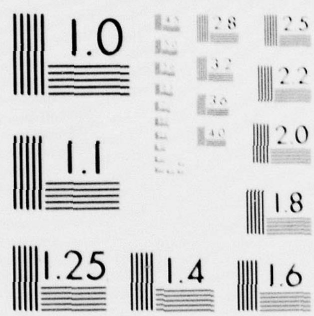
AD-A061 878 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 6/3
EFFECTS OF WASTEWATER AND SEWAGE SLUDGE ON THE GROWTH AND CHEMI--ETC(U)
NOV 78 A J PALAZZO
UNCLASSIFIED CRREL-SR-78-20 NL

| OF |
AD
A061878

END
DATE
FILMED
2-79
DDC



MICROCOPY RESOLUTION TEST CHART

Special Report 78-20

November 1978

EFFECTS OF WASTEWATER AND SEWAGE SLUDGE ON THE GROWTH AND CHEMICAL COMPOSITION OF TURFGRASS

Antonio J. Palazzo

DEPARTMENT OF THE ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
CORPS OF ENGINEERS
HANOVER, NEW HAMPSHIRE 03755

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Special Report 78-20	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECTS OF WASTEWATER AND SEWAGE SLUDGE ON THE GROWTH AND CHEMICAL COMPOSITION OF TURFGRASS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Antonio J. Palazzo		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE November 1978 13. NUMBER OF PAGES 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) CRREL-SR-78-20		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

12 14p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Growth (general)
Heavy metals
Sewage sludge
Turfgrasses
Wastewater treatment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A greenhouse study was conducted to determine the effects of wastewater and sewage applications on the growth and chemical composition of two turfgrass mixtures. A mixture of tall fescue (*Festuca arundinacea* Scheb var. 'K-31') and annual ryegrass (*Lolium multiflorum* Lam.) was compared to a mixture of Kentucky bluegrass (*Poa pratensis* L. var. 'Merion'), red fescue (*Festuca rubra L.* var. 'Pennlawn') and annual ryegrass. The mixtures were grown in pots of Chariton silt loam in a greenhouse. Prior to seeding, soil in some pots was amended with sludge at rates of 45 or 90 g/pot. Commerical fertilizer supplying N, P, and K was incorporated with soil in pots designated as controls. Treated municipal wastewater was applied on unamended and sludge-amended soil at rates of 5 or 10 cm per week. Wastewater

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

037 100

LB

20. Abstract (cont'd)

and sludge treatments increased yields, and total uptake of N, P, K, Zn, Cd, P, Cu, and Ni by the turfgrasses differed by treatment. The two grass mixtures were similar with regard to yields and composition. Larger yields corresponded to greater plant uptake of N, P, K, and metals. Similar removal rates were noted for N and K, suggesting that turfgrasses removing high amounts of N require high amounts of K. Plant concentrations of N, P, K and metals in all treatments were neither deficient nor toxic to plant growth, indicating the suitability of these materials in fulfilling the nutritional requirements of plants. Nitrogen concentrations were similar for all treatments. Phosphorus concentrations were highest in plants subjected to treatments that included sludge additions. Plant concentrations of Zn and Cd were highest in treatments that received wastewater. The highest turfgrass yields for successive clippings were obtained from the control, followed by the 10-cm/wk wastewater and 90-g/pot sludge treatment. During the latter stages of the study, yields were similar, with the exception of the lower yields from pots that received sludge but not wastewater.

PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by Corps of Engineers Civil Works Research and Investigation Project CWIS 31297, *Optimization of Management Techniques for Wastewater Renovation.*

The author gratefully acknowledges the technical review of this report by John Bouzoun of CRREL and Dr. Thomas Hinesly of the University of Illinois, as well as the helpful suggestions and assistance given by Dr. Harlan L. McKim of CRREL, and Dr. Robert W. Duell of Rutgers University. The author also acknowledges the technical assistance of John M. Graham.

