# Use of Sewage Sludge in Forest Cultivation

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The sludge recovered in domestic sewage treatment is a valuable fertilizer containing nitrogen and phosphorus. The fertilizer uses of sludge are limited due to a high concentration of heavy metals in it. The tests done by the authors of this article show the sludge to hold promise for fertilizing forest crops.

The results of five years long explorations show that optimum fertilizer doses (3 – 4 kg per planting spot) to improve the substrate of lean sandy dunes have stimulated the survival of young plants, and in the long run enhanced the growth in height (for pine by 30 – 70 % in 4 years, for spruce – by 40 – 60 %). In case of mulching applications (30 t/ha), the effect of sludge is less and short – term only.

Sludge used as a fertilizer for forest crops affects to some extent of chemical composition of forest vegetation. The ash content in pine needles and mushrooms reduces, while the concentration of nitrogen, calcium and magnesium increases.

The given fertilizer also somewhat increases the content of heavy metals in forest vegetation, yet for berries and mushrooms it remains considerably below the admissible level (between 20 and 50 % of the maximum admissible concentration).

**Key words:** sewage sludge, heavy metals, increment of forest crops.

## Introduction

Large amounts of sludge accumulate at domestic sewage treatment facilities of big cities. Its chemical composition may vary depending on the industries in the given locality and the method of sewage treatment. Typically, sludge includes an increased amount of nitrogen and phosphorus compounds but less potassium ones. Depending on treatment technology, the dry solids of sludge may contain 1 – 5 % of nitrogen and 0,5 – 4 % of phosphorus, or 1,5 - 4,5 times more than stable manure, respectively. (Anspoks, Voicehemska, 1990) The amount of N and P held in 1 t of sludge (the content of dry solids 30 – 40 %) equals that of 50 kg of ammonium nitrate and 100 kg of superphosphate, respectively. (Grisnana, Uljanov, 1992; Rekomendacija..., 1990).

Apart from nutrients that can be used by living plants, the sludge contains also heavy metals (lead, copper, zinc, cadmium, mercury), thus restricting its fertilizer uses. In small amounts heavy metals act as microelements and represent a necessary component of the nutrients used by living organisms. Yet, in higher concentrations, they pollute the environment and become toxic. (Latvijas Rep..., 1994)

The sludge is, in limited scope, used for fertilizing the crops other than food for animals or human beings. To widen the application of sewage sludge, we have started research on its use for fertilizing forest crops. (Anspoks, Voicehemska, 1990; Latvijas Resp...,1994).

To establish forest on dry sandy areas, burnt forest sites, coastal dunes, as well as abandoned farmlands, large investments are required. It especially refers to dry site type forests with lean soils, lacking nutrients and humus. Taking additional measures to increase mineral and organic matter availability in the substrate is a necessary precondition for a successful forestation of sites like that. The observations made so far show sewage sludge to hold promise for cultivating forest crops. It may also be used as a fertilizer in tree nurseries and in green lining the towns and cities. The use of sewage sludge for improving forest soils will help us solve the problem of its utilization (Gradeckas et al., 1994; Gradeckas, Kubertavičienė, 1998). The aims of the present project were to determine possible ways for using of sewage sludge as fertilizer and soil improver in forestry in Latvia, to investigate ecological and economical aspects of the problem and to find optimal solutions.

## Materials and methods

Established experimental plots (20 total):
1. Ventspils district, coastal dunes 3 objects;
2. Saulkrasti forestry, coastal dunes 3 objects;
3. Lilaste forestry, inland dunes 4 objects;
4. Buļļupe (Dune forestry), coastal dunes 4 objects;
5. Bolderāja municipality, coastal dunes 2 objects;
6. Jugla forestry, inland dunes 3 objects;

7. Iecava municipality, agricultural lands 1 object.

To test the fertilization effect of sewage sludge on pine, the trial sites were chosen on sandy coastal dunes (12 experimental plots, total area 4 ha) and on inland sandy areas that had suffered from forest fires (7 experimental plots, total area 2,8 ha). Mechanically well-graded sand ($SiO_2$ accounting for 99 % of it, the particle size 0,25 – 0,05 mm) and raw substrate was typical of the site on the dunes. The nutrient and humus availability were low (Table 1).

