USE OF CONTAMINATED DREDGED SLUDGE AS A SUBSTRATUM FOR FOREST GROWTH - CASE STUDY

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Abstract

Preliminary research was done to assess the suitability of dredged sludge as a growing medium. On an experimental sludge site, consolidated and aged during 3 years, physical, chemical and biological environmental parameters were analyzed.
Cuttings of poplar clones were used to evaluate growing response, in comparison with identical clones on the nursery site.
This study, conducted in order to attempt the potentiality of afforestation, affirms its intention. Afforestation seems to be possible. As a consequence, relatively high amounts of heavy metals will be introduced into the forest ecosystem.

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1. INTRODUCTION

To maintain a waterway navigable, dredging is often necessary. As a consequence, sludge must be removed and stored outside the canal. In Flanders the dredged material is generally transferred and dumped into a terrestrial depot.
In earlier times it was used by farmers to enrich their soils, because the waterborne sludge is a potential source of primary plant nutrients.
Nowadays, the effect of waterpollution has increased the concentration level of certain elements (especially heavy metals) in a way that the amendment of sludge for agricultural purposes in most situations must be dissuaded.

Afforestation could be an alternative. Preliminary research was done to determine some physical, chemical and biological properties of consolidated sludge soils. Main objective was to get an indication whether those grounds are able to sustain a forest vegetation by fulfilling the fundamental life and growing conditions.

2. RESEARCH SITE

This study was conducted at a sludge disposal site, i.e. terrestrial depot (figure 1), located approximately 15 km west of Ghent, near Nevele. The sludge originates from a nearby waterway (Afleidingskanaal van de Leie).

The construction of a depot is briefly described as follows (fig 1):

- local ground [1] is displaced to embank [2] the disposal area,
- water and dredged material is pumped into the basin (hydraulic transport by means of a pipeline [3]),
- initial dewatering takes place due to waste weir system,
- after primary consolidation the top of the embankment is pulled over [4] the solid sludge substratum,
- only a small area is covered with original ground material.

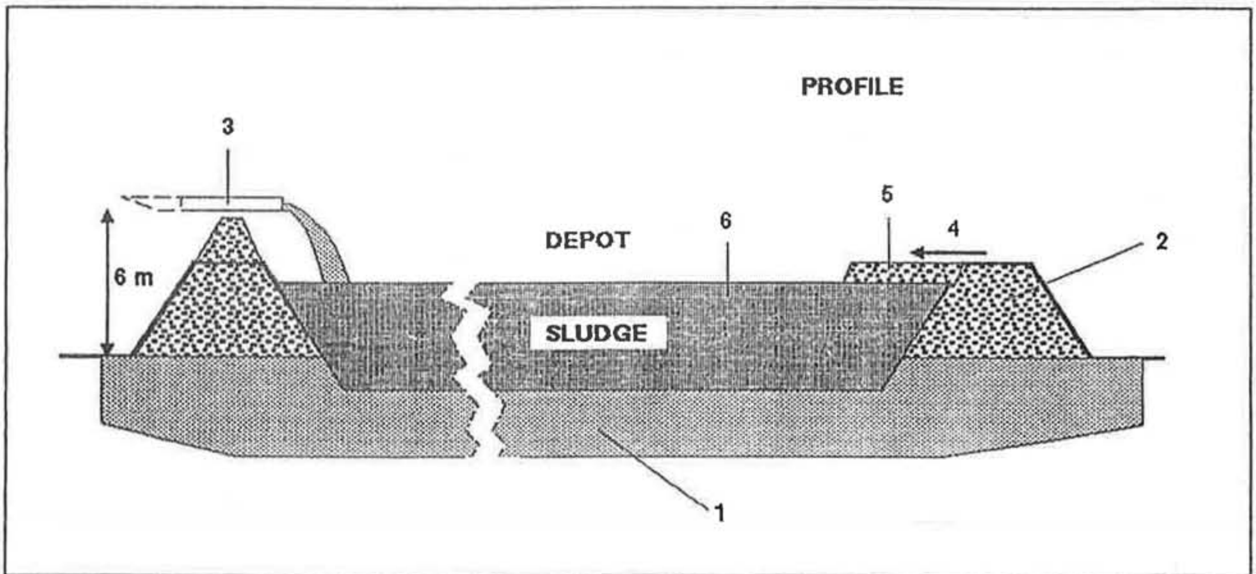

Fig. 1. Schematic vertical section of a sludge disposal basin

Finally two areas can be discriminated: - [5] ground covered and - [6] sludge substratum (not covered).
All experiments were conducted in the latter.
Table 1 lists some site specific information.

Table 1. Experimental site characteristics

TOTAL AREA	9.8 ha
EXPERIMENTAL AREA	2.5 ha
DUMPING START	03/05/85
DUMPING END	26/11/85
CONSOLIDATION TIME	3 yrs
CONSOL. SLUDGE LAYER	2-2.5 m
MAIN TEXTURE	Clay
VEGETATION	Herbal plants
HUMAN ACTIVITY	None

3. EXPERIMENTAL DESIGN

To assess a geometrical determination of the experimental sludge area a square grid was established (figure 2):

- dimension: rectangular 75 by 200 m
- 36 sample points, coded A1, A2, ... D9
- inter sample point distance 25 m

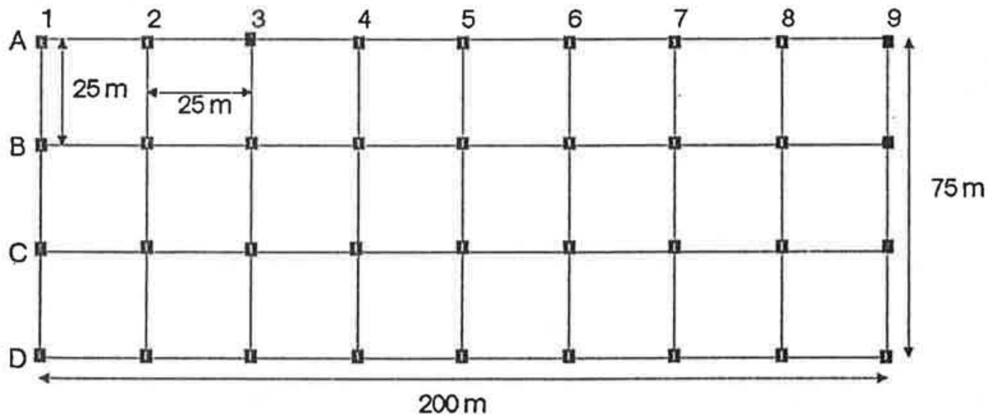

Fig. 2 Square grid with sample point codes

At each sample point following soil data were obtained:

- Texture (fractions: 0-2µm, 2-10µm, 10-20µm, 20-50µm, 50µm-2mm)
- Specific weight
- Bulk density
- Porosity
- Waterretention (pF 0.4, 1, 2, 2.54 and 4.19)

- Organic material
- $CaCO_3$ Six experimental plots were laid out in April 1988. They were designed to fit exactly in the grid (figure 3).