EFFECTS OF WASTEWATER AND SEWAGE SLUDGE ON THE GROWTH AND CHEMICAL COMPOSITION OF TURFGRASS

Antonio J. Palazzo

INTRODUCTION

Turfgrasses have the potential to be an effective crop for use in treating municipal wastewaters and sewage sludges. As well as renovating wastewater, turfgrass sod is in demand for lawn use in urban areas, and fewer health constraints are placed on the use of turfgrasses as compared to food and feed crops. Practices for growing turfgrass sod differ from pasture management in that turfgrasses require clipping or mowing weekly. Materials removed from the site during sod harvest consist of the aboveground or aerial portions of the plant, an organic thatch layer which includes grass clippings, and approximately 1.25 cm (½ in.) of soil which contains roots and rhizomes. The sod is harvested throughout the growing season, and a new crop is established prior to the winter months or nongrowing season. The site is covered with vegetation which reduces soil losses by erosion during the winter.

Turfgrasses include species and varieties that require large annual applications of fertilizer. State agricultural experimental station recommendations for N applications to turfgrasses grown under average conditions can range from 5 to 6 lb/1000 ft^2 (240 to 287 kg/ha) per year for Merion Kentucky bluegrass (*Poa pratensis* L.), 3 to 5 lb/1000 ft^2 (144 to 240 kg/ha) for tall fescue (*Festuca arundinacea* Schreb.), and 4 to 6 lb/1000 ft^2 (191 to 287 kg/ha) for colonial bentgrasses (*Agrostis tenuis* Sibth.) (Juska et al. 1969). Clippings from a well-fertilized Merion Kentucky bluegrass lawn, mowed weekly, may contain up to 6% nitrogen (Pesek et al. 1971). As noted in a review on turfgrass fertilization by Beard (1973), N influences the growth rates of turfgrass tissues, roots, and shoots.

Phosphorus accumulation in soil is one of the possible limiting factors to the life of a land treatment system. Red fescue (*Festuca rubra* L.) and Kentucky bluegrass have been shown to grow without any detrimental effects on soils containing up to 1500 lb/acre (1650 kg/ha) of phosphorus (Juska et al. 1965).

The thatch layer, removed from the site during sod harvesting, has a high cation exchange capacity, and includes undecomposed grass clippings, roots and rhizomes. This thatch layer or organic mat provides a good removal mechanism for wastewater-applied NH_4-N, P, and metals, as well as for N and P contained in the grass clippings. About 2 lb/1000 ft^2 (96 kg/ha) of extra N/yr was required in a Merion Kentucky bluegrass area where the grass clippings were removed to maintain color, shoot density, and turfgrass quality, as compared to an area where the clippings were returned to the soil (Beard 1973). Also, since metals and P are relatively immobile in soils, the thin layer of surface soil removed during sod harvest below the thatch layer should contain high concentrations of these elements. Thus, sod farming would be an excellent method of removing chemical elements in wastewater that accumulate in the surface layer of the soil.

The objective of this study was to determine the effects of wastewater and sewage sludge on the growth and chemical composition of two turfgrass seed mixtures grown on a Charlton silt loam soil. The study was conducted in a greenhouse in Hanover, New Hampshire.

MATERIALS AND METHODS

Treatments consisted of weekly applications of ozonated secondary wastewater throughout the study on 25-cm diameter pots containing 8.2 kg of Charlton silt loam soil (oven dry) with and without one-time initial applications of 45 or 90 g/pot (dry weight) of primary digested sewage sludge from Hanover, New Hampshire (Fig. 1). The initial soil chemical data are shown in Table I. The sludge was added prior to seeding each of the turfgrass mixtures. The initial metal concentrations of the sewage sludge, wastewater, and soil are shown in Table II. The metal concentrations of the three materials are low due to the fact that the soil was not previously treated with organic wastes and the wastewater and sewage sludge were primarily from domestic sources. All treatments, including controls, were replicated three times. Four separate applications to total 5 or 10 cm of wastewater were applied on a particular day during each of the 30 weeks. All treatments received supplemental irrigation of distilled water when necessary to maintain good plant growth rates. Fertilizer was admixed with the soil in control pots just prior to seeding to provide 0.23, 0.10, and 0.19 g/pot of N, P, and K, respectively. Soil in control pots was topdressed with fertilizer at 79, 119, 152, 182, and 240 days after seeding with rates similar to initial applications, except on the 152nd day when only a half-rate application was made. Wastewater used in the study contained 24.2, 7.7 and 12.3 mg/l of N, P, and K, respectively. (Concentrations expressed are means of individual determinations from samples collected during each application.) Sewage sludge contained 1.1% N and 2.8% P, but only trace amounts of K. Components of the two turfgrass mixtures and the seeding rates (in g/pot) were as follows:

1. Bluegrass mixture — Kentucky bluegrass (*Poa pratensis* L. var. "Merion") at 0.35 g, red fescue (*Festuca rubra* L. var. "Pennlawn") at 0.37 g, and annual ryegrass (*Lolium multiflorum* Lam.) at 0.09 g.

