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Use of bark and combined paper sludge for the re-vegetation of bark-covered land

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## **ABSTRACT**

This study investigated the use of bark and combined paper sludge, poor and rich in nutrients, in order to develop a suitable plant growth substrate and to establish a vegetation cover on bark-covered land. A short-term field experiment was established in Taschereau, Quebec, Canada to: 1- determine a suitable plant growth medium on a bark-covered land; 2- determine which plant mixture should be selected for establishment on this site and 3- determine a fertilization program for one selected plant. By the end of the summer, the best soil cover consisted of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, which gave good plant appearance, cover, and yield. On this soil cover, the Savoureux mixture (53% perennial grasses and 37% perennial legumes) in combination with birdsfoot trefoil (*Lotus corniculatus* L.), Lab02 (65% perennial grasses and 35% perennial legumes) in mixture with MR77 (100% perennial grasses), and birdsfoot trefoil in mixture with brome grass (*Bromus inermis* L.) gave good vegetation growth and yields. For the birdsfoot trefoil fertilization experiments, and over all soil covers, nitrogen fertilization was not required, but phosphorus and potassium fertilizations should be, respectively, 140 kg P<sub>2</sub>O<sub>5</sub>/ha and 160 kg K<sub>2</sub>O/ha to obtain good plant growth and yield. These first results suggested that combined paper sludge and black bark can be used as topsoil to favor plant establishment on bark-covered land.

## **KEYWORDS:**

Topsoil, paper sludge, bark, birdsfoot trefoil, brome grass, fertilization, NO<sub>3</sub><sup>-</sup>-N, phosphorus.

## **INTRODUCTION**

About 178 million tons of woody residues in the United States (McKeever and Falk 2004) and 12 million dry tons of bark residues in Canada are produced annually (Stirling 2003). In the province of Quebec, 575 000 tons of dry wood and bark residues are produced annually (Association des Industries Forestières du Québec, Ltée; personal communication). When usable products cannot be made, these bark residues are burned for energy purpose or piled on land to create biomass parks. In the United States about 86 million metric tons are left unused, and in Quebec about 10% are simply piled in biomass parks. These unused bark residues have accumulated for decades and several hectares of soil have been covered over time in northern areas of the Quebec province. These residues have reached a rate of accumulation that causes a marked change on land, incoherent with the general landscape and the community. These bark residues, exposed to air, decompose over time and yield bark at various decomposition ages, i.e., from fresh to old bark. Among them, black bark has reached the oldest decomposition level, similar to that of organic soils. In the absence of effective sustainable management, bark-covered lands remain without vegetation. Under these conditions, these bark-covered lands need a new soil cover, or plant growth substrate, to favor their re-vegetation.

For surface reclamation, the first step towards sustainability is the restoration of ecosystem function (Bradshaw 1996). For biomass parks, nutrient deficiencies and/or toxicities may impede the establishment of a plant cover. Also, an excessive soil internal drainage and poor water retention capacity may lead to shortages in plant water supply even in wet climates, similar to sandy soils. Substrates with high bulk densities may impede plant establishment

(Zeleznik and Skousen 1996). Therefore, the new soil cover needs to improve both plant nutrition and water retention capacity. For these reasons, combined paper sludge, a mixture of wastepaper from the primary treatment and activated sludge from the secondary treatment systems of the pulp and paper industry, was selected as the second amendment to use in combination with bark since it is rich in plant nutrients. In addition, the paper sludge has been used in the past for land reclamation (Watson and Hoitink 1985; Fierro et al. 1999), and some of which may have a very high water retention capacity, i.e. 65% at -33 kPa (Fierro et al. 1999). Used alone or in combination, the bark and combined paper sludge could support plant growth but they have to be considered as organic substrates, a situation that is completely different from that of a mineral soil substrate.

In spite of the potential of bark and combined paper sludge as re-vegetation tools for bark-covered land, their field evaluation has never been conducted. The specific objectives of this study were to : (i) determine a suitable plant growth medium on the site; (ii) determine which plants should be selected for establishment on this site and (iii) determine a fertilization program for one selected plant.

## **METHODOLOGY**

The research was conducted on 7 ha of a biomass park located at Taschereau, Quebec, Canada. The experimental site (48°40'N, 78°42'W) was located at the edge of a small rural community. This area accumulates 1366 degree days (base 5° C) (Environment Canada 2004), and the frost free period varies from 74 to 83 days. This site was visited and areas

with bark of various ages were determined. Different areas per bark age were selected and sampled for physico-chemical analyses.