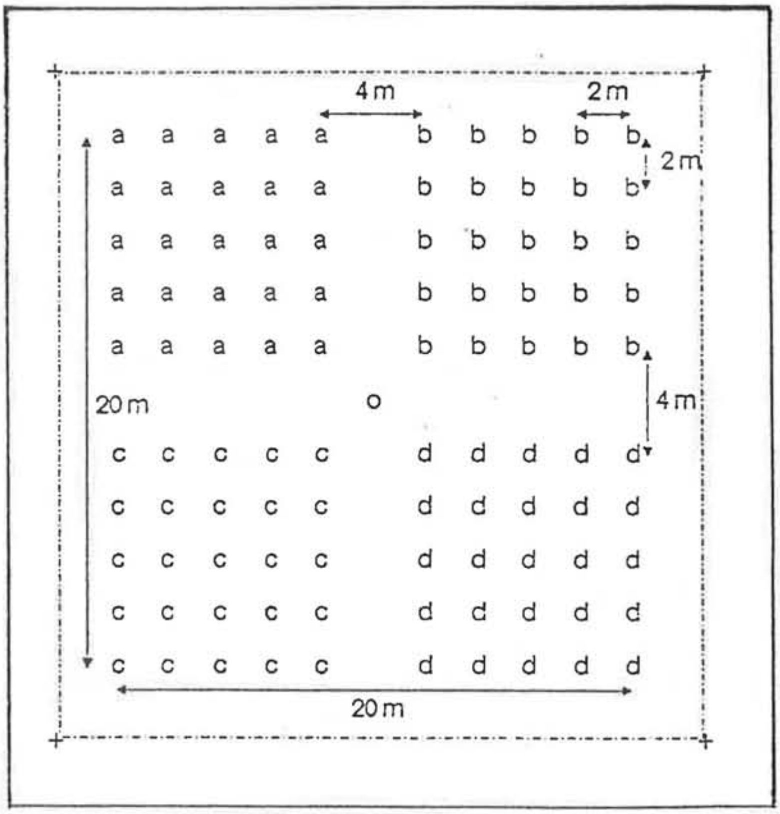

Fig 3. **Experimental plot located in between 4 sample points - (a,b,c,d) tree species / (o) Piezo-metric tube / (+) sampling point (grid)**

In the middle of each plot, a piezometric tube was installed to monitor the movement of the groundwatersystem. The depth and the consistence of sludge layers was investigated by digging a vertical profile.

Five tree species were included in the design: <u>Populus trichocarpa x P. deltoïdes</u>, <u>Salix alba L.</u>, <u>Salix viminalis L.</u>, <u>Quercus robur L.</u> and <u>Fraxinus excelsior L.</u> .

This contribution mentions the analytical results of the first (main) test species only.
It was selected for a number of reasons:

- typical pioneer, suitable on wet soils,
- fast growing species with a high adaptation capacity,
- clones can be obtained (genetic identical material),
- reference data exist.

It is imperative that cloned trees are used to assess the impact of sludge as a growing medium, in order to reduce the genetical variation to zero, especially when the field trials are compared to reference plots. Identical sampling methods were used.

The reference plots were located on the nursery site where originally the trees came from. Three clone types were used, each represented by 50 individual trees. The clone characteristics are shown in table 2.

Table 2. Characteristics of experimental clones

75.016/5

Year of controlled crossings : 1975
S.763-50 x V.24

parent : S.763-50
sprung from crossing 1961 : S.77-8 x V.12
S.77-8 : half-sib : origin Iowa
V.12 : origin Illinois
parent : V.24 = P. trichocarpa (Oregon)

71.009/2

Year of controlled crossings : 1971

S.333-44 x P. trichocarpa
S.333-44 : half-sib P. deltoïdes origin Michigan (parent)

69.039/4

Year of controlled crossings : 1969

parent : V.471 : P. trichocarpa, origin Washington
parent : S.620-225 : P. deltoïdes half-sib, origin Michigan

All poplars: Age: two yrs
Height: 400-500 cm
No roots

These Populus trichocarpa x P. deltoïdes clones are resistant to Xanthomonas populi Ridé (cancer) and leaf diseases as Melampsora spp. and Marssonina spp.. They take very easily roots and have a high vitality (fast growing trees). At the end of the summer they produce a high total leaf area.
As a consequence of the fast growing process there is also an important disadvantage : a fragile topshoot.

Clone 71.009/2 was selected for chemical analysis.

Extensive research was done to determine the short time response of:

- tree vitality
- shoot development
- root system development
- major element concentration in the leaves
- trace element concentration in the leaves

Soil samples were taken close to the selected trees.
Parameters analyzed:
- pH
- Cation exchange capacity (CEC)
- Macronutrients: N, P, K, Ca, Mg
- Other elements: Na, Fe, Mn, Cd, Cu, Ni, Zn, Pb and Cr.

Same elements were investigated in the poplar leafs.

The lack of a root system (discarded in nursery) made it possible to push the poplar cuttings into the sludge soil. Depth of planting: 60 - 100 cm.
No growing stimuli nor herbicide treatments were applied which could possibly interfere the results.
Weed competition can be considered as an extra stress.

4. PRELIMINARY RESULTS

4.1 PHYSICAL PROPERTIES OF SLUDGE

4.1.1. Soil

Analysis of 36 soil samples lead to the results mentioned in table 3 and 4.