Figure 1. Overview of turfgrass study.

Table I. Initial soil analyses of the Charlton silt loam soil.*

Parameter	*Concentration*
Total P	226.6
Extractable P	23.1
pH	6.6
Soluble salts (mmho/cm)	0.32
Cation exchange capacity (meq/100 g)	13.5
Extractable cations	
Ca	752
Mg	45
K	35
Na	18

*All concentrations in ppm unless otherwise noted.

Table II. Initial metal concentrations of soil, wastewater, and sewage sludge.

Parameter	Cd (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)	Cr (ppm)	Pb (ppm)
Charlton soil	0.91	30	91	27.7	25.5	21.1
Effluent*	0.0012	0.2	0.22	0.016	<0.001	
Sludge		188	258		33.7	

*Effluent values from Iskandar (1975).

2. Tall fescue mixture — tall fescue (*Festuca arundinacea* Scheb var. "K-31") at 0.27 g and annual ryegrass (*Lolium multiflorum* Lam.) at 0.09 g.

Turfgrasses were harvested 14 times for yield determinations by clipping at a height of 5 cm. Plant foliage samples were collected from the 5th to the 10th clippings, washed in distilled water, dried to constant weight, and ground to pass through a 20-mesh sieve. Concentrations of N, P, K, Cu, Cd, Zn, Ni, Cr, and Pb in plant foliage were determined by standard Kjeldahl, colorimetric, and atomic absorption procedures after ashing in a muffle furnace (Jackson 1967).

Yields and chemical concentration data were subjected to an analysis of variance for a split-plot design with wastewater and sludge treatments as the subplots. Duncan's Multiple Range Test was used to determine differences in treatment means.

Weekly wastewater applications added more N and K, but less P than single sludge applications, which were made prior to seeding (Table III). Amounts of major nutrients applied on control plots were similar to amounts supplied as constituents of wastewater at a rate of 5 cm/wk.

The total amounts of N applied on a kg/ha basis for the various treatments and the control are also presented in Table III. Applications of 10 cm/wk of wastewater on pots amended with 90 g of sludge added N in amounts that were almost four times those applied on control pots.

RESULTS AND DISCUSSION

Yields

Wastewater and sewage sludge applied at various rates resulted in significant differences in grass yields, which were similar for the two turfgrass mixtures (Table A1). Yields increased with applications of wastewater alone or with sludge, as compared to those with sludge alone (Table IV). Highest yields were obtained with the 10-cm/wk wastewater application rate in combination with the sewage sludge treatment of 90 g/pot. Lowest yields were observed when sludge was applied alone. Sludge alone had the lowest N fertility and probably lower availability of the total N supplied because much of it was most likely contained in the organic fraction. Yields may also have been affected by low amounts of available K on pots with only added sludge (Table I). Differences in yields were due primarily to differences in amounts of wastewater and sludge-borne N.

Prior to the eighth harvest, 152 days after seeding, photographs were taken of two turfgrass mixtures growing on pots in soil. Differences in grass density and growth as affected by wastewater and sewage sludge treatments can be compared to conditions on control pots by examining Figures 2-5.

Table III. Total amounts of N, P, and K applied in the different wastewater and sludge treatments.

Treatment: Wastewater (cm)	Treatment: Sludge (g)	Nitrogen (g/pot)	Nitrogen (kg/ha)	Phosphorus (g/pot)	Potassium (g/pot)
5	0	1.89	149	0.60	0.96
10	0	3.79	298	1.20	1.91
0	45	0.49	39	1.29	0
0	90	0.98	77	2.58	0
5	45	2.38	187	1.89	0.96
5	90	2.87	226	3.18	1.91
10	90	4.77	376	3.78	1.91
control*		1.27	100	0.55	1.05

*Control includes six applications of commercial fertilizer.