A paper mill located at less than 100 km was selected on the basis of the chemical analyses of their sludge. Their sludge complied with the environmental regulations required by the Quebec Ministry of Environment (2004). Samples were collected at different times for physico-chemical analyses.

### **Physical and chemical characteristics**

Bark of various ages and combined sludge samples were collected on the experimental site and at the paper mill, and sent to our laboratories. All analyses were replicated. The bark granulometry was determined by sieving 250 g of bark through a series of sieves of 19, 9.5, 6.3, 4.0, 2.0 and < 2 mm. The proportion of large particles was higher in the fresh bark than in the black bark (Table 1). The water content was determined by drying 10 g of substrate to constant weight at 105 °C. The fresh and young bark had a water content of 60%, compared with 70% for the light brown, brown and black bark. The combined paper sludge had a water content of 78%.

The water flow rate was measured in situ on the young, brown and black bark, using the methodology by Marsh (1991). These analyses were repeated three times. The flow rate of water in young bark was  $2.44 \times 10^{-3}$  m/s. This rate increased to  $2.64 \times 10^{-3}$  m/s with light brown bark and decreased to  $5.56 \times 10^{-4}$  m/s for the black bark. These values are similar to the water flow rate of a very coarse sand.

To determine the plant available nutrients, the samples were dried at 37 °C for 48 h, sieved and ground to 2 mm, using a Wiley Mill. The pH of each sample was determined from a 1:40 dilution after a 1 h agitation (C.P.V.Q. 1988). The electrical conductivity was measured after filtration. Available phosphorus (P) was determined using the Mehlich III method (Mehlich 1985) and measured by spectrophotometry. Exchangeable potassium, calcium and magnesium (K, Ca and Mg) were extracted with BaCl<sub>2</sub>-NH<sub>4</sub>Cl (Amacher et al. 1990) and their contents were determined by ICP (Perkin Elmer Plasma 40, Perkin Elmer, Boston, MA, USA).

The ammonium and nitrate nitrogens were extracted with a 1N KCl solution and their concentrations were measured using a Dionex DX 500 chromatograph (Dionex Corporation, Sunnyvale, CA) equipped with AG5 and CS5 columns. Nitrate and ammonium were detected by the AD20 absorbance module and quantified using PeakNet Software (Dionex Corporation, Sunnyvale, CA, USA). To determine the total nutrients, the substrate samples were dried at 60 °C for 48 h, sieved and ground to 0.12 mm using a Retsch Ultracentrifugal Mill (Retsch Inc., Newtown, PA, USA). The total nitrogen was measured by dry combustion (CNS-1000, Leco; Michigna, USA). Concentrations of total P, K, Ca and Mg were determined by ICP (Perkin Elmer Plasma 40, Perkin Elmer, Boston, MA, USA), after digestion in a mixture of H<sub>2</sub>SO<sub>4</sub>/Se/-H<sub>2</sub>O<sub>2</sub> (Parkinson and Allen 1975). Selected physical and chemical properties are presented in Table 2, which comprises the contrasting plant nutrients and salt contents between bark and combined paper sludge, as well as plant nutrients variations as bark aged.

## **Soil cover**

Several experiments using different combinations of bark and combined sludge were selected to evaluate four soil cover treatments. These were: (i) 5 cm of combined paper sludge, (ii) 2.5 cm of combined paper sludge, (iii) 2.5 cm of combined paper sludge + 2.5 cm of black bark, and (iv) 5 cm of black bark applied on the top of bark. The experimental site was divided into four areas of about 2 ha, one part per soil cover, to favor the use of large equipments (10-wheel trucks, front loader, spreader, etc.).

## ***Plants selection***

The first experiment was set up to determine which plants should be selected for this site. The experiment was set-up as a nested design where the soil cover treatments were fixed, since large equipments were required to spread the soil cover treatments. Five blocks were nested within each plant species, alone or in mixture. The plants seeded for establishment on site were:

(i) Savoureux mixture (32% timothy *Phleum pratense* L., 20% red clover (*Trifolium pratense* L.), 15% Ryegrass (*Lolium perenne* L.) Aubade, 10% Johnstone fescue (*Festuca sp.*), 7% white clover (*Trifolium repens* L.) Huia, 5% Kentucky bluegrass (*Poa pratensis* L.), 4% birdsfoot trefoil (*Lotus corniculatus* L.) Mirabel, 4% Orchardgrass (*Dactylis glomerata* L.) Sumas, 2% Ladino clover (*Trifolium repens* L.), 1% redtop (*Agrostis gigantea* Roth) in combination with birdsfoot trefoil;