**Table 1.** Soil characteristics of the coastal dune site, (Soil type - NIj to NIe)

| Horizon (cm) | Moisture (%) | Organic (%) | Active nutrients (mg/100g) | | | | | $pH_{KCl}$ |
|---|---|---|---|---|---|---|---|---|
| | | | $NH_4$ | $P_2O_5$ | $K_2O$ | CaO | MgO | |
| 0 – 10 | 1,2 | 0,43 | 0,9 | 2,0 | 1,2 | 43,6 | 21,6 | 6,6 |
| 10 – 30 | 1,8 | 0,15 | 0,6 | 2,5 | 1,3 | 19,9 | 9,4 | 6,5 |
| > 30 | 2,1 | 0,09 | 0,4 | 2,1 | 1,3 | 21,6 | 9,2 | 6,7 |

On the inland dune site the sand was less graded and richer in nutrients. On the burnt area the soil cover was destroyed, a part of the nutrients was leached away and the nitrogen deficiency was apparent; podzolization was typically of average degree (Table 2).

**Table 2.** Soil characteristics of the inland dune site, (Soil type – POt to POf)

| Horizon | Moisture | Organic | Active nutrients (mg/100g) | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 – 30 | 5,4 | 0,8 | 1,1 | 4,5 | 4,8 | 42,0 | 16,5 | 4,6 |
| 30 - 50 | 6,7 | 1,0 | 2,2 | 7,0 | 6,7 | 88,4 | 31,1 | 5,1 |
| > 50 | 6,6 | 0,3 | 1,3 | 5,7 | 5,6 | 69,5 | 29,5 | 5,6 |

Trial plantations of spruce were established on the sites formerly used for agriculture (1 experimental plot with total area 1,5 ha). The soil was average heavy sandy clay. A deficiency of active nitrogen was found there, too. The amount of humus in the topsoil layer was about 3,5 %, followed by a sharp fall in deeper horizons. The amount of active phosphorus and potassium represent average values. The soil was leached renzina (Tables 3, 4).

Pine and spruce were planted (5,000 plants per ha) on the sites as described above. Two – year- old seedlings of pine and three – year – old seedlings of spruce were used. For the purpose of the experiment sludge was applied to the planting spots or spread over the soil surface as mulch. The dosage was the following: 1 – 10 kg of stabilized sludge with dry matter content 30 – 40 % per planting spot (2 - 20 t/ha d.m.) and 30 t/ha (12 t/ha d.m.), when used for mulching. A planting hole of the size 40 x 40 x 40 cm was made and filled with sludge and sand over sludge layer. The planting was done using the planting wedge after filling in the planting hole. Mulching was done in a plantation and in a mature forest (70 years old). The aim was to establish the content of heavy metals in the substrate and follow up the variations in it after fertilizer application. Respective plantations of pine and spruce were established for the control. Over a number of years field data were taken at the end of the growing season. The data were compared with the control.

**Table 3.** Soil characteristics of the test plantation of spruce, (Soil type – VKz to VKi)

| Horizon (cm) | Moisture (%) | Organic (%) | Active nutrients (mg/100g) | | | | | $pH_{KCl}$ |
|---|---|---|---|---|---|---|---|---|
| | | | $NH_4$ | $P_2O_5$ | $K_2O$ | CaO | MgO | |
| 0 – 10 | 20,6 | 3,47 | 1,4 | 6,1 | 4,5 | 52,8 | 17,1 | 6,8 |
| 10 – 30 | 18,8 | 1,18 | 1,1 | 6,9 | 4,1 | 55,1 | 16,6 | 6,7 |
| 30 – 50 | 18,4 | 0,33 | 1,2 | 6,3 | 5,0 | 54,3 | 18,2 | 7,0 |

The field data show the fertilizer dose of 3 – 4 kg per planting spot (6 – 8 t/ha d.m.) to be most efficient. High doses as well as mulching are less efficient and their effective time is shorter.