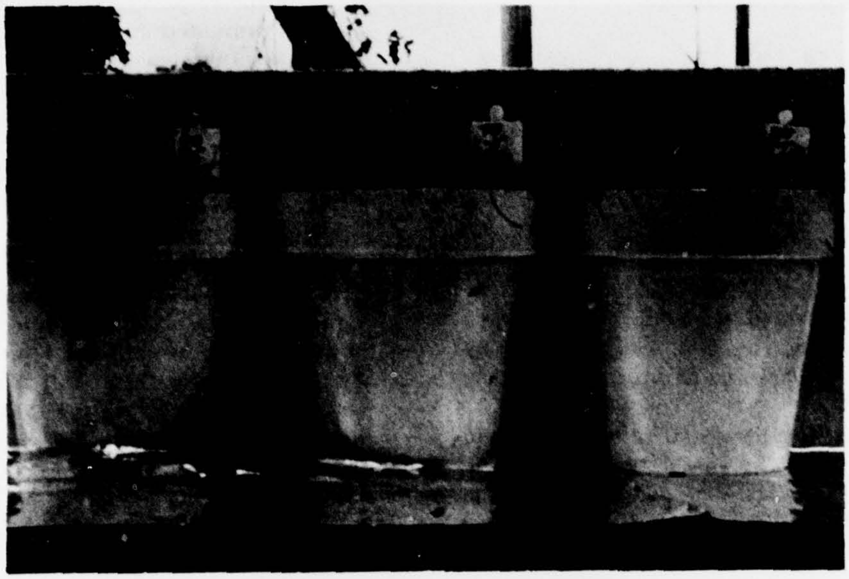


Figure 2. Bluegrass mixture (left to right — control, 5-cm/wk and 10-cm/wk applications of wastewater).

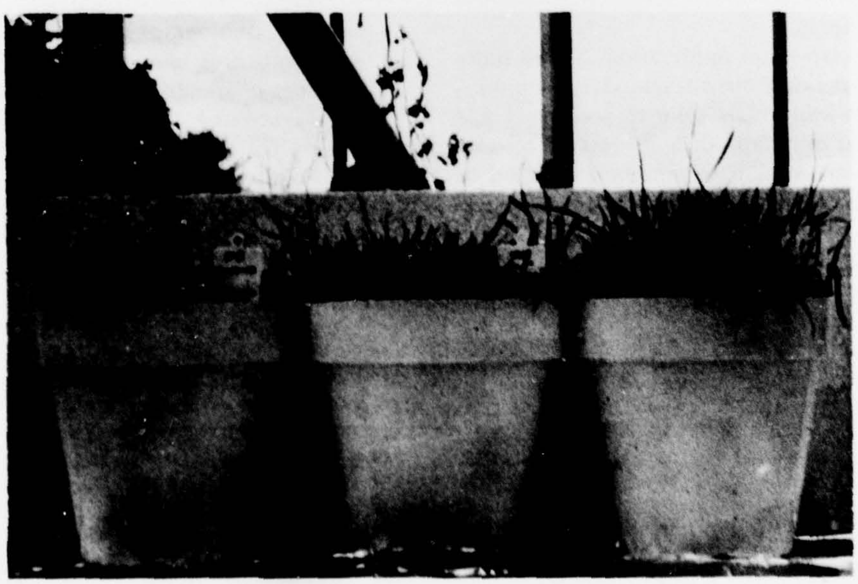


Figure 3. Tall fescue mix (left to right — control, 5-cm/wk and 10-cm/wk applications of wastewater).