(ii) Lab02 (40% alfalfa (*Medicago sativa* L.) Echo, 35% timothy, 25% birdsfoot trefoil in mixture with MR77 (40% Chewing fescue (*Festuca rubra* L. *ssp. commutata* Gaudin), 30%

tall fescue (*Lolium arundinaceum* (Schreb.) S.J. Darbyshire)), 20% Kentucky bluegrass, 10% redtop ;

(iii) Lab01 (30% Chewing fescue TATJANA, 15% tall fescue TRIBUTE, 10% Reliant Hard Fescue (*Festuca trachyphylla* (Hack.) Krajina), 10% Crimson clover (*Trifolium incarnatum* L.), 10% alsike clover (*Trifolium hybridum* L.), 7% white clover, 6% birdsfoot trefoil, 2% Sainfoin (*Onobrychis sativa* Lam.), 2% black medick (*Medicago lupulina* L.), 2% strawberry clover (*Trifolium fragiferum* L.), 6% wild flowers);

(iv) MR-77 in mixture with birdsfoot trefoil;

(v) birdsfoot trefoil;

(vi) birdsfoot trefoil in mixture with bromegrass (*Bromus inermis* L.).

Each plot measured 8 m by 8 m. An index scale from 1 (poor) to 10 (excellent) was used to determine plant growth based on plant color, grass and legume heights and their cover (Norrie and Gosselin 1996). An index of 5 is acceptable. The plants were harvested into 30 cm per 30 cm quadrats, and their yield was expressed in kg/ha.

### ***Birdsfoot trefoil experiments***

#### **Nitrogen fertilization**

The second experiment studied the effect of three nitrogen levels on plant growth, plant cover, nodulation and biomass of birdsfoot trefoil. The experiment was also set-up as a nested design where four blocks were nested within each soil cover treatment. The nitrogen levels were randomized within each block and the levels studied were 30, 60 or 90 kg N/ha. The P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O fertilization were kept uniform at 80 kg/ha and 160 kg/ha, respectively.



Each plot measured 10 m by 10 m, and birdfoot trefoil was seeded at 20 kg/ha. Again, the index scale of 1 to 10 was used to determine plant growth (Norrie and Gosselin 1996), and the Horsfall-Barratt (1945) scale was used to determine the percentage of plant cover.

The plant biomass was measured within 30 cm per 30 cm quadrats for each plot and their yield expressed in kg/ha. Finally, the number of nodules per root and their size were measured to determine a nodulation index. A rank of 1 was given to a nodule with a diameter of 1 mm, 8 for a nodule of 2 mm, 27 for a nodule of 3 mm and 64 for a nodule of 4 mm. These ranks corresponded to the number of times that the volume of a 1 mm sphere can be included in a 2, 3 and 4 mm spheres. Each nodule was ranked and their summation made, before dividing them by the number of harvested plants to create the nodulation index. In addition, ammonium, nitrate and phosphate contents were measured within these new soil covers.

### **Phosphorus and potassium fertilization**

The third experiment investigated phosphorus fertilization at 20, 50, 80, 110 or 140 kg P<sub>2</sub>O<sub>5</sub>/ha in combination with potassium fertilization at 20, 90, 160 or 230 kg K<sub>2</sub>O/ha on plant cover and biomass of birdfoot trefoil. The experiment was set-up as a nested design where four blocks were nested within the soil cover treatments, and the phosphorus and potassium treatments were randomly arranged within each block. Each plot measured 8 m by 8 m, and birdfoot trefoil was seeded at 20 kg/ha. Plant growth and biomass were measured as mentioned above.

### **Statistics**

The soil cover treatments were fixed, but the other treatments were randomized and nested within the soil cover (Hicks 1964; Steel and Torrie 1980; Gomez and Gomez 1983; Montgomery 2001). For the first experiment, a two factor experimental design was used with four soil covers and six plant species mixtures. A randomized block design was set up; using five blocks nested within the soil covers. For the second experiment, a two factor experimental design was used with four soil covers and three levels of nitrogen to fertilize birdsfoot trefoil. A randomized complete block design was set up; using four blocks nested within the soil covers. For the third experiment, a three factor experimental design was used with four soil covers, five levels of phosphorus and four levels of potassium to fertilize birdsfoot trefoil. A split-plot block design was set up, using four blocks nested within the soil covers (Hicks 1964; Montgomery 2001).

