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DYNAMICS OF MUNICIPAL WASTEWATER SLUDGES ON FOREST LAND*

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ABSTRACT

Forest land application of municipal wastewater sludge enhances the production of lignocellulosic materials and represents a promising sludge management alternative to disposal in the environment. This research project had two objectives: upgrading, or recycling, residual sludge produced by water-treatment plants, and increasing silvicultural yields through fertilization. An experiment in greenhouses was conducted for a period of some four months. Varying amounts of anaerobic sludge were used as fertilizer to grow larches in sand. The experiment proved conclusively that sludge from water-purification plants can be put to good use in forest fertilization.

INTRODUCTION

In any industrialized society, individuals can obtain consumer goods that make life more pleasant and comfortable. Improvements in living conditions over those of our forefathers have their cost with increased amounts of waste in various forms—liquid, solid, and gas [1-3]. Unfortunately, all such waste materials pollute the environment. Recently, a general awakening to the situation and a willingness to improve it has fostered the desire to preserve a healthy, unblemished environment, while maintaining our lifestyle and consumption level [4, 5].

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The fight against pollution is expensive and is not always justifiable economically. With waste recovery, however, costs can be assigned to a new form of production—recycling of waste materials. Water is considered a consumer product which, after being used for residential and industrial purposes, is contaminated and unfit for reuse. The simplest and fastest solution is to return used water to the natural environment (lake or river). This has resulted in substantial environmental deterioration, making bodies of water unfit for consumption and eventually unusable for recreational purposes. The situation has become intolerable, and some governments have decided to correct the problem [6, 7].

Sewage treatment plants discharge waste material called sludge, which can pollute the environment unless recycled. This article describes the possible management of sludge and its use as a fertilizer [8-10]. A market must be found to support recycling. This may be through improvements in agriculture or, more preferably, forestry. Although levels of contamination by pathogenic organisms (Table 1) are minimal when sludge is stabilized, it does contain heavy metals (Table 2) and synthetic compounds (Table 3). Since forestry products do not enter the human food chain, the risks associated with this stabilization are avoided [11-17].

Two objectives guided the research project. The first was the useful application (or recycling) of sludge produced by sewage treatment plants, and the second was the increase in forest yield through fertilization [18].

EXPERIMENTAL PHASE

The research involved an experimental application in a greenhouse, in which tamarack trees (*Larix laricina*) were grown in sand fertilized with different quantities of anaerobic sludge (Figure 1). The experiment was conclusive: sludge from a sewage treatment plant can be used profitably in forest fertilization.

For 119 days, we grew tamaracks in sand. The crop was fertilized with varying quantities of anaerobic sludge from the Valcartier military base plant near Québec City. The composition of the anaerobic sludge is shown in Table 4. The sludge was applied to the surface for the first fourteen treatments after the seeds had been sown (Figure 2). In treatments 19 and 20, it was buried in 10 cm of sand before the seeds were sown. The different treatments were based on nitrogen content.

The tamarack plants' height was measured several times during the experiment (Table 5). At the end, the diameter of the stump and the dry biomass were also measured.

RESULTS AND DISCUSSION

The graphs (Figures 3 to 7) show changes in growth height from the start until the end of the experiment (119 days). Improvement varied in proportion to the number of applications and the total amount of sludge applied (Table 5). Despite

Table 1. Organisms Susceptible to Contaminate Urban Wastewater and Sludge in Canada [20-24]

Organisms	Disease	Host
BACTERIA		
Clostridium	Gas gangrene, tetanus, botulism, food poisoning	Animals, fish
Escherichia coli (enteropathogenic types)	Gastroenteritis	Man, domestic animals
Leptospira	Leptospirosis	Man, domestic and wild animals
Mycobacterium	Tuberculosis, skin granuloma	Man, domestic and wild animals
Pseudomonas	Local infection	Man
Salmonella (1 700 types)	Typhoid fever, paratyphoid fever, enteritis, salmonellosis, food poisoning	Man, domestic and wild animals, birds
Shigella	Shigellosis (dysentery)	Man
Yersinia enterocolitica	Epidemic gastroenteritis	Man, domestic and wild animals, lower animals
HELMINTHS		
Cestodes (Tapeworms)		
Echinococcus granulosis (dog tapeworm)	Unilocular echinococciosis	Dog
Echinococcus multilocularis	Alveolar hydatid disease	Dog, carnivores
Hymenolepis nana (dwarf tapeworm)	Taeniasis	Man, rat
Taenia saginata (Beef tapeworm)	Taeniasis	Man
Taenia solium (Pork tapeworm)	Taeniasis	Man

Table 1. (Cont'd.)