The sludge of the following chemical composition was used for trial plantations:

Organic matter (in dry soil) 59,8 %
Total nitrogen (N) 4,1 %
Total phosphorus (P) 1,8 %
Total calcium (Ca) 14,0 %
$pH_{KCl}$ 6,3

The content of heavy metals in dry solids, mg/kg: Cu – 733, Zn – 2 850, Ni – 206, Hg – 3,72, Mn – 374, Pb – 196, Cd – 2,64.

## Results

A positive effect of sludge application to forest crops is already visible in the first year of the growth. On sandy dunes the trees just planted usually suffer from the lack of moisture, and the percent of survival is low: 28 % for the control as against 72 % on the site with the sludge applied in the planting holes. On the other hand, spreading sludge over the substrate surface resulted in a nearly complete dieback of all the young plants. It was greatly due to the dark colour of sludge, promoting the substrate getting hot in the sun and drying up.

The sludge fertilizer positively affects not only the survival, but also the increment in height of the young trees. It refers especially to coastal dunes where the substrate is raw. Depending on climatic conditions and the method of fertilization used, in some cases the increment was 2 – 3 times higher as compared with the control. (Figure 1)

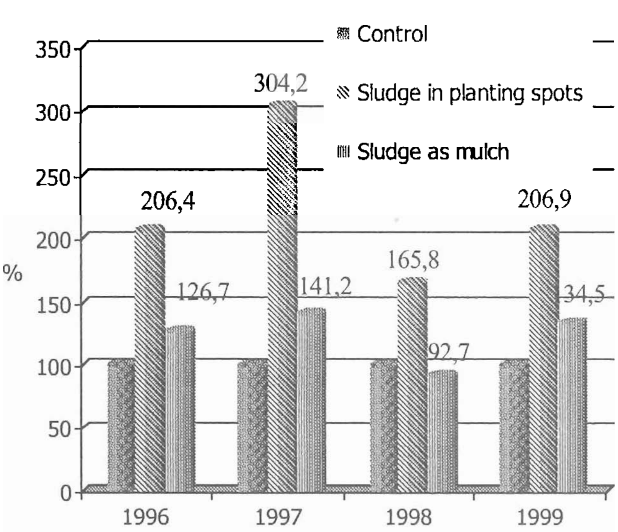


**Figure 1.** The increment of young pine on the coastal dune site.

On the inland sandy sites, where the substrate was more fertile, the fertilization effect was visible to a lesser degree as compared with coastal dunes. The effect was especially great for the first two years of the growth (Table 4).

**Table 4.** The increment of pine on the coastal dune site.

| Variant | 1997 | | 1998 | | 1999 | |
|---|---|---|---|---|---|---|
| | cm | % | cm | % | cm | % |
| *Control* | *2,9±0,3* | *100,0* | *8,9±0,5* | *100,0* | *16,8±1,2* | *100,0* |
| Sludge 3 kg per planting spot untilled soil (6 t/ha d.m.) | 5,1±*0,4* | 175,9 | 15,0±*0,6* | 146,1 | 19,3±*1,1* | 114,9 |
| *Control* | *3,0±0,2* | *100,0* | *9,1±0,4* | *100,0* | *21,5±0,9* | *100,0* |
| Sludge 3 kg per planting spot on ploughed bed (6 t/ha d.m.) | 4,7±*0,3* | 156,7 | 11,8±*0,5* | 130,0 | 22,2±*1,2* | 103,2 |

It seems that site preparation is of importance, too. As to the increment, the performance of pine was better on untilled sites than on tilled. The differences are believed to be due to different humidity regimes for the topsoil horizons.

The application of sludge as extra fertilizer on the burnt site (12 t/ha d.m.) was effective over two years only. The annual growth in height on average increased 35 – 45 %, reaching 10 % only starting with the third year of the growth (Figure 2). The sludge rapidly decomposed, the nutrients were partly used by the plants or leached away by precipitation. The effect of substrate fertilization appears to be of short duration.

