 60	15,733
Breedwell silt loam..................	0 - 20	1,759
Carlton silt loam....................	0 - 12	877
Cascade silt loam....................	3 - 60	11,384
Chehalem silty clay loam.............	3 - 12	1,407
Chehalis silty clay loam.............	0	7,167
Cloquato silt loam...................	0	1,984
Cornelius & Kinton silt loam.........	2 - 60	33,261
Cove silty clay loam.................	0	2,968
Cove clay............................	0	2,042
Dayton silt loam.....................	0	2,672
Delena silt loam.....................	3 - 12	1,665
Goble silt loam......................	2 - 60	13,291
Helvetia silt loam...................	2 - 30	12,887
Hembre silt loam.....................	3 - 90	26,108
Hillsboro silt loam..................	0 - 20	4,289
Huberly silt loam....................	0	2,864
Jory.................................	2 - 60	3,536
Kilchis-Klickitat....................	60 - 90	3,362
Knappa silt loam.....................	0	1,203
Labish mucky clay....................	0	1,975
Laurelwood silt loam.................	2 - 60	39,246
McBee silty clay loam................	0	9,494
Melby silt loam......................	3 - 90	38,373
Olyic silt loam......................	2 - 90	42,573
Orenco silt loam.....................	0 - 20	1,713
Peavine silty clay loam..............	2 - 60	10,021
Quatama loam.........................	0 - 20	14,429
Saum silt loam.......................	2 - 60	11,462
Tolke................................	5 - 60	17,584
Urban land...........................	0	652
Verboort silty clay loam.............	0	6,756
Wapato silty clay loam...............	0	11,548
Willamette silt loam.................	0 - 20	7,328
Woodburn silt loam...................	0 - 20	34,122

Table B-2: Sample calculation of nitrogen required from Portland sludge to meet nitrogen requirement of a crop[a/]

Rotation: beans, wheat, corn, wheat

NR_i = nitrogen requirement of crop (i = year of application)

x_i = sludge nitrogen required to meet NR (i = year of application)

<u>1st year (beans)</u>

NR_1 (for beans) = 50 lbs. N/acre

Fall application: $0.384x_1 = NR_1$

$0.384x_1 = 50$ lbs. N/acre

$x_1 = 130.2$ lbs. sludge N/acre

<u>2nd year (wheat)</u>

NR_2 (for wheat) = 75 lbs. N/acre in the fall and in the spring

Fall application: $0.384x_{2f} = NR_{2f}$

$0.384x_{2f} = 75$ lbs. N/acre

$x_{2f} = 195.3$ lbs. sludge N/acre

Spring application: $0.384x_{2s} + 0.06x_1 = NR_{2s}$

$0.384x_{2s} + 0.06(130.2) = 75$ lbs. N/acre

$x_{2s} = 174.5$ lbs. sludge N/acre

Total sludge application (2nd year) = (fall)195.3 + (spring)174.5 = 369.8 lbs. sludge N/acre

(continued)

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a/ Assumptions: 4.58% N in sludge, dry weight; 4% solids in wet sludge; weight of gallon of sludge is 8.3 lbs.

Table B-2. (Continued)

3rd year (corn)

$$NR_3(\text{corn}) = 120 \text{ lbs. N/acre}$$

Fall application: $.384x_3 + .06x_2 + .02x_1 = NR_3$

$$.384x_3 + .06(369.8) + .02(130.2) = 120 \text{ lbs. N/acre}$$

$$x_3 = 247 \text{ lbs. sludge N/acre}$$

4th year (wheat)

NR_4(for wheat) = 75 lbs. N/acre in the fall and in the spring

Fall application: $.384x_{4f} = NR_{4f}$

$$.384x_{4f} = 75 \text{ lbs. N/acre}$$

$$x_{4f} = 195.3 \text{ lbs. N/acre}$$

Spring application: $.384x_{4s} + .06x_3 + .02x_2 + .006x_1 = NR_4$

$$.384x_{4s} + .06(247) + .02(369.8) + .006(130.2) = 75 \text{ lbs. N/acre}$$

$$.384x_{4s} = 134.6 \text{ lbs. sludge N/acre}$$

Total sludge application(4th year) = (fall)195.3 + (spring)134.6 = 330 lbs. sludge N/acre

Table B-3. Phosphorus and potassium fertilizer recommendations[a/] for selected crops grown in the Tualatin Valley.

