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EFFICIENCY OF SOME PLANTS IN REMOVING HEAVY METALS FROM WETLAND EFFLUENT

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ABSTRACT

Reuse properly treated wastewater for irrigation is compulsory option, particularly in arid and semi-arid areas, as it represents an additional, reliable source of water needed for agriculture. Constructed wetland was established (30 x 34m) as a research wastewater treatment and reuse in cultivating different plant species, at Sadat City, Egypt (90km in the western desert of Egypt). Different water reads were cultivated as biological filters *(Phragmites australis, Cyperus papyrus, Typhe Sp., Cana indica).* Plant samples were collected twice a year, then dried and sent for analyses with special reference to heavy metals content. All plants grown in gravel wetland were harvested, bio-mass production of each plant was determined as fresh weight. The aim of this study is to investigate the efficiency of these plants in heavy metal removal from the treated wastewater. Heavy metals considered the most hazardous problem in the wastewater beside the toxic organic molecules particularly when industrial wastewater is involved.

The obtained results indicated that, most successful plants are Cattails, Papyrus and Phragmites. The bio-mass production was 21.4, 19.9 and 3.7 kg/m2 of gravel surface respectively, meanwhile the uptake of these plants from heavy metals were quite significant. Cattails was the most effective plant in both bio-mass production and heavy metals up take, however papyrus produced good amounts of bio-mass and removed much less heavy metals while phragmited produced less bio-mass but removed more iron and medium amounts of cobalt, lead, zinc, copper and manganese. Bio-mass of these plants can be of economic value in market opportunities. Usage of the above mentioned plants will be discussed.

INTRODUCTION

Constructed wetland for wastewater treatments are man-made complexes of saturated substrate, emerged and submerged vegetation, animal life and water that simulates natural wetland. In such systems water undergoes a series of purification processes which include biological degradation, filtration, sedimentation and adsorption, resulting in significant reduction of organic compounds, suspended solids, and to some extent, nitrogen compounds, phosphorus and pathogen (Reed at al., 1995; US EPA, 1993).

The removal of nitrogen was more effective than that of phosphorus in the algal ponds studied by LI *et al.*, (1991) with efficiencies up to 99.3 % for nitrogen and 48.1 % for total phosphorus. Van-Coillie *et al.*, (1990) have reported nutrient nitrogen removal of approximately 92.95 %. De la Noue *et al.*, (1980) have examined the uptake of nitrogenous nutrients in a culture of Occystis SP. In preconditioned phase, and reported is potential for complete nutrients removal from wastewater and its efficiency in economic tertiary treatment of wastewater. Nitrogen elimination efficiency of 72 % was reported in algal-bacterial system (Bokil and John, 1981). Lavoie and de la Noue (1983) have demonstrated that the rate of removal of nitrogen. Ammonium and phosphorus in hyper concentrated cultures of Scenedesmus obliquus was proportional to algal concentration and independent of light limitations due to self-shading.

Microorganisms exhibit a number of metabolism-dependent and independent processes of the uptake and accumulation of heavy metals (Gadd. 1990). This property of heavy metal absorption has application in wastewater treatment it may render the algal bio-mass unsuitable for use as animal feed. However, experimental feeding of algae grown on sewage (Borowitzka, 1991).

The process of absorption appears to be largely passive, probably through ion exchange on the cell wall polysaccharides (Soeder *et al.*, 1978; Ting *et al.*, 1989)/ the proposed Unsaturated Flow Biological Filter with Passive Aeration System is an intensive treatment process based on a low cost method for convective aeration of the filter bed which enables very high BOD removal rates, but it does not depend on temperature gradients and their associated problems, as in Trickling Filters, or simple air pipes for the ventilation of lower media layers (Burka *et al.*, 1990, Reed *et al.*, 1995).

Health risks associated with the agricultural application of reclaimed wastewater involve farmers / agricultural workers and consumers (Crook, 1991; Strauss, 1991). Other environmental concerns are also important, particularly the fate of toxic substances (such as heavy metals) or Endocrine Disrupting Substances. The treatment methods alone (including or not effluent disinfection) or in combination with the proper irrigation techniques should eliminate the health and environmental risks involved.

MATERIALS AND METHODS

Experimental layout:

Location:

Sa'adat City is located in Northern Egypt between El-Cairo and Alexandria, about 100 km from the Mediterranean coast.