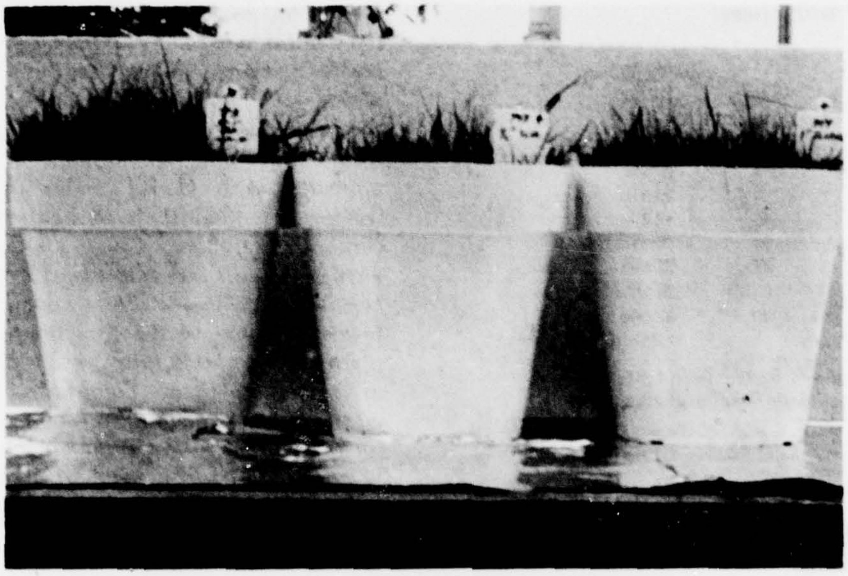


Figure 4. Bluegrass mixture (left to right — control, 45 and 90 g/pot of sewage sludge).

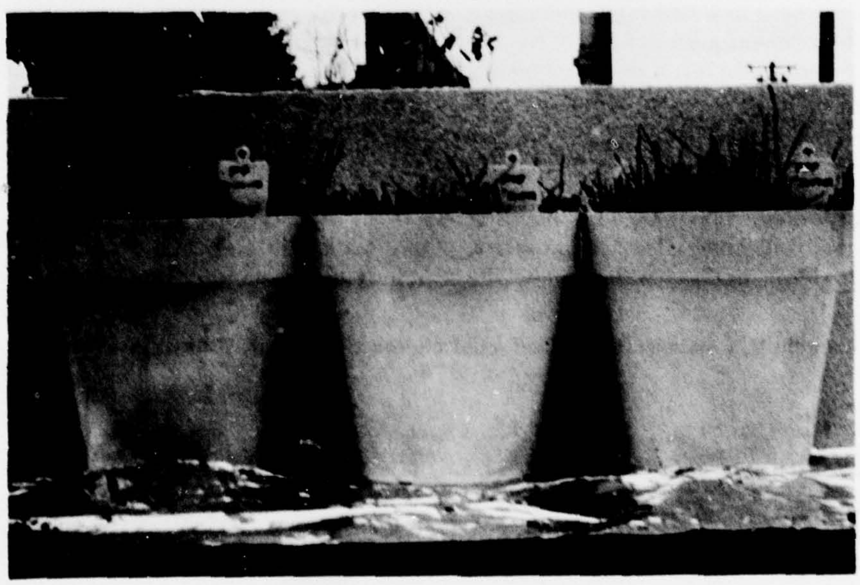


Figure 5. Tall fescue mixture (left to right — control, 45 and 90 g/pot of sewage sludge).

Table IV. Effects of various wastewater and sludge treatments on yields of turfgrasses.

Wastewater (cm)	Sludge (g)	Grass clipping yield (g/pot)
5	0	17.30d*
10	0	23.55b
0	45	7.87e
0	90	8.01e
5	45	21.80b
5	90	20.58bc
10	90	27.09a
control		17.37cd

*Yields followed by the same letter were not significantly different at the 5% level of probability.

Concentrations of N, P, K and trace elements

As was the case for yields, no differences were observed in the chemical composition of foliage from the two grass mixtures. The mean squares for the analysis of variance are presented in Table AII.

As may be seen in Table V, concentrations of P, K, Zn, Pb, and Cd in foliage tissues were affected by differences in wastewater and sludge treatments. But concentrations of N, Cu, Ni, and Cr were not different as a result of treatment differences. The highest P concentrations were in grasses receiving sludge alone, even though grasses in other treatments received greater amounts of this element (Table III). The highest concentrations of K were in foliage from control pots, even though only about one-half as much K was added to these pots as was supplied by wastewater applied at a rate of 10 cm/wk. Applications of wastewater tended to increase concentrations of Zn and Cd in grasses. Concentrations of Cd in plants from pots receiving the two levels of sewage sludge were similar to those in plants from control pots. Except for one instance, Pb concentrations were higher in plants from control pots than in plants growing on soil amended with sludge and/or irrigated with wastewater. Regardless of treatments, concentrations of N, P, and K were adequate for plant growth (Martin and Matocha 1973). Metal concentrations in plants are of concern since toxic levels of some of these elements can reduce plant growth and in turn cause serious problems in using soil-plant complexes to renovate wastewaters. Concentrations of metals in grasses included in this study were below levels generally considered to be toxic to plants (Patterson 1971 and Allaway 1968 for Ni, Allaway 1968 and Jones 1972 for Zn and Cu, Lisk 1972 and Mortvedt and Giordano 1975 for Cr, Warren and Delvault 1972 for Pb, and Bingham et al. 1975 for Cd).