Table 3. Fraction distribution of sludge (percent of weight)

TEXTURE	FRACTION	MEAN	ST.DEV.
clay	0 - 2 µ	33.7	2.7
loam	2 - 10 µ	10.6	2.6
	10 - 20 µ	12.0	1.3
	20 - 50 µ	31.0	1.9
sand	50µ- 2 mm	12.7	2.9

Table 4. Density and total porosity

		MEAN	ST.DEV.
SPECIFIC WEIGHT	g/cm3	2.46	0.07
BULK DENSITY	g/cm3	0.79	0.08
SOIL POROSITY	vol%	67.5	7.7

The high amount of small mineral particles (< 2µ) indicates a heavy soil type (clay). Granulometric variation within the experimental grid is low. However, two dimensional spatial analysis has shown a sorting gradient, starting from the point of sludge input (sand) to the basins most remoted point (clay).

Because of the relatively high amount of organic material (± 9.2%) the specific weight is less than the normal accepted value of 2.65 g/cm^3.

Bulk density, as determined on a dry weight basis, can vary from 0.2 (peat soil) to 1.9 g/cm3 (fragipan). A soil, developed under pasture, generally shows a b.d. of ± 1 g/cm^3 . The determined sludge density is comparatively low, principally due to an incomplete consolidation and dewatering process. As this process proceeds, b.d. is expected to raise.

A high organic content generally reduces bulk density, because specific weight of the organic material is less then the specific weight of mineral particles. In addition, organic matter has an structural effect on soils (aggregation), which leads to a higher porosity, and consequently lowers bulk density.

An unchanged soil sample volume consists for 2/3 of pores and less than 1/3 of solid material. Similar to bulk density, this proportion will change when consolidation proceeds and compactation will occur as a consequence of using machines and, not to underrate, human tread.

Table 5. Relation poral volume - diameter determined by water-retention analysis

diameter (µm)	volume (%)
< 0,2	27,7
0,2 - 8,6	13,8
8,6 - 28	5,5
28 - 296	9,5
> 296	11,0

Distinction can be made between macropores (> 100 µm), mesopores (30-100 µm) and micropores (< 30 µm).
Macropores are responsible for aeration and drainage. Mesopores, on the other hand, are responsible for discharge and redistribution of water in very wet soils. Micropores finally can store the remaining moisture. This water is mainly immobile and can only be partially used by plants.

As shown in table 5 the microporal volume exceeds 47%, which is ca. 70% of the poral volume. Meso- and macropores represent together a volume of 20.5% (30% of T.P.V).

Therefore, drainage and dewatering processes will proceed very slowly. In addition, aeration could be a delimiting factor for root-development. Roots can suffocate when CO_2 - levels are to high and no air refreshment can take place. Several tree species cannot stand long periods without any root respiration, and die off.

On the field, the structural properties of sludge depends of its degree of water saturation. On watery sites, sludge has no structure at all. When dewatered and dried up, cracks of 30 cm of depth and 1 to 3 cm of width can be detected.
The physico-mechanical behavior is strongly related to the clayish texture and the high humus content.

In case of absence of a vegetative ground cover, the root system of trees can be seriously damaged when cracks bare the roots. Therefore, a variety of herbs is recommended.

Associated with the consolidation process, aging of the sludge area is a very important, but complex phenomenon.
In this case study, several sludge profiles were investigated. Figure 4 shows a general outlook.

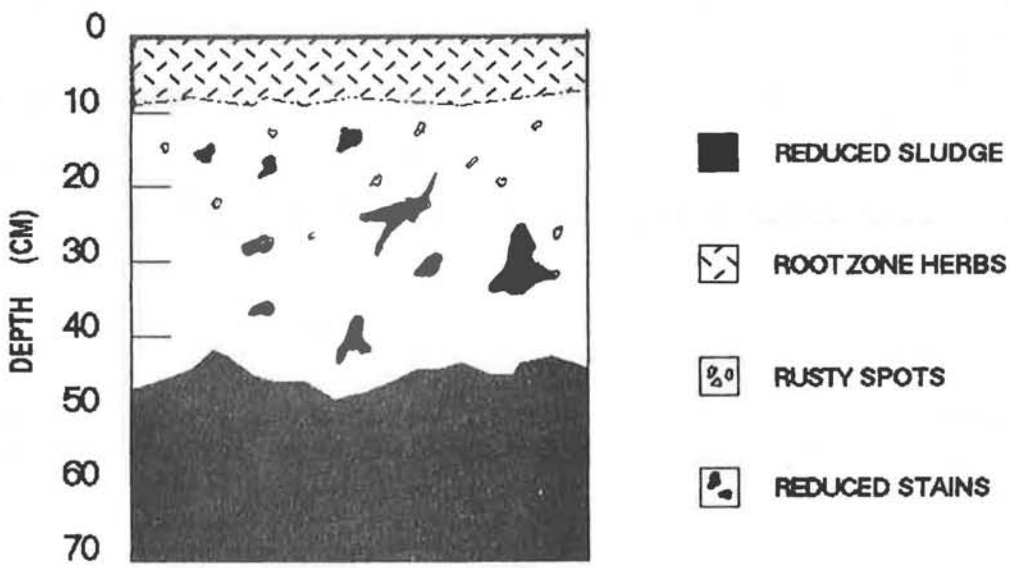

Fig. 4 **Sludge profile after 3 years of aging (03-08-88)**

Observation can be summarized in following information:

- rooting of herbs is limited to a depth of 10 cm below ground level;

- aging depth of the sludge varies from 40 to 60 cm; underneath the clearly distinguishable limit, a dark colored, reduced (anaerobe) material with a bad smell was perceived; stains of the same consistence were observed above this border;

- the reduced zone has a high density and can be considered as slightly permeable;
- occasionally rusty spots were noticed in the profile, probable due to oxidation-reduction reactions caused by the stowing effect above the impermeable zone; real gley-occurrences cannot develop in 3 years time;
- no earthworms or other macroscopic observable organisms were detected, nor any sign of their existence;
- the presence of developing layers were noticed: (1) an organic layer (A_{oo} / Ol : max. 2 cm); (2) an amorphous organical layer (A_o / Of + Oh :ca. 5 mm); (3) initial Ah. The layers are not mixed because of the absence of soil macro-fauna; according to Soil Taxonomy it could be labeled as Entisol.