Climate:

The climate is typical dry Mediterranean, with hot summers and mild winter. The average temperature in summer 26.4 °C, autumn 21.6 °C, winter 14.6 °C and spring 19.3 °C with mean evaporation in summer 8.8 mm/day and winter 5.2 mm/day.

The constructed wetland:

Design calculation:

Inflow = 400 m3/day

Loading = 400 m3/day * 150 mg BOD/l = 60 kg BOD/day

Maximum surface loading to the wetland for the given temperatures = 200 kg BOD/ha/day

Minimum area required for the wetland = [60 kg BOD/day] / [200 kg BOD/ha/day] = 0.3 ha

Maximum water losses due to evaporation (June) = 10.3 mm/day * 0.3 ha = 31 m^3/day

Cross-section of the embankments is depicted in figure 1.

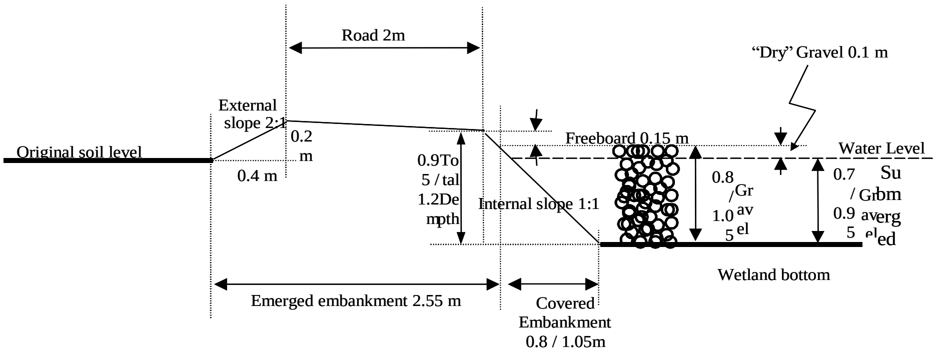

Figure 1: Cross-section of the embankment of the constructed wetland.

Layout and special structure:

Inlet:

Each parallel unit shall have its own inlet device including a constant-head manhole in the deviation from the main line. The inlet to each unit:

- Independent from the others (possible closure without interfering with the other units.
- The inlet device constructed of a perforated pipe.
- The inlet pipe is located close to the embankment of the unit.
- The opening located close to the surface of the bed.
- Inlet zone 1.5 m wide in which coarse gravel will be filled.

Outlet:

Each parallel unit owns independent outlet device. The outlet of each unit:

- Outlet zone 2.0 m wide in which coarse gravel will be filled.
- The outlet device constructed of a perforated pipe.

The perforated pipe situated in the lower part of the active depth (about 0.05-0.1 m above the bottom).

- The outlet pipe is located at about 1 m from the end of the unit.
- A manhole with an adjustable depth device.

The bottom of the manhole lowers than the bottom of the bed of the wetland.

The pipe to conveying effluent from the wetlands to the wet well deep enough to enable lowering of water level in each unit's manhole (as described above) to zero.

Bottom:

The bottom of the pond is flat but maintaining an active depth of 1.5m. as The soil of the site is sandy sealing was necessary to avoid excess seepage. Sealing made by lining using black polyethylene sheets.

Gravel:

Gravel size for the bed is 5 - 15 cm. Media for the inlet & outlet zone is also gravel of 5-10 cm size.