Organisms	Disease	Host
HELMINTHS (Cont'd.)		
Nematodes (Roundworms)		
Ancylostoma briziliense (cat hookworm)	Cutaneous larva migrans	Cat
Ancylostoma canium	Cutaneous larva migrans	Dog
Ancylostoma duodenale	Ancylostomiasis	Man
Ascaris lumbricoides	Ascariasis	Man, swine?
Enterobius vermicularis (pinworm)	Enterobiasis	Man
Necator americanus	Necatoriasis	Man
Strongyloides stercoralis	Stronglyloidiasis	Man, dog
Toxocara canis	Visceral larva migrans	Carnivores
Toxocara cati (cat roundworm)	Visceral larva migrans	Carnivores
Trichurus trichiura (whipworm)	Trichuriasis	Man
Protozoa		
Balantidium coli	Balantidiasis	Man, swine
Entamoeba histolytica	Amoebiasis	Man
Giardia lamblia	Giardiasis	Man, domestic and wild animals

Table 1. (Cont'd.)

Organisms	Disease	Host
VIRUSES		
Adenovirus (more than 30 types)	Respiratory disease, eye infections	Man
Enteroviruses		
Coxsackievirus A	Herpangia, respiratory disease, meningitis, fever	Man
Coxsackievirus B (6 types)	Myocarditis, congenital heart anomalies, rash, fever, meningitis	Man
New enteroviruses (4 types)	Meningitis, encephalitis, respiratory disease, acute hemorrhagic conjunctivitis, fever	Man
Polioviruses (3 types)	Paralysis, meningitis, fever	Man
Gastroenteritis virus type agents (2 types)	Norwalk epidemic, vomiting and diarrhea, fever	Man
Hepatitis A	Infectious hepatitis	Man, other primates
Parvovirus (adeno-associated virus, 3 types)	Associated with respiratory disease in children; etiology not clearly established	Man
Reovirus (3 types)	Not clearly established	
Rotavirus (Reoviridae family)	Epidemic vomiting and diarrhea, mainly of children	Man, domestic animals

Table 2. Comparison of Wastewater Sludges Composition in Québec and in the United States

Element	Québec	United States	Units
C org. total	31.5	31.0	%
N total	5.1	3.9	%
$NH_4^+ - N$	6,055	6,540	mg/kg
$NO_3^- + NO_2^- - N$	1,565	490	mg/kg
P total	2.0	2.5	%
K	0.2	0.4	%
Na	0.4	0.6	%
Ca	2.0	4.9	%
Mg	0.45	0.54	%
Ba	0.04	0.06	%
Fe	1.8	1.3	%
Al	1.1	1.2	%
Pb	180	1,360	mg/kg
Zn	526	2,790	mg/kg
Cu	551	1,210	mg/kg
Ni	36	320	mg/kg
Cd	≤ 10	110	mg/kg
Cr	53	2,620	mg/kg
Mn	701	380	mg/kg
B	≤ 125	77	mg/kg
As	5	43	mg/kg
Mo	12	28	mg/kg
Hg	2	733	mg/kg

slight differences, treatments 14 and 15 were better than treatment 13 (Figures 7 and 8). Several applications gave better results than a single application. For example, treatment 9 was better than 7, while 8 (Figures 5 and 9) was better than 4 (Figures 4 and 10). Upward growth is especially important: the higher the trees grow, the sooner they can compete with weeds [19].

Treatments which received seventeen successive applications of sludge gave the best results, except for treatment 13 (Figures 7 and 8). The average diameter of the tamaracks was larger with nine applications of sludge than with five. Treatments receiving only one or two applications were similar (Figure 11); the trees were smaller than those that received several applications. Buried sludge applications were found to be slightly better than their counterparts fertilized at the surface.

Table 3. Occurrence of Toxic Organics Compounds in Wastewater Treatment Sludge in Canada [25]

	Percent Occurrence at Stated Concentrations (13 Sludges Surveyed)		
Compound	≥ 1 mg/kg	≥ 10 mg/kg	≥ 100 mg/kg
Anthracene	23	15	15
Benzo-a-pyrene	23	15	0
Bis (2 ethyl-hexyl) phthalate	92	92	31
Chrysene	15	15	0
Di-n-octylphthalate	31	0	0
Fluorene	23	15	15
Hexachlorobenzene	8	0	0
Naphthalene	23	15	0
N-Nitrosodiphenylamine	54	15	0
Pentachlorophenol	8	0	0
Pyrene	38	15	15
2,4 Dichlorophenol	15	0	0

Figure 1. All the pots in the greenhouse.

Table 4. Analysis of the Anaerobic Sludge Used in the Experiment

Parameter	Concentrations	Units
Total solids	9,000	mg/L
Total volatile solids	3,100	mg/L
Dissolved solids	855	mg/L
Dissolved volatile solids	230	mg/L
pH	7.7	—
NTK (Total nitrogen)	42,000	mg/kg N
$N\text{-}NH_4$ (Ammonia nitrogen)	770	mg/kg N
$N\text{-}NO_3{+}NO_2$ (Nitrates+Nitrites)	≤ 0.5	mg/kg N
Total inorganic phosphorus	—	mg/kg P
Total phosphorus	10,500	mg/kg P
Aluminum	13,000	mg/kg Al
Arsenic	≤ 5	mg/kg As
Baryum	600	mg/kg Ba
Bore (1)	20	mg/kg B
Cadmium (2)	≤ 10	mg/kg Cd
Mercury	7.7	mg/kg Hg
Molybdenum	≤ 20	mg/kg Mo
Nickel	20	mg/kg Ni
Lead	680	mg/kg Pb
Potassium	880	mg/kg K
Sodium	1,500	mg/kg Na
Calcium	33,000	mg/kg Ca
Chromium	80	mg/kg Cr
Copper	2,900	mg/kg Cu
Iron	15,000	mg/kg Fe
Magnesium	2,500	mg/kg Mg
Manganese	200	mg/kg Mn
Zinc	950	mg/kg Zn
Selenium	≤ 5	mg/kg Se