4.1.2. Hydrology

Monitoring of the groundwater level fluctuations was started on 01/05/88 and measured with a 15 days interval till 30/12/88. Conclusions:

- depth under ground level for all plots varies between 3 and 63 cm during research period;
- range during growing season (1 may - 1 nov) : maximum depth 63 cm (30 june), minimum 12 cm (15 oct.);
- mean depth during growing season for all plots: between 40 and 45 cm;

The soil water retention is an important characteristic to evaluate moisture availability to plants (table 6).

Table 6. Water content (vol%) related to pressure, obtained by progressive extraction from saturation (N=36)

pF atm	0.4 1/400	1 1/100	2 1/10	2.54 1/3	4.19 15
Mean	62.4	56.5	47.0	41.5	27.7
St.Dev.	2.2	3.5	3.8	4.1	5.5

The relationship between mean water content (y) and pF (x) is almost linear : regression y=a+bx ; a=65.6048; b=-9.1771 (corr. coef. r=-0.9991). Standard deviation raises with higher pressure, mainly due to the increased effect of textural properties (especially quantity of 0-2 µ fraction). Structural properties are generally more important in the lowest pF ranges. Therefore, it could be stated that the sludges structural variation is more homogeneous than the textural (clay fraction) variation.

Important parameters can be derived from the soil water characteristic, graphically represented as a pF-curve (figure 5).

Field capacity of the sludge on the experimental site is strongly related to the depth of the groundwaterlevel.
A soil sample, located 40 cm above groundwaterlevel, has amoisture content corresponding to pF 1.6 (theoretically).
According to the pF curve one can derive :
volume of:

water 51.0%
air 16.5%

pores 67.5%

Literature mentions that plants grown under a moderate climate can extract soil water up to 15 atm. This extreme potential is known as the wilting point. The water bound more intensively (hygroscopic) equals 27.7% (St.Dev.:5.5%).

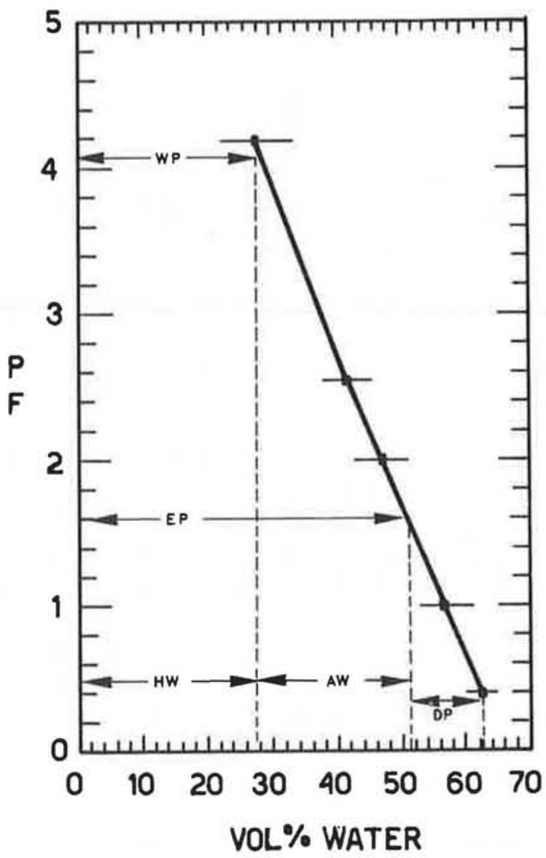

Fig. 5 Mean pF-curve with deviation; [WP] wilting point; [EP] equilibrium moisture content when GWL-depth is -40cm; [HW] hygroscopic water; [AW] available water; [DP] drainage pores (volume).

Several conclusions can be made when this pF curve is compared with the waterretention curve B12 (figure 6) of the "Staringsreeks", according to the soil classification system of the Netherlands (WOSTEN, BANNINK & BEUVING, 12).

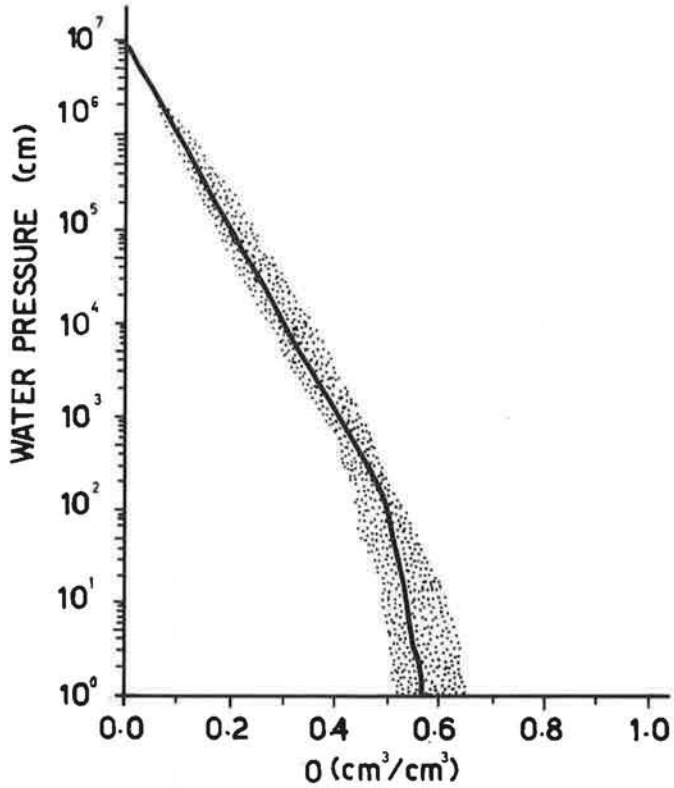

Fig. 6 Characteristic pF-curve of heavy clay; Staringsreeks B12

Conclusions:

- mean sludge pF-curve is similar to mean pF-curve B12, especially for pF-values higher than 2;
- water content differs mainly in the low pF-range (0-1), difference increases when pF decreases;
- figure 6 shows a larger deviation range at the right side of the curve, especially in the low pF range. It is notably at this site that the greatest differences occur between the two curves.

The latter conclusion illustrates the distinction between consolidated and not yet fully consolidated soils. Therefore, a shift to the left of the lowest part of the curve (figure 5) is expected when consolidation proceeds.
As a consequence, associated parameters will change too.