Removal of selected chemical elements as constituents of grass foliage

As shown in Table VI, only the removal of Cr by grass harvesting was unaffected by wastewater and sludge treatments. No differences were observed that were attributable to differences in turfgrass mixtures. This can be seen from an examination of mean squares for the analysis of variance, as exhibited in Table AIII. In general, treatment differences affecting removal of chemical elements from soil depended more on differences in yields than on concentration differences in plant tissues. From the correlations of total uptakes of N, P, and K with

Table V. Concentration of selected chemical elements in turfgrass foliage.

Treatment: Wastewater (cm)	Sludge (g)	N (%)	P (%)	K (%)	Zn (ppm)	Pb (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)
5	0	3.50a*	0.38c	3.18c	56.50c	4.10b	6.84ab	0.81a	8.67a	11.25a
10	0	3.81a	0.38c	3.23b	74.33ab	4.54ab	9.43a	1.49a	12.75a	11.50a
0	45	3.34a	0.51a	2.76c	57.33bc	3.32b	2.11c	1.49a	12.75a	7.57a
0	90	3.53a	0.54a	2.75c	46.92cd	4.02b	2.05c	1.25a	11.25a	12.12a
5	45	3.77a	0.37c	2.80c	67.75bc	4.04b	4.48bc	1.53a	8.75a	6.93a
5	90	3.59a	0.40bc	2.95bc	67.92c	3.72b	7.62ab	1.03a	12.33a	6.92a
10	90	3.55a	0.38c	2.68bc	86.58a	3.82b	5.48abc	1.13a	10.42a	8.08a
control		3.51a	0.44b	3.95a	36.42d	5.40a	1.42c	0.61a	11.50a	4.30a

*Columns of elements followed by the same letter were not significantly different at the 5% level of probability.

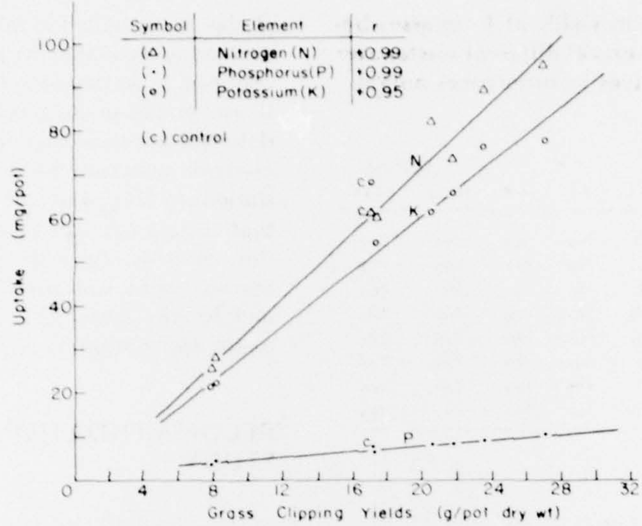


Figure 6. Total uptakes of N, P, and K as affected by grass yields.

Table VI. Total amounts (mg/pot) of selected chemical elements contained in turfgrass foliage harvested from pots.

Treatment Wastewater (cm)	Sludge (g)	N	P	K	Zn	Pb	Cd	Cr	Cu	Ni
5	0	60.72c*	6.63c	54.95c	0.98c	0.07b	0.12b	0.014a	0.15cd	0.19ab
10	0	89.20a	9.07ab	76.05a	1.74b	0.11a	0.21a	0.034a	0.29a	0.26a
0	45	25.64d	4.00d	21.29d	0.45d	0.03c	0.17c	0.012a	0.10d	0.06c
0	90	28.32c	4.37d	22.06d	0.38c	0.03c	0.16c	0.010a	0.09d	0.11bc
5	45	73.71bc	8.18bc	60.60bc	1.39b	0.08b	0.15ab	0.021a	0.25ab	0.14abc
5	90	82.03ab	8.13bc	60.84bc	1.48ab	0.09ab	0.11b	0.034a	0.19bc	0.15abc
10	90	95.02a	10.22a	77.40a	2.34a	0.10a	0.15ab	0.030a	0.28a	0.21ab
control		61.21c	7.60bc	68.72ab	0.63cd	0.09ab	0.25c	0.011a	0.20bc	0.25a