For each experiment, Bartlett's test was used to determine the homogeneity of the variances (Little and Hills 1978) prior to performing analyses of variance using Statistical Analysis System (SAS) procedures (Hicks 1964; Steel and Torrie 1980; Gomez and Gomez 1983; SAS Institute, Inc. 1990; Montgomery 2001). The yield, above-ground part and root biomasses, the soil ammonium, nitrate and phosphate soil contents, and the number of root nodules and the nodulation index were transformed to  $\log_{10}$  and the values presented in the text or tables are their antilog<sub>10</sub> (Little and Hills 1978). When no interaction was present among factors, means of the significant main factors are presented (Hicks 1964; Steel and Torrie 1980; Gomez and Gomez 1983; Montgomery 2001). When interactions were present, means averaged over non-significant factors are presented. These analyses of variance were performed using SAS (SAS Institute Inc. 1990).

## RESULTS

### *Plants selection*

The plant appearance, growth, and yield were significantly affected by the soil cover and the plant species (Soil cover\*Plant mixture  $P < 0.01$ ). In general, the best substrate consisted of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, which gave good results for plant appearance, growth and yield. This was followed by the 5 cm of combined paper sludge, and then the 2.5 cm of combined paper sludge (Tables 3, 4 and 5). Finally, 5 cm of black bark led to the lowest results for most plant species.

The Savoureux mixture in combination with birdsfoot trefoil, Lab02 in mixture with MR77, and birdsfoot trefoil in mixture with bromegrass gave good results in the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark. In contrast, in the most nutrient limiting substrate for plant growth, i.e., 5 cm of black bark, the Savoureux mixture in combination with birdsfoot trefoil, Lab01 and birdsfoot trefoil alone gave also good results. For further plant fertilization experiments, only birdsfoot trefoil was selected to avoid plant species interactions.

### *Birdsfoot trefoil experiments*

#### *Nitrogen fertilization*

Plant growth was affected by both the soil cover and the nitrogen fertilization (Soil cover\*N fertilization  $P < 0.02$ ; Figure 1). Plant growth decreased with nitrogen levels for the 5.0 cm of combined paper sludge or the 5 cm of black bark. For the 2.5 cm of combined paper sludge, plant growth remained relatively poor, but stable. For the 2.5 cm of combined paper

sludge on top of 2.5 cm of black bark treatment, plant growth increased from 30 to 60 kg N/ha, but remained stable thereafter.

Plant cover, yield, above-ground or root biomass were affected by the soil cover, but not by nitrogen fertilization (Soil cover  $P < 0.01$ ). The 2.5 cm of combined paper sludge on top of 2.5 cm of black bark treatment gave the best plant cover and yield (Table 6). However, on the basis of above-ground or root weight mass, no difference was noted between the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark treatment and the 5.0 cm of combined paper sludge treatment.

Part of the above mentioned difference can be attributed to the amount of N<sub>2</sub>-fixing nodules on the roots and the nodulation index for birdsfoot trefoil. In the presence of black bark, the number of nodules was significantly higher (7 to 10 nodules/plant) than in the presence of combined paper sludge alone (2 to 3 nodules/plant; Table 6). The nodulation ranks were significantly lower in the 2.5 cm of combined paper sludge and the 2.5 cm of black bark, but higher in the other two treatments (Table 6).

These differences can be partly attributed to the levels of ammonium, nitrate and phosphorus contents in the soil cover (Table 7). First, the levels of ammonium and nitrate in the soil cover differed significantly among soil covers, but were not affected by nitrogen fertilization. Therefore, only the ammonium and nitrate means, averaged over all N treatments, are presented (Table 7). On average, the ammonium and nitrate contents were significantly

higher in the 5.0 cm of combined paper sludge, intermediate in both treatments containing 2.5 cm of combined paper sludge, and lower in the 5.0 cm of black bark.

Furthermore, the levels of phosphorus in the soil cover differed significantly among the soil cover and the nitrogen fertilizations (Soil cover\*N fertilization  $P < 0.01$ ). The phosphorus content increased from 30 to 60 kg N/ha for the 5.0 and 2.5 cm of combined sludge, but decreased from 60 to 90 kg N/ha (Table 7). The situation was the opposite for the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark treatment. Finally, for the black bark, the phosphorus content was low regardless of the nitrogen levels.

#### **Phosphorus and potassium fertilization**

The plant growth was significantly affected by the soil cover and the phosphorus fertilization levels (Soil cover\*P fertilization  $P < 0.01$ ; Figure 2A), but not by the potassium fertilization. Therefore, only the means averaged over the potassium levels are presented. Plant growth tended to be higher in the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, and for the 5.0 cm of combined paper sludge, followed by the 2.5 cm of combined sludge, and last by the 5.0 cm of black bark. For this last treatment, plant growth was improved with increasing level of phosphorus.