1) Limit of detection of 45 mg/kg on solids fraction. As all obtained data in the solids fraction are below the limit of detection, actual concentrations are then between the range of the data shown on the table and the same data minus 45 mg/kg.

2) All data below 10 mg/kg of suspended solids or below 7.5 mg/kg of total dry solids.

Figure 2. Application of sludge.

A measurement for the stem biomass including the leaves is valuable because it provides a more complete picture of experimental results (Figures 4 to 7). Besides incorporating the stems' height and diameter, it is the ideal parameter for fibre production, in representing total matter produced.

Treatments resulting in less mass involved only one application of sludge. However, total nitrogen, combined with the number of applications, seemed to have an effect. For example, a rate of 125 kg N/ha was better than rates of 50 kg N/ha and 25 kg N/ha. Also, for the rate of 125 kg N/ha, five applications of 25 kg N/ha each (treatment 8; Figure 9) produced more biomass than a single application of 125 kg N/ha (treatments 4 [Figure 10] and 20).

Treatments that received nine and seventeen applications involved the largest amount of sludge overall and gave the best results, except in treatments 11 and 12, for which the opposite was the case (Figures 12, 13, 14 and 15 consecutively).

CONCLUSION

We conclude that sludge is a good forestry fertilizer for improving a substrate for growing tamarack. Although the experiment was conducted in a greenhouse, it is likely that similar results would be obtained in the field.

Table 5. Results on Average Growth Height at Various Time and Average Diameters and Leave's Mass at the End of the Experiment (119 Days)

Treatment Number	Final Characteristics	$\overline{H}$ after 69 days[d] (mm)	$\overline{H}$ after 105 days[e] (mm)	$\overline{H}$ after 119 days (mm)	$\overline{Ø}$ after 119 days (mm)	Leave's mass average after 119 days (mg)
1	Sa 0	30.8	33.6	27.9	0.58	17.6
2	B, Sa, Su, 1[a] × 25[b] = 25[c]	34.5	46.1	46.1	0.77	38.3
3	B, Sa, Su, 1 × 50 = 50	33.1	44.5	43.6	0.73	33.8
4	B, Sa, Su, 1 × 125 = 125	38.9	55.1	58.9	0.91	56.1
5	B, Sa, Su, 2 × 25 = 50	35.3	53.7	59.4	0.85	53.5
6	B, Sa, Su, 2 × 50 = 100	35.4	55.4	63.2	0.95	62.3
7	B, Sa, Su, 2 × 125 = 250	39.6	67.5	82.5	1.15	92.2
8	B, Sa, Su, 5 × 25 = 125	36.9	65.5	80.9	1.10	90.6
9	B, Sa, Su, 5 × 50 = 250	42.8	86.0	112.0	1.48	155.0
10	Fc, Sa, Su, 17 × 25 = 425	58.2	125.5	162.7	2.26	365.0
11	B, Sa, Su, 9 × 25 = 225	47.2	92.2	122.5	1.62	190.6
12	B, Sa, Su, 9 × 50 = 450	44.3	90.1	114.7	1.60	176.2
13	B, Sa, Su, 17 × 6.25 = 106	45.8	83.4	110.1	1.43	149.3
14	B, Sa, Su, 17 × 12.5 = 213	46.8	96.5	125.3	1.66	200.4
15	B, Sa, Su, 17 × 25 = 425	46.2	98.3	124.9	1.80	218.5
16	B, Sp, Su, 1 × 125 = 125	41.7	79.4	104.7	1.46	165.4
17	B, Sp, Su, 5 × 25 = 125	42.6	97.3	124.2	1.64	213.6
18	Fc, Sa, Su, 17 × 12.5 = 213	59.4	121.7	153.7	2.14	338.1
19	B, Sa, En, 1 × 50 = 50	34.9	41.0	42.2	0.77	37.3
20	B, Sa, En, 1 × 125 = 125	40.2	52.7	63.1	1.07	87.6

[a]Number of applications.
[b]Amount of sludges.
[c]kg N/ha
[d]After 71 days for treatments 19 and 20.
[e]After 95 days for treatments 19 and 20.

Note: $\overline{H}$ = average height, Ø = average diameter, B = sludge treatment, Fc = chemical fertilizer treatment, Sa = treatments on sand, Sp = treatments on seed-bed soil, Su = sludge applied on surface, En = sludge buried under 10 cm of sand.