*Columns of elements followed by the same letter were not significantly different at 5% level of probability.

yields, as depicted by Figure 6, it can be seen that N and K removals were affected to a greater extent by yields than by P removal. The low removal of P was due to the lower concentrations in plants. Potassium, an element not usually considered a potential pollutant, was removed by the grasses at a slightly lower rate than nitrogen. The two treatments which received 5 and 10 cm/wk of wastewater had only a 10 to 15% difference in the amounts of N and K contained in the plant. But the wastewater used in this study supplied twice as much N as K. Results from this study suggest that high plant requirements for K are necessary to remove maximum amounts of nitrogen. Wedin (1973) cites a report by the National Research Council-National Academy of Sciences (1970) in which it is stated that, at yields ranging from 8 to 16 tonne/ha, the removal of K by cool season grasses is 90% of that for N. From research performed at CRREL (Palazzo 1976), it was found that forages receiving 5 cm/wk of wastewater

Table VII. Differences in yields of turfgrasses between consecutive harvests at different wastewater and sludge treatments (yes = differences noted).

Treatment Wastewater (cm)	Sludge (g)	Harvests 1-3	4-5	7-9	10-12	13-14
5	0	No	No	No	Yes	Yes
10	0	No	No	No	Yes	Yes
0	45	No	No	No	No	No
0	90	No	No	No	No	No
5	45	No	No	No	Yes	Yes
5	90	No	No	No	Yes	Yes
10	90	No	Yes	Yes	Yes	Yes
Control		Yes	No	No	Yes	Yes

contained three times more N than K over a two-year period. Plants were marginally deficient in K, and available concentrations of this element in the soil were reduced to relatively low levels. In this study large amounts of K were absorbed by plants that were grown on control pots which received supplemental K fertilizer. Concentrations of K were 3.95% in the control plants and ranged from 2.75% to 3.23% (Table V) in plants subjected to other treatments.

Because yields are so important in the removal of wastewater constitutents, rapid initial growth is important. In this study, grasses grown on control treatments, which received commercial fertilizer, produced higher yields initially (Table VII). After three harvests the combination of 10 cm/wk of wastewater and 90 g/pot of sludge produced the highest yields. After 10 harvests, all treatments were similar in yields except for those where only sludge was applied, which were significantly lower. Rates of grass growth depended on amounts of availability of applied N. Sludges alone supplied less total N and some of this N may have been only slowly available.

CONCLUSIONS

Turfgrasses responded favorably to applications of wastewater. Higher quantities of total N supplied in wastewater promoted rapid initial growth resulting in significantly higher removal of sludge and wastewater constituents. Sludge applications increased yields over those from fertilized controls only when applied in combination with wastewater. Much of the N in sludge is contained in organic matter and is not as readily available to growing plants as that supplied in wastewater. Concentrations of N, P, K, and metals in the grasses studied were neither deficient nor toxic to plant growth. Compared to contents generally found, the range in concentrations of N (3.34 to 3.81%) was high, indicating that turfgrasses can take up large amounts of this element. To maintain high N and metal removal rates, soils used to renovate wastewater and for the disposal of sludge may need frequent applications of K fertilizers.

RECOMMENDATIONS FOR FURTHER STUDY

The capacity of turfgrasses to renovate wastewater needs to be determined under field conditions. Results from a field study can be used to more accurately define the effectiveness of these grasses and to identify problems which may occur in growing sod under high sludge and wastewater loading rates. Total amounts of wastewater constituents removed by sod harvesting need to be determined, where sod includes the grass leaves, organic thatch layer, and approximately 1.25 cm of surface soil. The capacity of thatch layers and surface soils to filter and remove heavy metals and P, the quality of the sod produced, and the problems of grass injury from diseases and insects need to be evaluated in this field study.

REFERENCES

Allaway, W.H. (1968) Agronomic controls over environmental cycling of trace elements. *Advances in Agronomy*, vol. 20, p. 235-274.

Beard, J.B. (1973) Fertilization. In *Turfgrass: Science and culture*. Englewood Cliffs, N.J.: Prentice-Hall, Inc., p. 408-465.

Bingham, F.T., A.L. Page, R.J. Mahler and T.J. Ganje (1975) Growth and cadmium accumulation of plants grown on a soil treated with a cadmium-enriched sewage sludge. *Journal of Environmental Quality*, vol. 4, p. 207-211.