Crop	OSU soil test P	P[b/] recommended	OSU soil test K	K[c/] recommended
	-- ppm --	-- lbs/acre --	-- ppm --	-- lbs/acre --
Spring barley	0 - 30	18 - 26	>125	0
	>30	>18	<125	58 BR or 25 BA[c/]
Corn	15 - 30	44 - 53	0 - 75	83 - 125 BR
	30 - 50	35 - 44	75 - 150	50 - 83 BR
	Over 50	26 - 35	150 - 200	33 - 50 BR or BA
			> 200	0
Beans	15 - 60	40 - 53	0 - 75	75 - 100 BR
	60	26 - 40	75 - 150	50 - 75 BR
			150 - 200	33 - 50 BR or BA
			> 200	0
Fescue	0	0	< 150	25 BA
Wheat	10 - 25	13 - 18	0 - 75	50 - 83 BR
	25	0	75 - 100	25 - 50 BR or BA
			> 100	0

a/ Based on rates suggested by Fertilizer Guides, OSU Extension Service, Corvallis, OR.

b/ Band requirement.

c/ BA = banded; BR = broadcast.

Table B-4: Average yearly elemental content of Portland sewage sludge[a/]

	Solids	Tot. N	NH_3-N	P	K	Zn	Cd	Cu	Ni	Pb
	per cent[b/]					ppm				
1975	4.1	4.0	1.7	1.3	.38	3,700	46	1,033	147	1,350
1976	3.95	4.58	1.9	1.2	.47	2,800	48	1,275	200	1,475
Average	4.02	4.3	1.8	1.25	.43	3,250	47	1,154	173	1,412

a/ Study entitled, "Sewage Sludge and Poultry Waste Application to Agricultural Land," OSU North Willamette Experiment Station.

b/ Dry weight basis.

Table B-5: Total sludge that may be applied to soils based on trace element content of anaerobically digested sewage sludge from Portland, Oregon a/

Element	Conc. kg/metric T d/	Max. application b/ metric T/acre d/		Max. application metric T/acre e/		Max. application gals × 10^6/acre	
		Low CEC c/	High CEC	Low CEC	High CEC	Low CEC	High CEC
Zinc	3.25	62	125	1,557	3,114	.413	.825
Cadmium	0.047	86	172	2,155	4,312	.536	1.073
Copper	1.15	88	176	2,200	4,400	.583	1.170
Nickel	0.17	238	476	5,954	11,912	1.895	3.060
Lead	1.40	289	578	7,225	14,453	1.800	3.580

a/ Average analyses for 1975 and 1976 of Portland sewage sludge.

b/ See Table 10.

c/ Low CEC = 5 - 15 meg/100g soil (Laurelwood and Cornelius); high CEC = >15 meg/100g soil (Willamette and Woodburn).

d/ Dry weight basis.

e/ Wet weight basis.

Table B-6: Non-agricultural limitations on land used for sewage sludge application

Feature	Limitation
Land use	Sludge should not be applied within 500 feet of concentrated population areas (urban and suburban housing tracts, rural subdivisions, commercial areas, industrial parks, recreation sites, schools, etc.) if surface applied and within 300 feet if subsurface injected.
Farm residences	Sludge should not be applied within 200 feet of rural homes or gardens if surface applied and within 100 feet if subsurface injected.
Surface water	Sludge should not be applied within 100 feet of perennial streams, ponds, lakes, or ditches unless it can be shown that closer application would not pose an environmental hazard. Sludge should not be spread within 25 feet of intermittent streams.
Ground water	Sludge should not be applied within 200 feet of private water supply wells or springs or within 500 feet of public water supply wells.
Flood hazard	Sludge should not be applied to soils where the risk of flooding is greater than 10% per year.