Assuming that 1) groundwaterlevel is 40 cm beneath mowing field, and 2) waterretention characteristics of the sludge do not significantly change up to -60 cm depth, and 3) equilibrium is established; one can calculate that:

- the total moisture content in the sludge soil (up to 60 cm depth) equals 357 mm;

- only 191 mm (54%) is available to plants;

- air content is ca 48 l/m³ (quantity of air shows a logarithmic decrease and tends to zero when GW-level is reached).

When the upper sludge layer (-40 to 0 cm) is considered, the air/available water ratio changes when groundwaterlevel descends. This ratio is 0.43 when GWL=-40 cm; 0.67 (GWL=- 60cm); 0.89 (GWL=-100 cm) and 1 (GWL=-120 cm). In the latter there is an equal volume of air and plant available water in the 40 cm upper zone. This can be regarded as an ideal situation with respect to the water/air economy of trees.

4.2. CHEMICAL PROPERTIES OF SLUDGE

4.2.1. Soil

As shown in table 7, an important characteristic of the examined sludge soil is its neutral pH. pH-H_2O, which is theoretically 1 unit higher than pH-KCl, is expected to be 7.5. DHAESE (5) however, who analyzed sludge on 14 different spots (several canals) found a very slight difference between pH-KCl (7.58) and pH-H_2O (7.60), due to a fully saturated adsorption complex with Ca, Mg, Na and K.

Table 7. Acidity of sludge samples

Number N	15	5
Depth (cm)	5-20	35-50
pH-KCl	6.44	6.28
St-Dev.	0.22	0.20

With increasing depth, sludge samples seem to have a higher acidity, but the difference is not significant. Deviation between the observations is low.

The amount of lime plays an important role as pH-buffer and lowers acidity. Analysis of 36 samples shows a mean value of 8.42 g $CaCO_3$ per 100 g dry sludge (St.Dev. 0.67).
Such a high amount of $CaCO_3$, precipitated as a salt and dispersed subtly is considered as favorable for clayish sludge-soils.
It guarantees the formation of a good soil-structure, an adequate

environment for soil-fauna and the development of a mull humus type due to a stimulated humification. Moreover, the acids produced by several decay processes can be neutralized efficiently and stable humus products are formed.

The examined sludge has a high organic material content. According to WALKLEY & BLACK's method, 9.17% (St.Dev. 1.86; N=36), was measured.Organic material and clay determine in a large measure the cation exchange capacity (CEC) of the sludge. A calculated value of 33 meq/100 g dry sludge was obtained.

In order to assess the nutritive value of the sludge soil, quantitative research was done (table 8).

Table 8. Macronutrients (mg/kg air-dry sludge); N=6 (K, Ca and Mg in Ammonium-acetate EDTA pH 4.65)

Element	P	K	Ca	Mg
Mean	212	192	29580	577
St.Dev.	58	44	550	99

To interpret the analyzed data, both the CEC of the sludge and the extraction medium has to be taken into account. Therefore, an evaluation table (table 9) is used (COTTENIE et al, 3).

Table 9. Evaluation ranges for soils with CEC > 25 extracted with NH_4Ac^- EDTA pH 4.65 - valid for a large number of Belgian soils.

	P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg
very high	>175	>400	>4000	>240
high	90-175	240-400	3000-4000	180-240
medium	50-90	160-240	2000-3000	120-180
low	25-50	80-160	1000-2000	60-120
very low	<25	<80	<1000	<60

Phosphorus and magnesium are evaluated as very high, potassium as medium. Calcium occurs to be extremely high. Converting the percentage of Ca into $CaCO_3$, 7.4% is obtained. This differs 1% with the above mentioned titrimetric percentage.

The sludge, just after dredging, contains ± 5000 mg/kg nitrogen (DESCAMPS & HEYSEN, 4). This is 5x as much as one can expect from an average flemish soil (ca. 0.1% of N).

Assuming a sludge area of 1 ha and a rooting depth of 60 cm, and using a bulk density value of 0.8 g/cm³, one can calculate:

Volume of sludge: 100m x 100m x 0.6m = 6000 m^3
Weight of sludge: 6000 m^3 x 800 kg/m^3 = 4800 ton

A percentage of 9.17% of organic material equals <u>440 ton O.M./ha</u>.

Suppose the O.M. consist of 50% organic carbon and 5% nitrogen, there is <u>220 ton C</u> and <u>22000 kg N per ha</u>.The latter value corresponds to 0.46% of nitrogen, which is nearly the same as found by DESCHAMPS & HEYSEN.

Information concerning presence and availability of trace elements is essential to assess the nutritive value of a soil.
Table 10 lists the results of a quantitative study.

Table 10. Trace elements (mg/kg air-dry sludge) extracted with NH_4Ac^- EDTA pH 4.65

element	mean	st.dev.
Na	19	44
Fe	2031	242
Mn	143	19
Cd	8.62	1.33
Cu	84.7	7.4
Ni	12.5	1.2
Zn	723	62
Pb	120	7
Cr	2.76	0.07

Table 11. Interpretation of Na and trace elements in mg/kg as determined with 0.5 n NH_4Ac + 0.02 M EDTA pH 4.65 as extractans - (valid for a large number of Belgian soils).

	Na	Fe	Mn	Zn	Cu
low	15	40	2	2	1
medium	30	200	80	8.5	6
high	50	600	170	18	20
	Cd	Ni	Cr	Pb	
average	0.5	50	50	10	

The concentration of sodium is very high. This element however, is regarded as not essential to plants. Unlike metal ions as Fe, Mn, Zn and Cu. The concentration of manganese can be considered as high; iron and copper very high and zinc extremely high (about 85x normal concentration).

The cadmium concentration is more than 17 times its normal value and the amount of lead occurs to be a factor 12 greater.
Nickel and chromium were detected in relatively small amounts.

Since the extraction with ammonium-acetate-EDTA is not a total fraction determination (aqua regia extraction), but an extractans which gives an indication of the available fraction of potential plant nutrients, even higher concentrations than the values mentioned in table 10 are present in the sludge.

Thus, Zn, Cd, Cu and Pb are theoretically available to plants in excessive concentrations.
However, there are some phenomena which ought to be considered when availability is concerned:

- the neutral pH and the high buffer capacity ($CaCO_3$) provide an important immobilization of heavy metals. The solubility of Cd, Zn, Cu, and Pb is low in this pH-range (BRUMMER & HERMS, 2). Fe and Mn are also less soluble.