Iskandar, I.K. (1975) Urban waste as a source of heavy metals in land treatment. In *International Conference on Heavy Metals in the Environment*, Toronto, Canada.

Jackson, M.L. (1967) *Soil chemical analysis*. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Jones, J.B. (1972) Plant tissue analysis for micronutrients. In *Micronutrients in agriculture*. Soil Science Society of America, Inc., Madison, Wisconsin, p. 319-341.

Juska, F.V., A.A. Hanson and C.J. Erickson (1965) Effects of phosphorus and other treatments on the development of red fescue, Merion, and common Kentucky bluegrass. *Agronomy Journal*, vol. 57, p. 75-81.

Juska, F.V., J.F. Cornman and A.W. Hovin (1969) Turfgrasses under cool, humid conditions. In *Turfgrass science*, American Society of Agronomy Monograph no. 14, Madison, Wisconsin, p. 491-512.

Lisk, D.J. (1972) Trace metals in soils, plants, and animals. *Advances in Agronomy*, vol. 24, p. 267-311.

Martin, W.E. and J.E. Matocha (1973) Plant analysis as an aid in the fertilization of forage crops. In *Soil testing and plant analysis* (L.M. Walsh and J.D. Benton, Eds.), Soil Science Society of America, Madison Wisconsin, p. 393-426.

Mortvedt, J.J. and P.M. Giordano (1975) Response of corn to zinc and chromium municipal wastes applied to soil. *Journal of Environmental Quality*, vol. 4, p. 170-174.

National Research Council-National Academy of Sciences (1970) Nutrient requirements of beef cattle. No. 4, 4th revised edition, Washington, D.C.

Palazzo, A.J. (1976) Land application of wastewater: Forage growth and utilization of applied N and P. *Proceedings, Eighth Annual Waste Management Conference*, Rochester, New York.

Patterson, J.B.E. (1971) Metal toxicities arising from industry. Agriculture Development and Advisory Service, Cambridge, England. Technical Bulletin, Ministry of Agriculture, Fisheries, and Food, vol. 21, p. 193-207.

Pesek, J., G. Stanford, and N.L. Case (1971) Nitrogen production and use. *In Fertilizer technology and use* (T.J. Army, J.J. Hathaway and V.J. Kilmer, Eds.), Soil Science of America, Madison Wisconsin, p. 217-270.

Warren, H.V. and R.E. Delavault (1962) Lead in some food crops and trees. *Journal of Science and Food Agriculture*, vol. 13, p. 96-98.

Wedin, W.F. (1973) Fertilization of cool-season grasses. In *Forage fertilization*, (D.A. Mays, Ed.), American Society of Agronomy, Madison, Wisconsin, p. 95-118.

APPENDIX A. MEAN SQUARES AND STASTICAL SIGNIFICANCE OF DATA INCLUDED IN STUDY

Table AI. Mean squares and statistical significance for differences in yields of turfgrasses.

Parameter	*Treatments*	*Seed mixtures*	*Error*
Yields	405.36*	1.48	8.66

*Significant at the 1% level of probability.

Table AII. Mean squares and statistical significance for differences in concentrations of selected chemical constituents in grasses.

Element	*Treatment*	*Seed mixtures*	*Error*
Nitrogen	0.20	0.00	0.26
Phosphorus	0.04†	0.00	0.00
Potassium	1.37†	0.01	0.11
Zinc	2109.52†	15.66	136.11
Copper	22.86	7.58	11.47
Nickel	66.17	2.57	32.14
Chromium	0.96	0.07	0.89
Lead	3.27*	0.01	0.96
Cadmium	72.12†	1.97	12.60

*Significant at the 5% level of probability.
†Significant at the 1% level of probability.

Table AIII. Mean squares and statistical significance for differences in plant uptake of selected chemical elements.

Element	*Treatment*	*Seed mixture*	*Error*
Nitrogen	5734.00*	3.53	135.54
Phosphorus	39.94*	0.55	2.68
Potassium	4103.14*	24.66	67.99
Zinc	3978712.90*	138.00	127114.63
Copper	50944.84*	1717.72	3979.58
Nickel	42184.85*	228.48	9775.04
Chromium	964.14	13.45	374.53
Lead	7925.60*	57.00	408.15
Cadmium	45483.76*	447.24	4672.75

*Significant at the 1% level of probability.