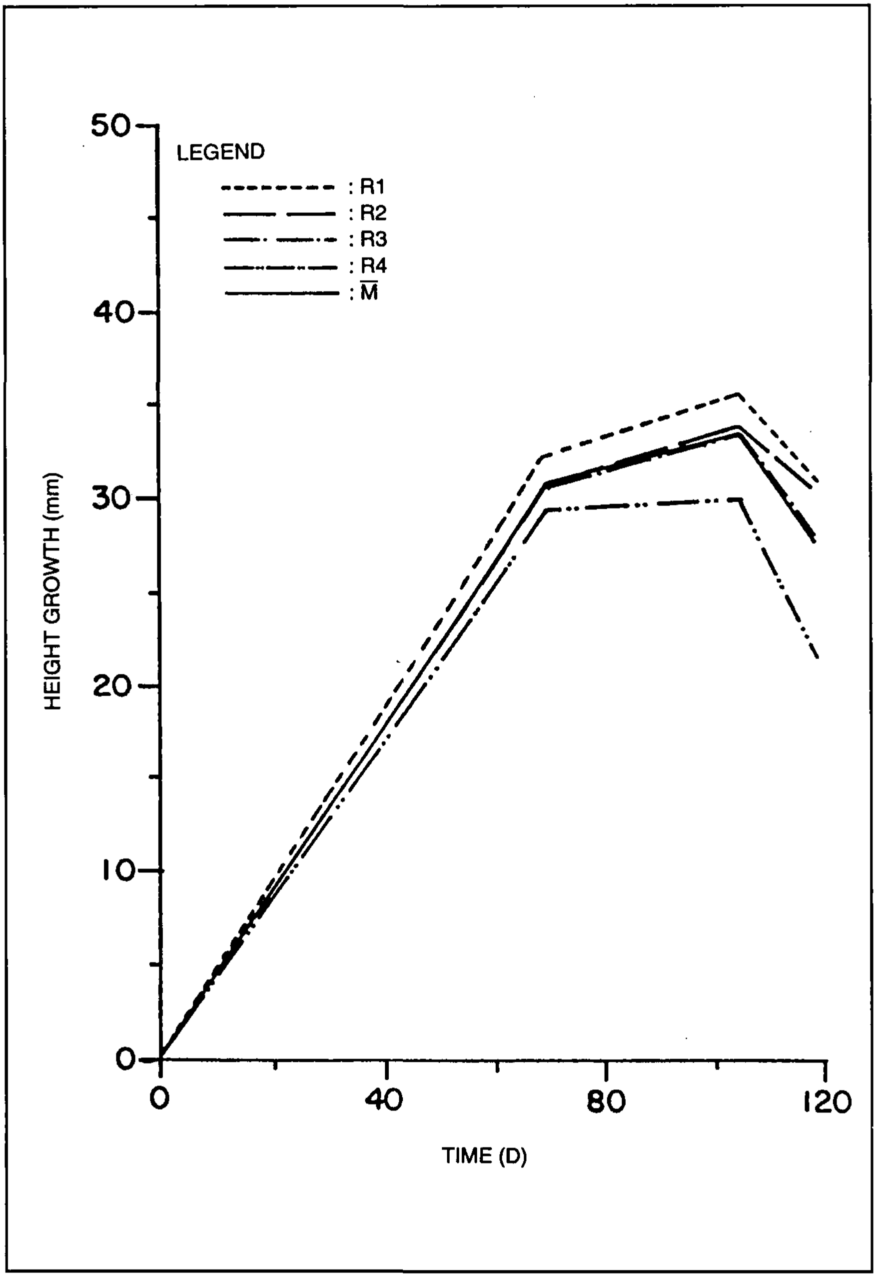

Figure 3. Changes in height growth over time by repeating treatment 1.