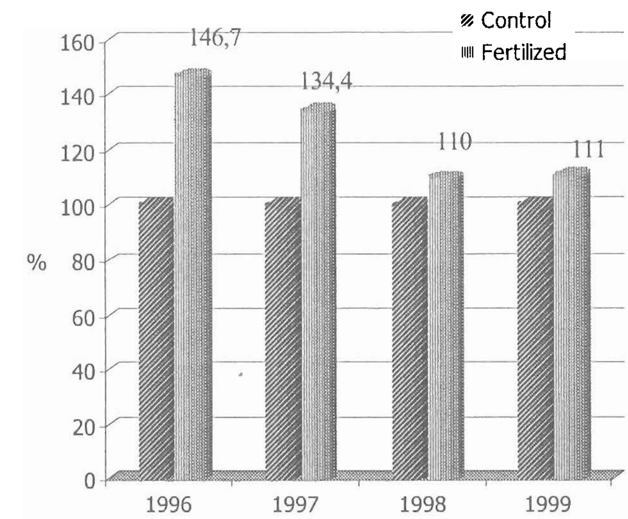


**Figure 2.** The effect of sludge applied as an extra fertilizer to young pine on burnt sites.

The fertilization effect depends on the method of applying sludge and the dose used. The optimum dose is found to be 3 – 4 kg per planting spot (6 – 8 t/ha d.m.). High doses often produce a reverse effect (Table 5).

**Table 5.** The effect of fertilizer dose on the annual increment of young pine on coastal dunes.

| Variant | 1997 | | 1998 | | 1999 | |
|---|---|---|---|---|---|---|
| | cm | % | cm | % | cm | % |
| *Control* | *2,9±0,2* | *100,0* | *7,6±0,2* | *100,0* | *7,9±0,4* | *100,0* |
| < 3 kg per planting spot (< 6 t/ha d.m.) | 2,8±*0,3* | 96,6 | 8,2±*0,4* | 107,9 | 8,4±*0,4* | 106,3 |
| 3 – 4 kg per planting spot (6 - 8 t/ha d.m.) | 5,2±*0,3* | 179,3 | 9,1±*0,3* | 119,7 | 11,0±*0,5* | 139,2 |
| 5 – 6 kg per planting spot (10 – 12 t/ha d.m.) | 3,5±*0,3* | 120,7 | 8,2±*0,4* | 107,9 | 9,5±*0,4* | 120,2 |
| > 10 kg per planting spot (> 20 t/ha d.m.) | 3,6±*0,3* | 124,1 | 4,7±*0,3* | 61,8 | 8,1±*0,6* | 102,3 |

Sludge may also be successfully used for fertilizing spruce. Optimal doses (3 – 4 kg per planting spot, 6 – 8 t/ha d.m.) already in the first year after planting increased the growth (Table 6). The fertilization effect lasted more than four years, with the increment exceeding the control by 23 %. However, the positive effect of sludge used as extra fertilizer (12 t/ha d.m.) was considerably less.

**Table 6.** The fertilization effect of sludge on the annual increment of young spruce.

| Variant | 1995 | | 1996 | | 1997 | | 1998 | | 1999 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | cm | % | cm | % | cm | % | cm | % | cm | % |
| *Control* | *4,4± 0,2* | *100,0* | *9,7± 0,4* | *100,0* | *12,6± 0,6* | *100,0* | *16,2± 0,7* | *100,0* | *27,9± 1,1* | *100,0* |
| 3 – 4 kg per planting spot (6-8 t/ha d.m.) | 7,0± *0,3* | 159,1 | 13,0± *0,3* | 134,0 | 17,5± *0,5* | 138,0 | 22,8± *0,8* | 22,8 | 34,4± *1,3* | 123,3 |
| 30 t/ha mulch (12 t/ha d.m.) | 4,1± *0,2* | 93,2 | 12,9± *0,3* | 133,9 | 12,8± *0,4* | 101,6 | 18,3± *0,4* | 18,3 | 30,6± *1,0* | 109,7 |

Fertilization by sludge affects not only the increment but also chemical composition of forest vegetation. Thus, the ash content in pine needles reduced by 0,25 – 0,30 %, while that of nitrogen, calcium and magnesium increased. In mushrooms the concentration of nitrogen increased even by 0,6 %, but that of magnesium doubled (Table 7). The least fertilization effect was observed with bilberries, showing virtually no difference in chemical composition between the crops fertilized and the control.