- the high amount of clay-particles and humus guarantee a high CEC which leads to possible adsorption for heavy metals. Antagonisms with major elements, however, will occur.

- interactions between the OM and heavy metals can result in complexes which can change the concentration in soil water.

4.2.2. Foliar analysis

Foliar analysis was conducted at two sites: 1- sludge research site and 2- nursery site. Identical poplar clones were sampled using the same method and during the same period.
The trees had the same age and the same provenance. Only difference was that the trees on the research site had rooted and grown 1 year in a sludge substratum (table 12).

Table 12. Foliar concentration of macronutrients (% dry weight) ; identical clones grown on [A] a sludge substratum, [B] loamy ground (nursery). (N_A=12; N_B=3)

element	substratum sludge		loam	
	mean	st.dev	mean	st.dev
N	3.24	0.14	2.25	0.04
P	0.21	0.01	-	-
K	1.83	0.10	2.22	0.07
Ca	1.86	0.15	1.19	0.18
Mg	0.19	0.03	0.29	0.01

The poplar trees growing on a sludge substratum have a higher foliar concentration of nitrogen and calcium. The trees which remained on the nursery site have a higher potassium and magnesium content. More important than absolute quantities are relative proportions. The K/N ratio in the nursery is ±1, on the research site only 0.56. The Ca/N ratio is comparable (0.53 and 0.57 resp.); while Mg/N is much lower for sludge grown poplars as it is for nursery trees. Potassium and calcium concentrations in the leaves are comparable on sludge, while the K/Ca ratio in the nursery equals 1.86.

Evaluation according to BINNS et al (1983) - element ratio (%/%):

element ratio	deficit	medium	optimum	sludge
P/N	< 5	5 - 10	10	6.5
K/N	< 25	25 - 50	50	56

GARTEN (1976) reports an optimum Ca/Mg ratio of 7.7 (sludge area poplars: 9.8)

In general, comparison with literature data shows a higher nitrogen and calcium concentration in leaves of the sludge grown trees.

Table 13. Foliar concentration of trace elements (mg/kg d.w.) ; identical clones grown on [A] a sludge substratum, [B] loamy ground (nursery). (N_A=12; N_B=3)

element	substratum			
	sludge		loam	
	mean	st.dev	mean	st.dev
Na	729	118	267	24
Fe	80.6	16.2	65.0	2.7
Mn	149	29	112	11
Cd	16.6	6.4	4.53	1.00
Cu	5.42	0.95	7.86	0.48
Ni	5.02	1.71	5.02	0.79
Zn	954	151	249	21
Pb	10.0	3.0	5.9	1.7
Cr	< 2	-	< 2	-

As shown in table 13, different concentrations seem to exist for the elements Na, Fe, Mn, Cd, Cu, Zn and Pb. Striking is the low foliar concentration of copper on the sludge site, unlike the general trend of higher concentrations.
It is explained by VAN DEN BURG (8) who states that poplar species do not accumulate copper, in contrast with their high affinity of accumulating zinc and cadmium.

When the foliar concentrations are compared, one can arrange the elements in decreasing order of deviation: Zn (3.8x), Cd (3.7x), Na (2.7x), Pb (1.7x), Mn (1.33x) and Fe (1.2x).
The concentration of nickel is identical; chromium content stays beneath the detection limit.

Arranging soil concentration levels in decreasing order (first evaluated as very high) results in: Zn, Cd, Cu, Pb, Fe, Na, Mn and Ni.

This illustrates element uptake and incorporation of trace elements in the leaves, in a one year growing period. High soil concentrations lead in this circumstances to a high foliar concentration.
High response can be noticed for Zn, Cd, Pb and Na.
Cu concentration-response is not observed which confirms the no-accumulation property of poplar species.

According to VERLOO & COTTENIE (11) the uptake of trace elements differs. In general, zinc and cadmium are easily taken up, manganese, iron and aluminium in a moderate way and copper, lead and chromium to a lesser extent. This can be approved for Zn, Cd and Cu. Hence, the analyzed trees prove to accumulate also lead in a relatively high amount.

4.3. BIOLOGICAL ANALYSIS

4.3.1. Vegetation

As soon as the watery sludge becomes a substratum, a succession of herbs is initiated. These pioneers give birth to a young ecosystem characterized by a high number of individual plants, but only few species (table 14). Dynamic and net biomass productivity is high in contrast with low ecosystem stability.

Table 14 Inventory of species in descending order of occurrence (22-08-88)

Polygonum lapathifolium L.
Polygonum persicaria L.
Bidens tripartita L.
Chenopodium rubrum L.
Lycopus europeus L.
Rumex hydrolapathum Huds.
Tussilago farfara L.
Phalaris arundinacea L.
Taraxacum spp.
Urtica dioica L.
Matricaria recutita L.
Lythrum salicaria L.
Phleum pratense L.
Typha latifolia L.
Poa annua L.
Juncus effusus L.
Plantago major L.
Epilobium hirsutum L.
Lamium purpureum L.
Calystegia sepium (L.) R.Brown
Iris pseudacorus L.

Preliminary phytosociological investigation learns that most of these herbs are typical for

- watery sites with high groundwaterlevel and local marshland characteristics;
- rich soils, especially for nitrogen;
- heavy soils (clay) with a high organic content;
- a changing environment due to constant disturbance of changing parameters. (dynamical equilibrium not yet attained)

In august 1988, the height of the vegetation was measured. As an average, 125 cm was obtained. Especially Polygonum spp and Bidens tripartita L. , the dominant species, formed very dense formations all over the experimental site. These remarkable achievements of growth can be explained mainly by the continuous water supply and the abundant availability of nutrients.
These herbs can compete with small trees (< 1.5 m).

4.3.2. Top shoot- and rootsystem development.

At the end of the growing season, terminal shoot length of the experimental trees was measured (table 15). Survival of all clones was about 99% !.Although roots were to be formed, all clones on the experimental site had larger shoots. The difference with identical clones in the nursery is often more than 20 cm.

Table 15 Comparison between mean length (cm) of the terminal shoot on experimental - and nursery site

type	site	
	sludge	nursery
clone 1	48	30
clone 2	68	36
clone 3	65	45

Rootsystem analysis can give important information with respect to the sludge substratum. The presence or absence of roots as a function of depth reflects directly the impact of various environmental parameters.
In each plot one poplar clone was investigated. Two types of root-profiles could be discriminated (figure 7).