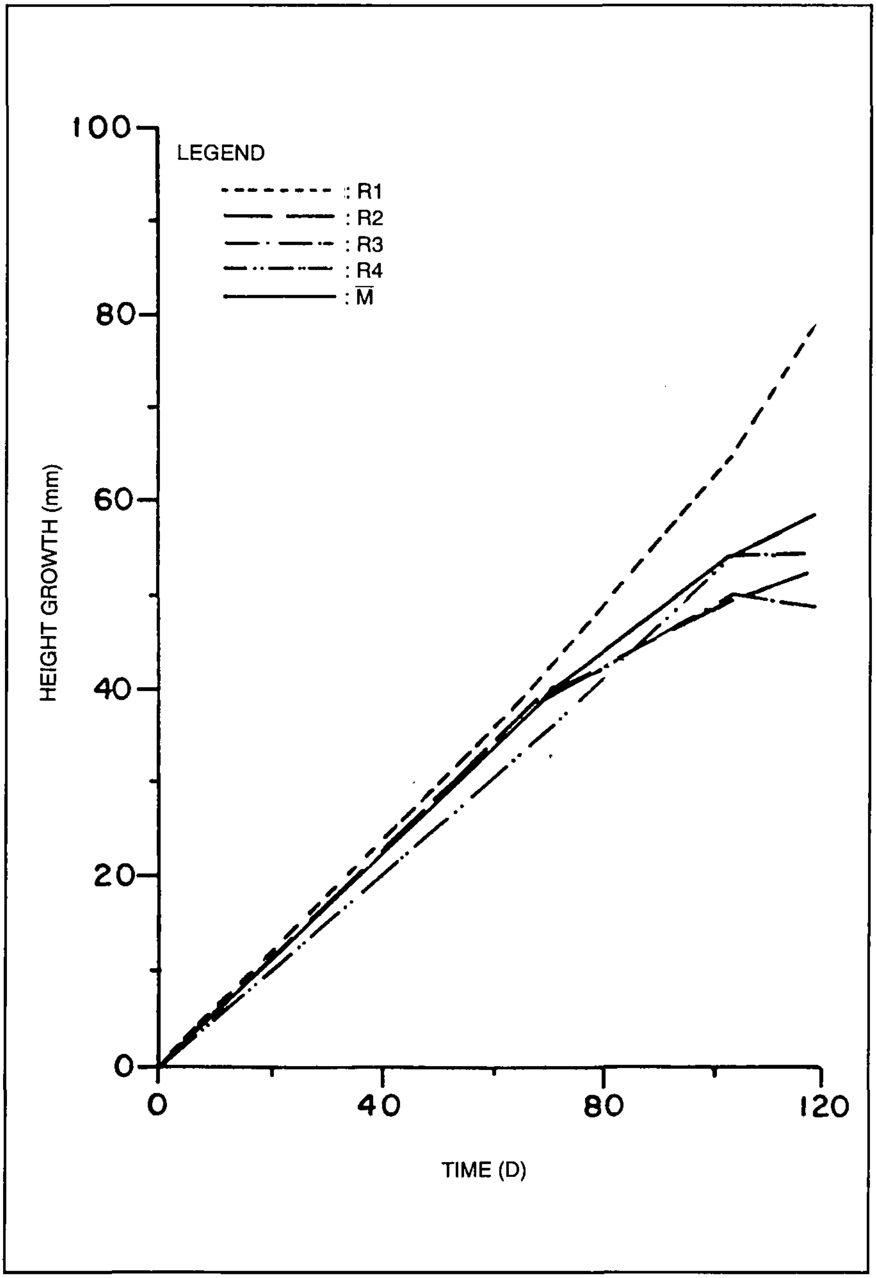

Figure 4. Changes in height growth over time by repeating treatment 4.