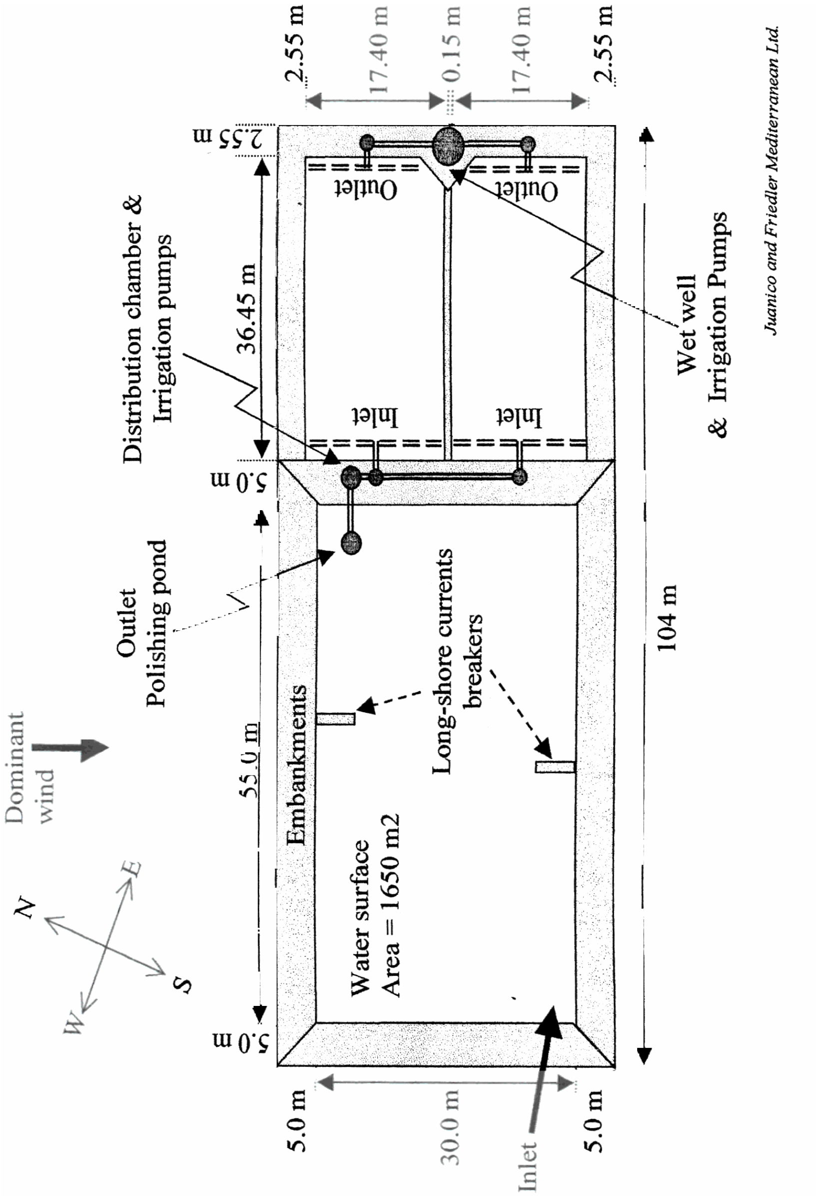

Figure 5. Layout of the polishing pond + the constructed wetland

Plants:

Several plants were cultivated, the most successful species were Reed (Phragmites sp.), and cattails (Typha sp.) and papyrus

Typical roots depths:

- Phragmites sp. - 0.6 m
- Typha sp. -0.3 m
- Papyrus - 0. 50 m

Hydraulic profile:

The polishing pond was partially excavated. Water level was about 0.05 m above soil level. The difference in water level between the outlet of the polishing pond and the water level in the wetland was about 0.55 m. as shown in fig (1). This hydraulic head was enough to cover head losses due to gravitational overflow from the pond to the wetland and distribution chamber.

Required outflow quantity and quality.

The quantity of effluent required for the pilot station on wastewater irrigation was 200 m3/day. The treatment system was designed provided that BOD5 water high level (150 mg/l), faecal coliform of about 105 and EC of about 1.6 dS/m. The actual values at the experimental time were completely different as shown in table (1) and (2).

The cultivation of constructed wetland:

Plants species were planted in the gravel bed holes, (GBH) during September and October 2002. The gravel-constructed wetland is of 30m width and 34m length. The reason for using mixed of these planted species in (GBH) is related to the different between the species in quantity and quality of accumulated toxic metals. For example water hyacinth plants accumulated high quantity of Mn, Cd, Cr and Zn rather than Fe, Cu, Pb, Co, and Ni. On the other hand reed plants accumulated more Co and Pb than Fe, Zn, Cu, Cr and Ni. Therefore mixed different plant species in GBH in this research was the main target to study the possible for production high quality effluent water for agriculture.

Water sampling and analyses:

The following parameters were taken as indicators for water quality in the water samples.