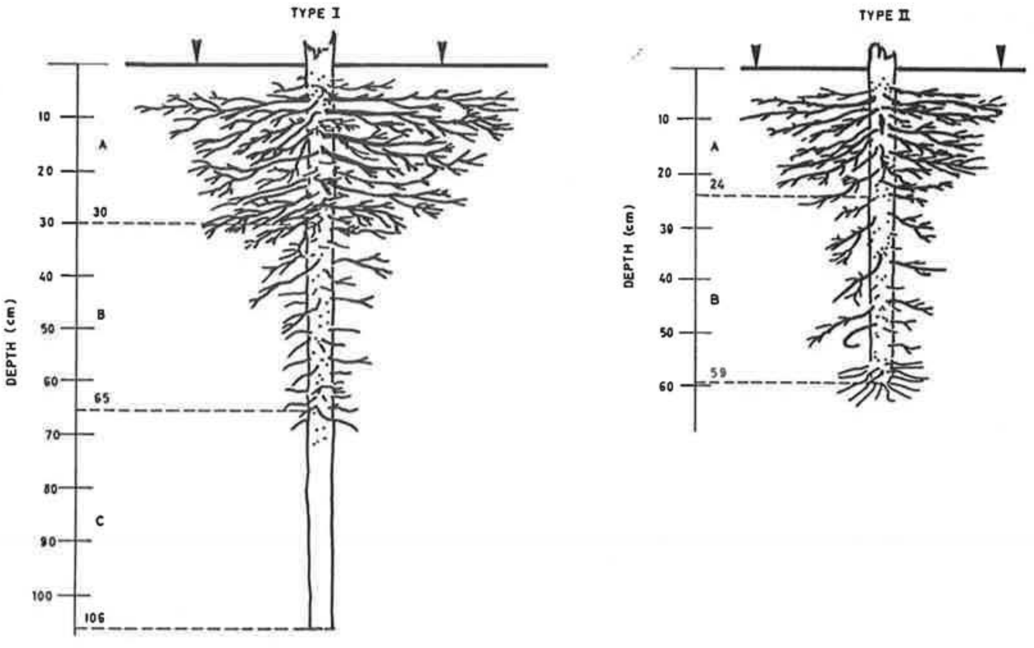

Fig. 7 Rootsystem profile (two types) in a sludge substratum; poplars 1 yr growth; cutted

Characteristics of representative (type I): 71.009/2 clone, total height 5.22 m and a diameter of 4.6 cm (1.30 m height).
Type II was a 75.016/5 clone, total height 4.94 m; diameter 3.7 cm.

In general, three zones can be distinguished:

ZONE A: 0 - 30 cm (25-40) ; highest root biomass
ZONE B: 30 - 60 cm (55-70) ; transition zone with few roots
ZONE C: > 60 cm (55-70) ; rootless zone

Zone c is not observed when planting depth is less than 70 cm (type II). The border of 60 cm corresponds to the aging depth of the sludge. No roots were observed beneath this level (for all trees examined). In addition, very few roots are present in the upper 10 cm, due to weed competition.
The boundary between zone A and B corresponds roughly to the mean groundwaterlevel.

Quantitative analysis showed that 78% of all roots are present in the upper 40 cm (figure 8).

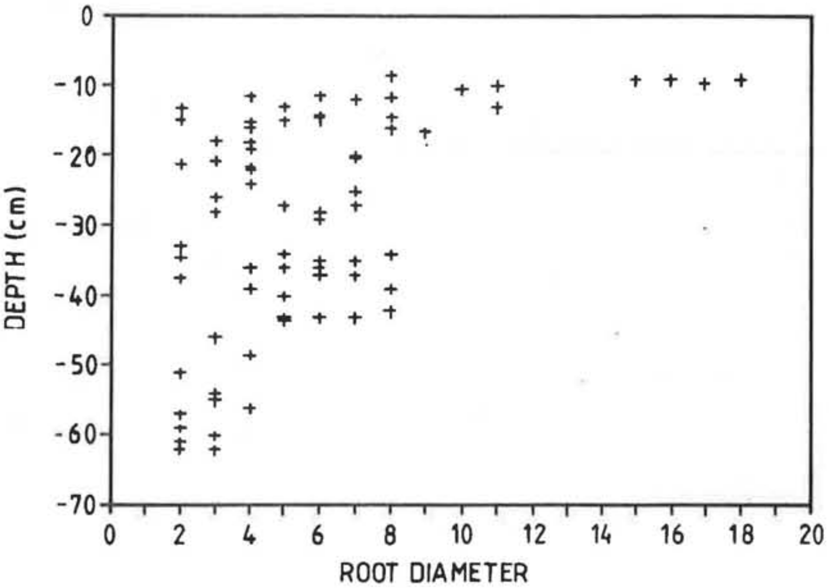

Fig. 8 Plot of rootdiameter (mm) versus depth beneath groundlevel (cm) - 1 clone 71.009/2.

Roots with a diameter higher than 9 mm are exclusively present in the upper 15 cm. Diameters till 8 mm are found up to -43 cm, beneath this level a withdrawal can be clearly noticed. As already mentioned this depth corresponds to the mean groudwaterlevel during growing season.

5. DISCUSSION

5.1. Root development

A certain volume of sludge is used by a root system of a tree, and its dimensions depend mainly on 1) the possibility of penetration (physical property), 2) the local soil conditions (physico-chemical properties) and 3) competition with other root systems (biological). The way of expansion (type of root system) and the tolerance with respect to unfavorable conditions depends upon individual and species specific genetical properties.

Theoretically, the resistance of root penetration is rather small, especially in the upper sludge zone (0-40cm), which can be derived from the low bulk density values and the related high porosity. With increasing depth (>60 cm), however, and mainly in the reduced sludge zone, resistance to penetration will raise and is expected to restrict vertical root growth.

When the sludge substratum is not covered with vegetation or litter, direct insolation will dry out the upper sludge zone and an impenetrable crust will be formed. Germination of seeds is impossible. Due to physico-mechanical forces, a shrinking proces will be activated and cracks will occur. Knowing that most of the root-biomass is situated in the upper 30 cm, serious damage will be caused to the roots (especially desiccation).