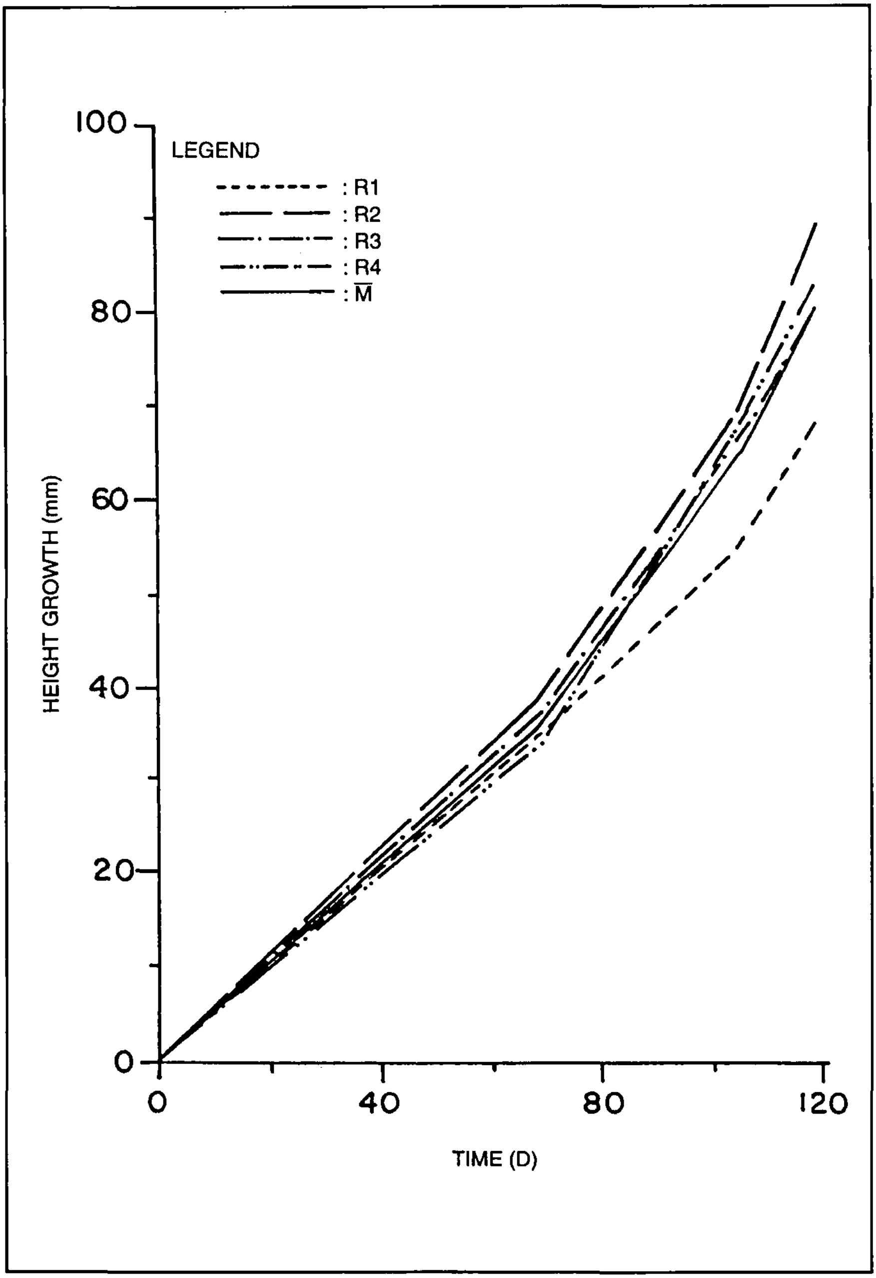

Figure 5. Changes in height growth over time by repeating treatment 8.

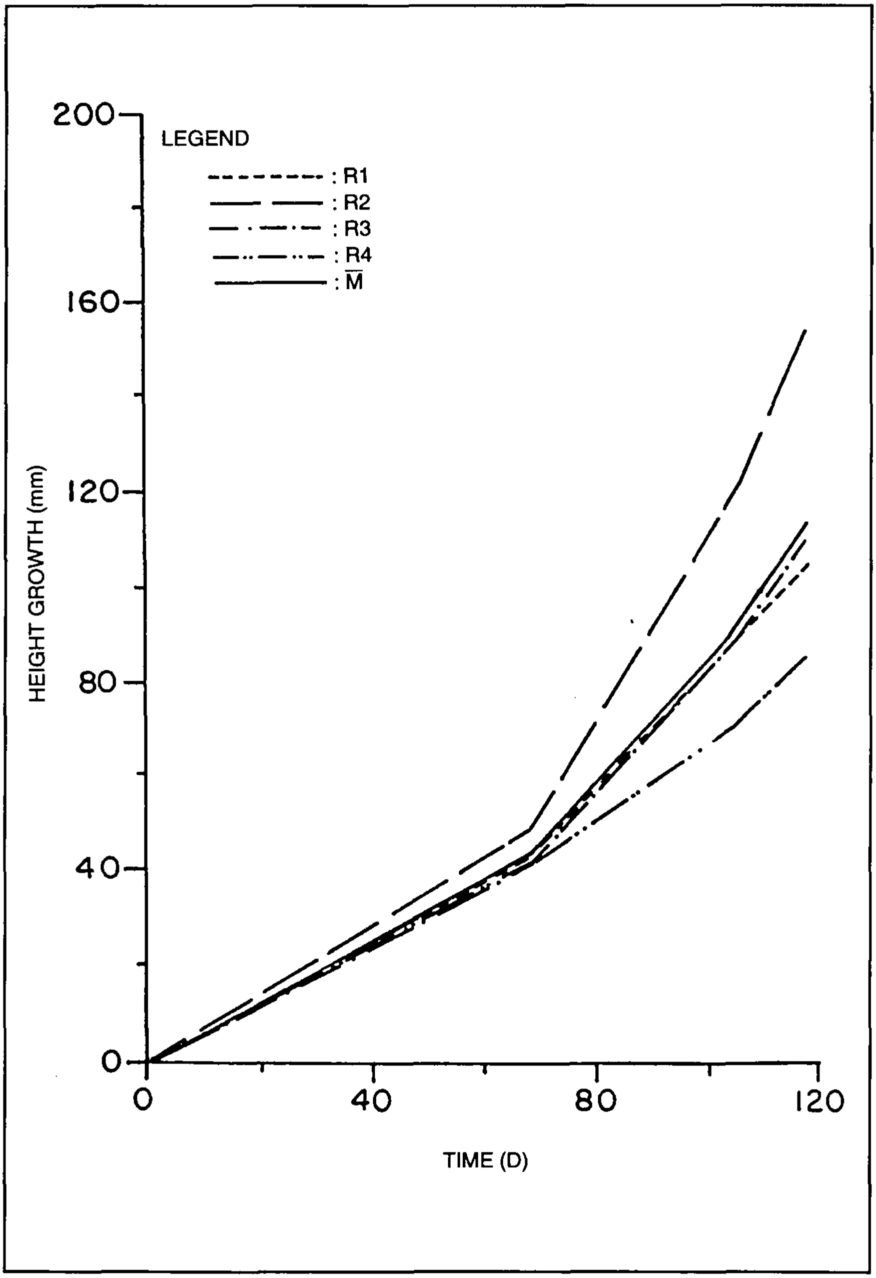

Figure 6. Changes in height growth over time by repeating treatment 12.