- COD chemical oxygen demand.
- BOD biochemical oxygen demand.
- SS suspended solids.
- NH_4-N.
- Total P.
- Heavy metals (Cu, Ni, Pb, Fe, Co, Cr, Cd, Zn,….).
- Total phenolic compounds.
- Total hydrocarbon.
- Total coliform bacteria.
- Faecal (pathogenic bacteria) Coli forms bacteria.
- Two sets of water samples have collected for analyses .

RESULTS AND DISCUSSION

Water analyses:

A complete set of water samples was collected twice, first one in Jan. 2004 by an environmental expert “Sues Canal University”, and the last one in June 2004 by “Ministry of Health and Population. Data are stated in (Table 1 and 2).

Table (1): Wastewater analyses before and after reclamation treatments. Date of sampling 15/1/2004.

Parameters	Inlet *(oxidation pond effluents)*	Polishing pond Effluent	Wetland bed Effluent	Fresh water	Overall removal efficiency
PH unit	9.1	9.2	8.5	8.3	
Total Alkalinity mg/L	246	293	362	349	
Total suspended solids mg/L	76	92	43	9.0	
Volatile suspended solids (VSS) mg/L	48	52	21	---	
Volatile %	62 %	70 %	40 %	---	
Total dissolved solids (TDS) mg/L	905	925	1120	560	
Biochemical oxygen demand (BOD_5) mg/L	40.0	32.0	16.0	---	
Chemical oxygen demand (COD) mg/L	82.0	65.0	36.5	---	
Ammonia-Nitrogen (NH_4-N) mg/L	2.3	1.6	1.1	---	
Nitrate-Nitrogen (NO_3-N) mg/L	3.0	2.3	1.2	---	
Total phosphorus(T-P)mg/L	3.1	3.2	2.7	---	
Oil & Grease mg/L	0.3	0.2	0.0	---	
Faecal Coliformbacteria Number/100 ml.	2000	600	350	---	
EC, dS/m	1.53	1.52	1.54	0.8	
Cl me/l	11.9	11.4	6.9	10.5	
Fe me/l	0.40	0.32	0.16	0.43	
Cu *ppm*	Nd	0.02	0.01	0.01	
Zn *ppm*	0.03	0.04	Nd	Nd	
Mn *ppm*	0.04	0.17	0.5	0.01	
Cd *ppm*	0.008	0.005	0.004	0.002	
Pb *ppm*	0.014	0.008	0.006	0.004	

(--)Not determined , (ND) Not detected

Table (2): Wastewater analyses before and after reclamation treatments. Date of sampling 15/6/2004.

Parameters	Inlet (oxidation pond effluents)	Polishing pond Effluent	Wetland bed Effluent	Fresh water	Overall removal efficiency
PH unit	8.45	8.67	8.82	8.30	
Total Alkalinity mg/L	346	365	340	320	
Total suspended solids mg/L	118.6	86.7	67.2	28.9	0.52%
Volatile suspended solids (VSS) mg/L	69.0	63.4	42.5		
Volatile %	58.2	73.1	63.2		-5%
Total dissolved solids (TDS) mg/L	109.8	856	760		-6.5%
Biochemical oxygen demand (BOD5) mg/L	85.0	41.0	13.0		0.72 %
Chemical oxygen demand (COD) mg/L	123.5	76.4	22.6		1.00 %
Ammonia-Nitrogen (NH4-N) mg/L	2.7	2.3	1.2		0.02%
E3Nitrate-Nitrogen (NO3-N) mg/L	3.1	2.6	1.4		0.02 %
Total phosphorus(T-P)mg/L	8.6	7.3	4.9		0.04%
Oil & Grease mg/L	0.72	0.50	0.32		
Faecal Coliformbacteria Number/100 ml.	10700	3200	1200		
EC dS/m	1.41	1.67	2.40		
Cl me/l	16.3	12.4	10.0		
Fe me/l	2.45	2.00	1.90		
Cu ppm	0.16	0.10	0.50		
Zn ppm	2.10	1.80	1.12		
Mn ppm	3.60	2.00	1.05		
Cd ppm	0.40	0.31	0.20		
Pb ppm	0.25	0.19	0.06		

Table (3) indicated that Typhe Sp. (Cattails) and papyrus produce the high amounts of bio-mass therefore pollutant rate of removal from the constructed wetland should be correlated to the bio-mass production. In the case of Sadat Pilot Site it seems that Cattails and Papyrus remove appreciable amounts of Cobalt, Zinc, Copper, Iron and Manganese while the reeds removes relatively more Zn and Copper.