**Table 7.** Variations in chemical composition of forest vegetation resulting from sludge application (%).

| Plants | Ash | N | $P_2O_5$ | $K_2O$ | CaO | MgO |
|---|---|---|---|---|---|---|
| *Needles control* | *2,03* | *1,11* | *0,24* | *0,73* | *0,47* | *0,45* |
| Needles fertilized | 1,74 | 1,36 | 0,25 | 0,64 | 0,56 | 0,63 |
| *Bilberries control* | *1,96* | *1,30* | *0,25* | *0,83* | *0,33* | *0,28* |
| Bilberries fertilized | 1,97 | 1,49 | 0,24 | 0,77 | 0,31 | 0,31 |
| *Bilberries leaves control* | *4,22* | *1,28* | *0,22* | *1,39* | *1,24* | *1,47* |
| *Bilberries leaves fertilized* | 4,60 | 1,57 | 0,23 | 1,40 | 1,29 | 1,20 |
| *Mushrooms control* | *8,82* | *1,44* | *0,42* | *2,29* | *0,31* | *0,30* |
| Mushrooms fertilized | 8,69 | 2,03 | 0,44 | 2,57 | 0,31 | 0,69 |

Apart from macro element concentration, the given fertilizer affects also the content of heavy metals in forest vegetation. Thus, for example, the content of zinc and copper in pine needles (total solids) increased by 14 % as against the control, that of cadmium – by 10 %. The content of lead alone doubled. The observations were similar also for bilberries: the fertilization increased the concentration of zinc and copper in berries on average by 10 %, while that of lead even reduced; only the concentration of cadmium increased 30 %.

The accumulation of heavy metals resulting from sludge application is the highest in mushrooms. The content of the metals analysed increased 15 – 26 %. The only exception here is lead. Its content in mushrooms reduced by 40 %. The concentration of such toxic element as cadmium increased only by 15 % (Table 8).

When comparing the field data with the maximum admissible concentration of heavy metals in forest berries and mushrooms, it is obvious that the concentrations detected are considerably below the admissible ones set out in 1994 Regulations of the Ministry of Welfare of the Republic of Latvia. Thus, even in case of mulching by sewage sludge (12 t/ha d.m.) there are no grounds to claim that a single application of the above fertilizer pollutes the berries and mushrooms to a degree harmful to man (Table 9).

**Table 8.** Variations in the content of heavy metals in forest vegetation (total dry solids) resulting from sludge fertilizer (mg/kg).

| Variant | Zn | | Cu | | Pb | | Cd | |
|---|---|---|---|---|---|---|---|---|
| | mg/kg | % | mg/kg | % | mg/kg | % | mg/kg | % |
| *Pine needles control* | *54,0* | *100,0* | *1,4* | *100,0* | *0,5* | *100,0* | *0,20* | *100,0* |
| *Pine needles fertilized* | 61,5 | 113,9 | 1,6 | 114,3 | 1,0 | 200,0 | 0,22 | 110,0 |
| *Bilberries control* | *21,0* | *100,0* | *2,9* | *100,0* | *0,4* | *100,0* | *0,10* | *100,0* |
| *Bilberries fertilized* | 23,5 | 111,9 | 3,1 | 106,9 | 0,3 | 75,0 | 0,13 | 130,0 |
| *Bilberries leaves control* | *32,6* | *100,0* | *3,1* | *100,0* | *0,2* | *100,0* | *0,10* | *100,0* |
| *Bilberries leaves fertilized* | 30,5 | 93,6 | 3,0 | 96,8 | 0,2 | 57,0 | 0,11 | 110,0 |
| *Mushrooms control* | *55,0* | *100,0* | *26,5* | *100,0* | *0,7* | *100,0* | *2,00* | *100,0* |
| *Mushrooms fertilized* | 69,2 | 125,8 | 31,5 | 118,9 | 0,4 | - | 2,30 | 115,0 |

**Table 9.** The admissible and actual concentration (mg/kg, naturally humid mass) of heavy metals in forest berries and mushrooms.