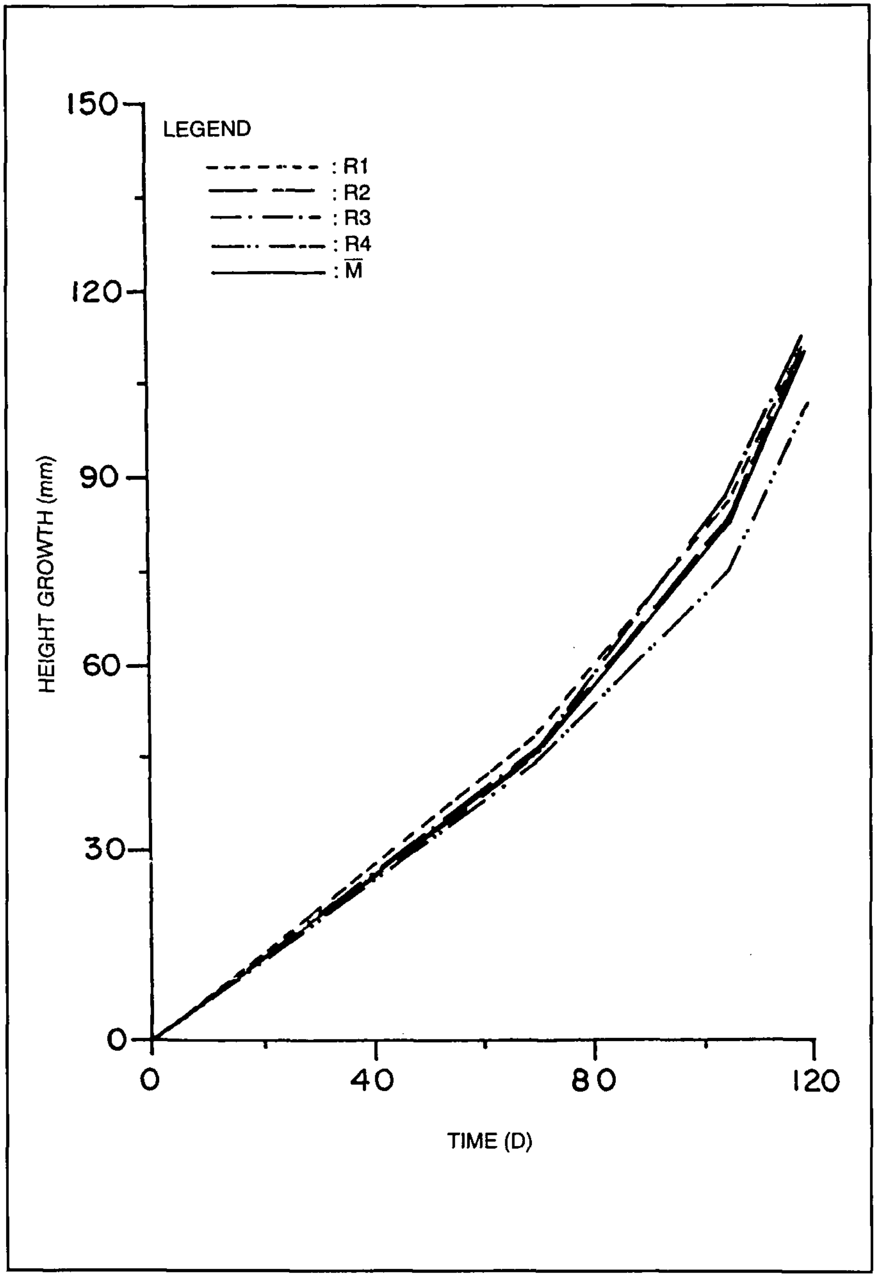

Figure 7. Changes in height growth over time by repeating treatment 13.

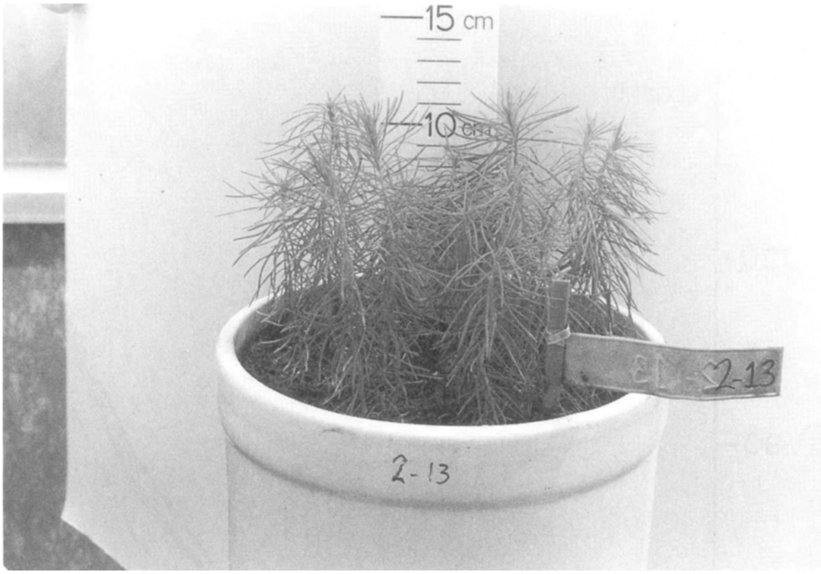

Figure 8. Second repetition of treatment 13 after 119 days of growth.