Table (3): concentration of some pollutants in some cultivated wetland crop Date sampling 25/7/2004.

Pollutants PPM in the Biomass	cattails	Cyperus papyrus	Reed
Co	12	13	11
Pb	53	49	45
Cd	6	5	5
Ni	22	17	18
Zn	27	25	26
Cu	3.45	5.60	2.85
Fe	159	115	219
Mn	369	13	93

Table (4) some growth factors for aquatic plants grown in the gravel-constructed wetland at Sadat Pilot site. Date of measurement March 2004).

Plant type	No. of plants per m^2	Average of fresh weight of single plant g.	Total bio-mass fresh weight in kg/m^2	Average of plant height in cm
Typhe Spp. (Cattails)	**48**	**440.5**	**21.14**	**40**
Cyperus papyrus	**150**	**129.24**	**19.9**	**120**
Phragmited australis, (Reed)	**45**	**78.65**	**3.7**	**133**

Table (3) and (4) indicated the heavy metal contents of bio-mass produced in the gravel-constructed wetland at the two dates of sampling. In both cases (Cattails) and (papyrus) produce more than bio-mass than (Reed) (21.14, 19.90, and 3.70) respectively. However reed remove more heavy metals than both (Cattails) and (papyrus), but produces less bio-mass. The absolute removal then was more by (Cattails) and (papyrus) than that with Reed. The important observation in both table (3) and (4) that Reed is removing more cadmium than the Cattails and Papyrus. While the high efficiency of heavy metal removal of cattail plants.

Soil analyses:

Soil samples were collected at different depths from the different experimental plots to represent all soils receiving different water qualities and different irrigation methods. Soil samples were a dried sieved and analyzed for some physical, chemical and heavy metal analysis. Soil samples were collected twice a year. Data are presented in the following table (5).

Measurement of the pollution in some crops

Data of Table (6) shows the concentration of some pollutants in the different parts of cultivated test crops irrigated with fresh water, wetland and polishing effluents. Data indicated that plant roots accumulated more pollutants than shoots and seeds. All concentration of pollutants was quite low, lead in not detected. More work is needed to evaluate the level of pollutants the main crops cultivated in the different treated plots due to irrigation using reclaimed wastewater.

Table (5): Some soil chemical characteristics of the different experimental plots at Sadat pilot Site.

Parameter	Non irrigated soil	Polishing treatment	Wetland treatment	Fresh water
EC dS/m	0.25	0.52	1.23	0.29
pH	8.10	8.10	8.05	8.15
Ca me /l	1.45	1.21	3.77	1.50
Mg me /l	0.27	0.90	1.05	0.37
Na me /l	0.53	1.20	2.40	0.56
K me /l	0.95	0.26	0.67	0.86
CL me /l	0.76	1.45	1.73	0.92
SO4 me /l	1.03	0.82	4.59	0.65
Fe PPm	1.65	3.5	2.48	1.40
Cu PPm	0.10	0.08	0.04	0.32
Zn PPm	1.01	1.02	0.52	1.34
Mn PPm	1.01	2.64	1.48	2.10
Cd PPm	0.02	0.10	0.06	0.02
CaCO3 %	4.3	2.80	2.30	4.04

Table (6): concentration of some pollutants in some cultivated crops irrigated different quality reclaimed water.

Pollutants ppm	Polishing pond effluents	Wetland effluents	Fresh water
Co in			
Roots	1.13	0.53	0.46
Shoots	0.90	0.61	0.59
Pb			
Roots	ND	ND	ND
Shoots	ND	ND	ND
Cd			
Roots	0.46	0.46	0.76
Shoots	0.37	0.39	0.40
Ni			
Roots	1.53	1.23	1.25
Shoots	1.23	0.70	0.84

(ND) Not detected

Data of Table (6) shows the concentration of some pollutants in the different parts of cultivated test crops irrigated with fresh water, wetland and polishing effluents. Data indicated that plant roots accumulated more pollutants than shoots and seeds. All concentration of pollutants was quite low, lead in not detected. More work is needed to evaluate the level of pollutants the main crops cultivated in the different treated plots due to irrigation using reclaimed wastewater.