SOURCE: Webb Bauer, "Guidelines for Land Application of Sewage Sludge," (unpublished).

APPENDIX C

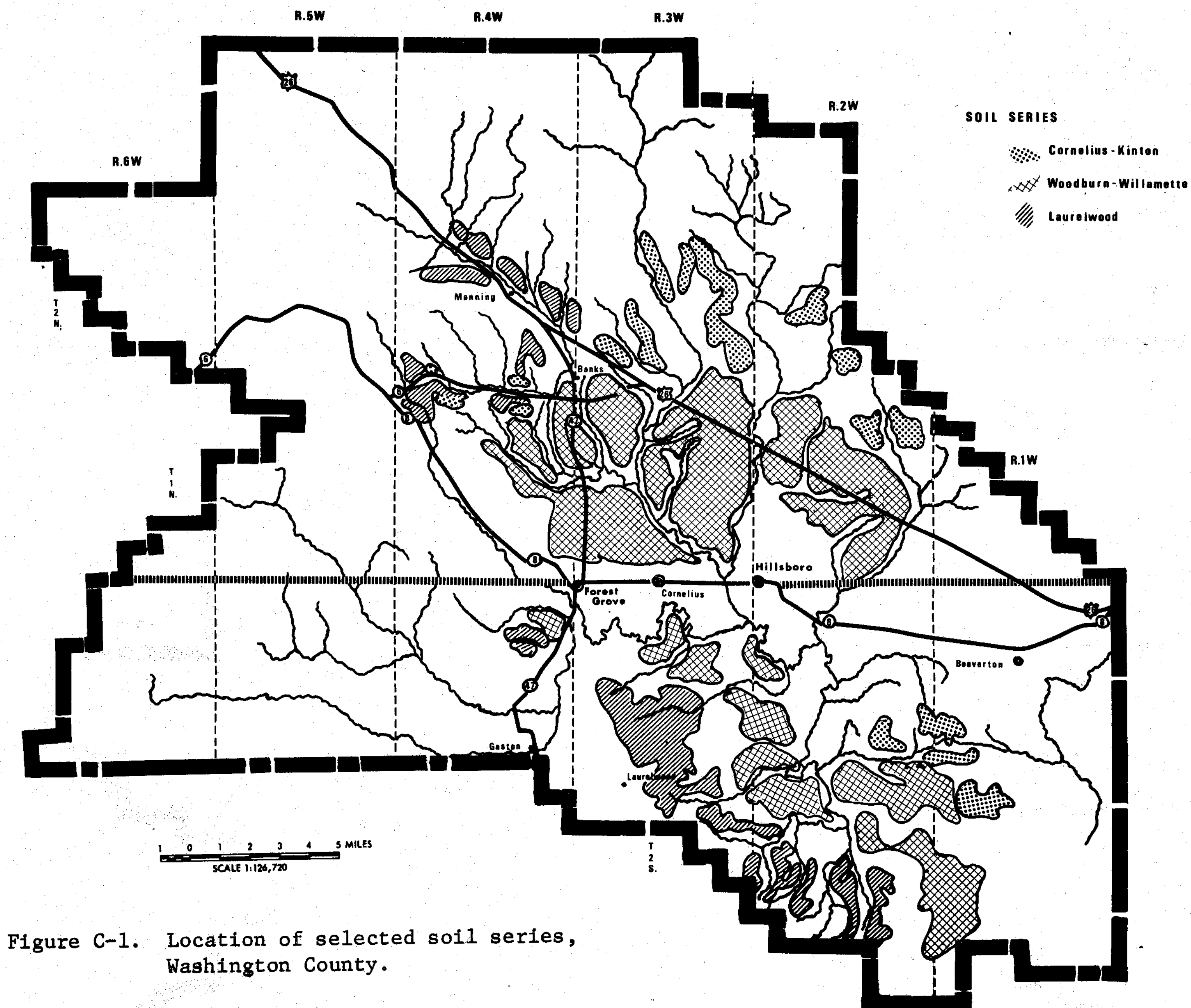

Figure C-1. Location of selected soil series, Washington County.