However, there is also a positive consequence. Aeration is possible and organic material can be introduced into the soil.
Hence, narrow cracks are preferential ways for root development.

Of major importance and decisive for root development is the oxygen supply. This factor is strongly related to the air- and moisture content, which is function of groundwater, textural - and structural soil properties.

Preliminary research has shown that maximum depth of the groundwater level is ca 60 cm beneath ground level. This corresponds with the oxidized (aged) depth of the sludge. Beneath this level, anaerobe conditions prevent trees from deep-rooting. This has been proved in the root development study.

Research has also lead to the conclusion that 78% of the roots were present in the upper 40 cm of the sludge soil. This depth corresponds to the average depth of the groundwater level during growing season. It could be proved that a higher air content is related to number and diameter of roots.

As a consequence of the sludge's properties: heavy clay texture, low percentage of macropores, absence of structure, high moisture content, etc. the diffusion rate of gasses in the pedosphere is low. So, lack of oxygen can arise with increasing depth and roots will die off. The absence of earthworms and their galleries enhance this problem.
Therefore, it is recommended to use highly tolerant tree-species which can survive under these conditions. They play an important role in making the sludge substratum accessible to other species.

The rooting-volume of an individual tree is also restricted by concurrential root-systems. Herbal plants exploit the first 10 cm of the sludge soil and form the upper boundary. Competition along the sides is coming from other trees, and depends on planting distance.
Due to the high amount of nutritive elements, a rather small root-volume is likely to be formed.

Most important limitation of root development seems to be the high groundwater level and its linked environmental parameters. Therefore measurements ought to be taken to lower this level.
In addition, all processes should be stimulated which improve soil structure, resulting in the improvement of soil aeration and gas diffusion. In the long run, better conditions for plants and soil organisms will be developed.

5.2. Biogene elements.

Plants need nutritive elements to grow. Quantities and type of nutrients needed, varies with species and is related to age and development stage.

It is difficult to assess the requirements of trees and forests for minerals. The demands with respect to the qualitative and quantitative proportions is constantly changing during growth and development, both in short term (growing season) and in long term (lifetime) processes.

Though, in literature, indicative data could be found (table 34). It is important to notice the high amount of recycled elements returning each year through litterfall. This can be more than 80%. The amount of nutrients needed are only a small fraction of the quantities available in sludge (table 17).

There is also a deposition out of the atmosphere which should not be underestimated (in the long term) and the release of nutrients by weathering of mineral components.

Output of nutrients, away from the sludge disposal site, is expected to be rather small. Mainly because of the construction of the basin and the impermeable sludge layer. Export of minerals will take place when thinning and felling of trees will be done and biomass is removed. RENNIE (7) mentions over a 100-year period (deciduous forest) an export of 1930 kg calcium, 483 kg potassium and 106 kg phosphorus per hectare.
Over such a period of time, nutrient stock will be nourished by air-deposits and weathering. Therefore no deficits will occur when acceptable fellings are carried out.

Table 16 Requirements of a general forest ecosystem for major elements (kg/ha)

Author	N	P	K	Ca	Mg
REMEZOV° (21)	6-22	1-4	9-12	14-29	3-5
FLEDLER	25-45	3-6	11-35	20-40	-
RIBEL					
uptake	30-55	2-3	5-20	20-100	4-22
return	24-46	1-2	3-1	15-75	3-17
RUEBNER °°					
uptake	35-50	-	9-3	11-42	4-24
return	30-40	-	3-9	3-6	1-6
° deciduous trees			°° Estimate for Europe		

Table 17 Potential and available major elements (kg/ha) present in an upper sludge layer of 60 cm

N	P	K	Ca	Mg
22000	1018	922	142000	2770

Due to the high concentration of minerals in the leaves, a rich litter will be formed. Thanks to the high amount of nitrogen, fast decay will take place, and the excess of calcium will activate the formation of a mull humus type.

5.3. Heavy metals

Some metals are essential as trace elements and play a role in the fundamental life sustaining processes. However, when their concentration exceeds certain levels, they become toxic to plants, animals and micro-organisms.

Little is known about toxic concentration levels of heavy metals in trees, although frequently high accumulation in leaves of deciduous trees had been found.
Each tree species has its own tolerance range, and research has shown that species preferentially take up specific elements.

In a study of VAN DEN BURG et al (9), five tree species (genera:

Quercus, Populus, Alnus, Betula and Acer) were analyzed, planted in sewage sludge with comparable quantities of heavy metals. No symptoms of toxicity were observed. Zinc and cadmium were taken up preferentially by poplar and birch, copper by oak and black alder. Nickel was found in all species.
When a sludge area is afforestated, heavy metals are introduced in the forest ecosystem. High accumulations in the leaves (table) will enrich litter- and humuslayers, as already noticed by VAN HOOK et al. (10) in a deciduous forest (elements: Cd, Pb and Zn).
GRUNEKLEE et al (6) assumed that the increased heavy metal content of the litter had negative effects on its decomposition.
When heavy metals are released out of the humic layers they can be taken up, by trees or herbal vegetation.
ZASOSKI (1981, 1) investigated different plots were sludge was amended and found in Rubus spp. twice as much Pb and six times as much Cd then in the control plots. Thistles accumulated even more: Pb concentrations raised a factor 11 and Cd 15 times.

Mushrooms have a high affinity to accumulate heavy metals. Birds and small mammals will take in have metals by eating berries and other plant products. Rabbits and hares by grazing.

It is very likely that most of the heavy metals will remain in the forest ecosystem. The will be accumulated in the main components of the biogeochemical cycle: soil, humus layer and biomass. Forest products should not be used for human consumption because of a high risk of contamination (esp. zinc and cadmium.).

6. CONCLUSION

Contaminated dredged sludge, as investigated on the experimental site, can be afforested. Field trials show a high response to the abundant amount of biogene elements and the constant supply of water.
However, attention should be paid to :

1. soil aeration by lowering the groundwater level; this can be technically solved by drainage;

2. aging depth, which is related to depth of the reduced sludge zone; this zone limits vertical root formation;

3. the accumulation of heavy metals in the leaves; litterfall introduces toxic elements in the forest ecosystem; uptake by fauna and vegetation is likely to be expected.

Future monitoring of afforested sludge areas will give more information about survival and growth responses of trees. More experimental data are needed to assess the toxic effects, species specific tolerance and overall ecosystem response.

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