Conclusion:

The most successful plants are Cattails, Papyrus and Phragmites. The bio-mass production was 21.4, 19.9 and 3.7 kg/m2 of gravel surface respectively, meanwhile the uptake of these plants from heavy metals were quite significant. Cattails was the most effective plant in both bio-mass production and heavy metals up take, however papyrus produced good amounts of bio-mass and removed much less heavy metals while phragmited produced less bio-mass but removed more iron and medium amounts of cobalt, lead, zinc, copper and manganese. Bio-mass of these plants can be of economic value and market opportunities.

Table (7) heavy metals removal efficiency of wetland plants

Pollutants PPM in the Biomass	cattails	Cyperus papyrus	Reed
Co	140.4	20.8	99.0
Pb	620.1	78.4	405.0
Cd	70.2	8.0	45.0
Ni	257.4	27.2	162.0
Zn	315.9	40.0	234.0
Cu	40.36	8.96	25.65
Fe	1860.3	184.0	1971.0
Mn	4317.3	20.8	837.0

From the data shown in table (7) it can be concluded that Cattails is the most efficient plant in heavy metals removal followed by Phragmites then the Papyrus.

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كفاءة بعض النباتات في إستخلاص العناصر الثقيلة من مياه الصرف الصحي فى البرك الزلطيه الصناعية

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إعادة استخدام مياه الصرف الصحي المعالجة في الري ضرورة حتمية خصوصا في المناطق الجافة وشبه الجافة، حيث تمثل مصدر إضافي للمياه يمكن توفيره في حالة معالجته بالطرق السليمة واستخدامه بصورة آمنة في مجال الزراعة.

تم إنشاء البركة الزلطية لكي يتم بها زراعة النباتات محل الدراسة بأبعاد ٣٠ × ٣٤ متركبحث لدراسة معالجة مياه الصرف الصحي وإعادة استخدامها في الزراعة وتم زراعة أنواع مختلفة من النباتات بها في مدينة السادات التي تبعد حوالي ٩٠ كيلو متر عن القاهرة.

وقد تم زراعة أنواع مختلفة من النباتات في هذه البركة الزلطية والتي لها قدرة على إستخلاص العناصر الثقيلة من المياه لتعمل كمرشحات حيوية وهذه النباتات هى البوص ***Phragmites australis,*** والكنه ***Cana indica*** والبوط ***Typhe Sp.*** والبردى ***. Cyperus papyrus***

ويتم جمع العينات النباتية مرتين في السنة وتجفيفها وإرسالها إلى المعامل للتحيل لمعرفة محتواها من المعادن الثقيلة.

وتم حصاد كل النباتات التي تم نموها في هذه البركة الزلطية وتم حساب المادة العضوية المنتجة لكل نبات كوزن طازج.

تهدف هذه الدراسة إلى التعرف على مدى كفاءة هذه النباتات لإستخلاص المعادن الثقيلة من المياه المعالجة حيث تعتبر المعادن الثقيلة المشكلة الأكثر خطورة في مياه الصرف الصحي المعالج بجانب المواد العضوية السامة وخصوصا عندما تكون مياه الصرف الصحي مخلوطة بمياه الصرف الصناعي.

وقد أظهرت النتائج بأن أكثر النباتات الناجحة هي البوط- Cattails والبردى - Papyrus والبوص Phragmites حيث كان الإنتاج من المادة العضوية هو ٢١,٤ ، ١٩,٩، ٣,٧ كيلوجرام/م[٢] على التوالي، ومن ثم كانت قدرة هذه النباتات على إستنفاذ المعادن الثقيلة معنوية، وكان نبات البوط (Cattail) الأكثر فاعلية في كل من إنتاج الكتلة الحيوية وإستخلاص المعادن الثقيلة، ومع ذلك أنتج نبات البردى (Papyrus) كميات جيدة من المادة العضوية وإستخلص كمية أقل من المعادن الثقيلة أقل بينما نبات البوص (Phragmites) أنتج كمية أقل من المادة العضوية وأستخلص كمية أكبر من الحديد وكمية متوسطة من الكوبالت والخارصين والزنك والنحاس والمنجنيز. وقد يكون للمادة العضوية لهذه النباتات قيمة إقتصادية يمكن الإستفادة منها.