| Variant | Zn | | Cu | | Pb | | Cd | |
|---|---|---|---|---|---|---|---|---|
| | mg/kg | % | mg/kg | % | mg/kg | % | mg/kg | % |
| *Admissible level berries* | *10,0* | *100,0* | *5,0* | *100,0* | *0,40* | *100,0* | *0,030* | *100,0* |
| *Admissible level mushrooms* | *20,0* | *100,0* | *10,0* | *100,0* | *0,50* | *100,0* | *0,100* | *100,0* |
| *Bilberries control* | *4,2* | *42,0* | *0,6* | *12,0* | *0,08* | *20,0* | *0,012* | *40,0* |
| *Bilberries fertilized* | 4,7 | 47,0 | 0,6 | 12,0 | 0,07 | 17,5 | 0,010 | 33,3 |
| *Mushrooms control* | *10,4* | *52,0* | *5,0* | *50,0* | *0,13* | *26,0* | *0,070* | *70,0* |
| Mushrooms fertilized | 11,9 | 59,5 | 5,9 | 59,0 | 0,07 | 14,0 | 0,080 | 80,0 |

The analyses show the maximum content of heavy metals in forest berries and mushrooms to be only 60 % of the admissible concentration.

## Conclusions

1. The sludge of domestic sewage is a valuable fertilizer that can be used to great advantage for improving forest soils of low fertility.

2. Fertilizer application in optimal doses (3 – 4 kg per planting spot) improves the survival of young trees after planting and increases their growth in height. For pine, over the first four years of the growth this increase comprised 40 – 60 %. The mulching of the topsoil layer by sludge is inefficient, with a limited fertilization effect lasting for two years only.

3. Sludge application affects also the chemical composition of forest vegetation. In pine needles and mushrooms the ash content reduces, while that of nitrogen, calcium and magnesium increases.

4. As a result of fertilization by sludge the concentration of heavy metals in needles, berries and mushrooms increases, yet remains by 20 – 50 % below the maximum admissible concentrations.

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# ИСПОЛЬЗОВАНИЕ ИЛА СТОЧНЫХ ВОД В ЛЕСНОМ ХОЗЯЙСТВЕ

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*Резюме*

Ил городских сточных вод является ценным удобрением с высоким содержанием азотных и фосфорных соединений. Кроме того, ил в значительном количестве содержит тяжелые металлы, количество которых ограничевает применение ила в сельском хозяйстве.

В течений нескольких лет нами изучено влияние ила городских сточных вод как удобрения малоплодородных лесных земель и приморских дюнных песков. Изучуно влияние доз удобрения от 1 до 10 кг ила в посадочном месте. Оптимальной дозой ила установлено 3 – 4 кг на посадочное место, закладывая удобрение в ямки на глубине 35 – 40 см. Поверхностное удобрение 30 т/га малоэффективно и действует короткий срок.

Оптимальные дозы удобрения положительно влияют на приживаемость культур на дюнных песках и увеличивает текущий прирост. Так же и на зандровых песчаных отложениях данное удобрение положительно влияют на приживаемость сосновых культур. В течений 4-х лет прирост увеличивается в среднем на 30 – 40 %. Положительное влияние ила доказано и на рост ели в плантациях. Дополнительный прирост достигает 40 – 60 % в год и сохраняется более 5 лет.

В результате удобрения илом изменяется химический состав растений. В сосновой хвое и в грибах снижается валовое количество золы, но повышается содержание азота, калция и магния.

Кроме того велись наблюдения о распределении тяжелых металлов в почве и в растениях. Установлено, что небольшое количество внесенного в почву ила (до 30 т/га), загрязняют среду незначительно и повышение количества тяжелых металлом в почве не превышает установленные нормы. В растениях – хвое, ягодах и грибах – наблюдается некоторое увеличение содержания тяжелых металлов. В большенстве случаев этот прирост не превышает контрольных данных более чем на 25 – 30 %. Исключением является сосновая хвоя, в которой содержание свинца возростает на 100 %. Но такой прирост достигает лишь 1 мг/кг сухой хвои и не является опасным для окружающей среды. В ягодах и грибах валовое количество отдельных металлов составляет лишь 20 – 50 % от допустимых норм.

**Ключевые слова** – ил городских сточных вод, удобрение, прирост культур, тяжелые металлы.