Figure 9. Second repetition of treatment 8 after 119 days of growth.

Figure 10. Second repetition of treatment 4 after 119 days of growth.

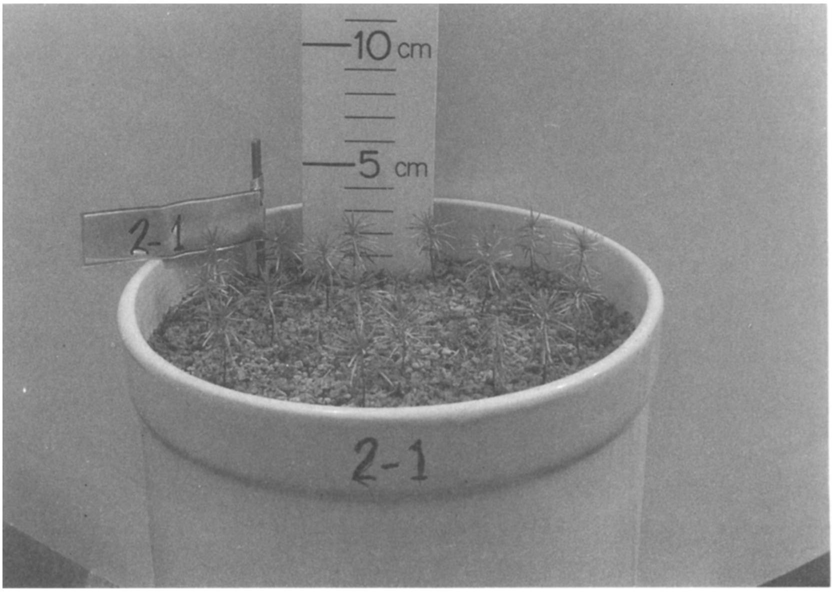

Figure 11. Second repetition of treatment 1 after 119 days of growth.

Figure 12. Second repetition of treatment 12 after 25 days of growth.

Figure 13. Second repetition of treatment 12 after 69 days of growth.

Figure 14. Second repetition of treatment 12 after 105 days of growth.

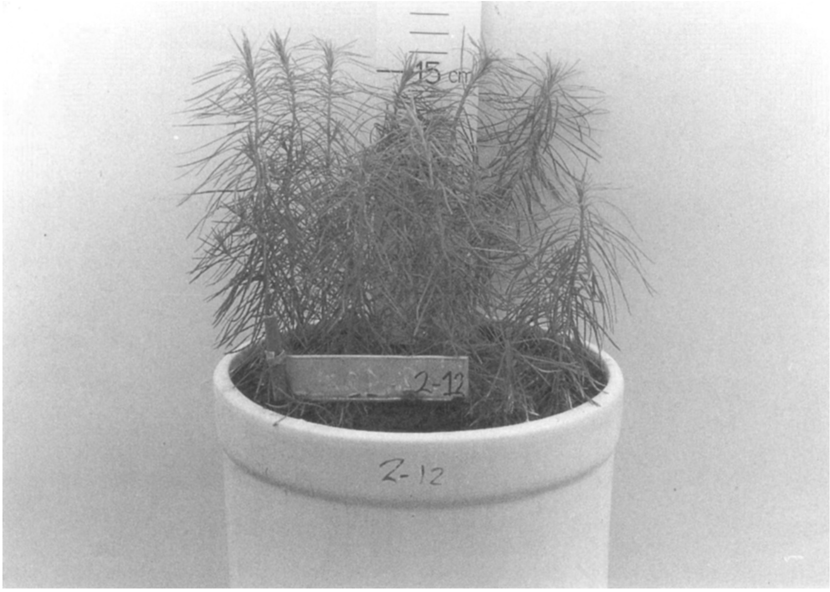

Figure 15. Second repetition of treatment 12 after 119 days of growth.

It is difficult to determine the ideal quantity and number of applications. We may conclude from the experimental results that, for a given total amount applied, biomass production is greater with repeated applications that with a single massive application (treatment 9 is better than treatment 7 and 8 is better than 4). However, the costs of several applications are higher. In addition, for a given number of applications, larger amounts of sludge produce better results (treatment 15 is better than 14, which is better than 13).

The results also indicate that more applications of a small amount give better results than fewer applications of larger quantities (treatment 14 is better than treatment 12). Treatment 13 is an exception because its rate of 6.25 kg N/ha per week never produced the best results.

It would be interesting to study the behavior of a treatment involving one massive application of 425 or 450 kg N/ha in order to compare it with treatments receiving this quantity cumulatively. Finally, we cannot say whether burying the sludge is preferable to surface fertilization because differences in the results were not great enough.

This experiment, done in greenhouse conditions, indicates that more biomass is produced when sludge is used as fertilizer. Since sludge must be disposed of somewhere, it is logical that we should try to recycle it.

Figure 16. All the pots at the end of the experiment.

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