The yields were affected by the soil cover and phosphorus fertilization levels (Soil cover\*P fertilization  $P < 0.01$ ; Figure 2B). Plant growth tended to be higher in the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, and for the 5.0 cm of combined paper sludge, followed by the 2.5 cm of combined sludge, and last by the 5.0 cm of black bark. For

most soil covers, the highest yield was obtained with 140 kg P<sub>2</sub>O<sub>5</sub>/ha, except for the 5.0 cm of black bark for which the highest yield was obtained with 110 kg P<sub>2</sub>O<sub>5</sub>/ha.

The yields were affected by the potassium fertilization. On average, for all soil covers and phosphorus fertilization levels, the yields were 136 kg/ha at 20 kg K<sub>2</sub>O/ha; 152 kg/ha at 90 kg K<sub>2</sub>O/ha; 172 kg/ha at 160 kg K<sub>2</sub>O/ha; 159 kg/ha at 230 kg K<sub>2</sub>O/ha.

## **DISCUSSION**

The bark residues produced by wood industries are piled in biomass parks when other mills are too far away for their re-use. In general, the young bark was coarse and very acidic, whereas the old bark was finer and less acidic. They were poor in nutrients, such as nitrogen, phosphorus, potassium, and magnesium. However, calcium concentration increased with bark age, and the black bark was richer in calcium than fresh bark. Also, the water retention capacity increased with the bark age, whereas water flow rate decreased. Therefore, the black bark can improve the water retention and calcium content in a soil substrate. On the other hand, the combined paper sludge was rich in nutrients. These results led us to develop a new soil cover made of black bark and combined paper sludge to support initial re-vegetation of the surface of bark-covered land.

On the bark-covered land, the best substrate consisted of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, which gave good results for plant appearance, cover and yield, followed by the 5 cm of combined paper sludge treatment, and then the 2.5 cm of combined paper sludge. Finally, 5 cm of black bark led to the lowest results. The combined paper

sludge and black bark application appeared to have been effective in accelerating restoration of ecosystem function, at least from a biomass production standpoint. Plant biomass is an indicator of ecosystem function (Bradshaw 1996), but for one growing season, it would not necessarily reflect its degree of establishment and stability.

The Savoureux mixture in combination with birdsfoot trefoil, Lab02 in mixture with MR77, and birdsfoot trefoil in mixture with bromegrass gave good results in the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark. In contrast, in the most limiting substrate for plant growth, i.e., 5 cm of black bark, the Savoureux mixture in combination with birdsfoot trefoil, Lab01 and birdsfoot trefoil alone gave good results. It is generally agreed that a closed plant canopy is an effective way to stabilize and protect the soil, so the combination of perennial legumes and grasses will favor plant cover and stability over time.

In order to establish a fertilization program, birdsfoot trefoil was selected to determine the adequate nitrogen, phosphorus and potassium fertilization levels. For the birdsfoot trefoil fertilization experiments, the 2.5 cm of combined paper sludge on top of 2.5 cm of black bark gave good results for plant appearance and growth, regardless of the nitrogen, or phosphorus, and potassium fertilizations. Nitrogen fertilization did not improve plant appearance and cover, growth and yield. The treatment consisting of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark led to productivity per plant similar to that obtained with 5 cm of combined sludge; on the basis of nodulation, and ammonium and nitrate contents data, it can be speculated that plants growing on the former soil cover relied more on symbiotic N<sub>2</sub> fixation and less on combined N (ammonium and nitrate) for their nitrogen nutrition than

plants growing on the latter soil cover (Chalifour and Nelson, 1987). On the basis of nodulation data, the treatment consisting of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark appeared particularly conducive to symbiotic N<sub>2</sub> fixation, significantly more than any of the other soil covers; the factors favoring nodulation of birdsfoot trefoil for that soil cover need to be identified.

The above-mentioned results are consistent with the fact that birdsfoot trefoil, similarly to other forage legumes, can fulfill most of its N requirements through symbiotic N<sub>2</sub> fixation (Allahdadi et al. 2004). Apparently, the nutrients from the combined paper sludge accumulate within the black bark and can eventually sustain long-term plant nutrition. Over all soil cover treatments, the adequate phosphorus and potassium fertilization was 140 kg P<sub>2</sub>O<sub>5</sub>/ha and 160 kg K<sub>2</sub>O/ha. This combination gave good plant growth. These levels of fertilization are similar to the CPVQ (1994) recommendations for the establishment of legume crops grown on soils low in plant available nutrients.

The development of re-vegetation strategies of abandoned bark-covered land requires multidisciplinary knowledge, since these biomass parks should be considered as organic soils. From an environmental point of view, it would not be acceptable to use mineral soil to cover these biomass parks. Therefore, the development of new organic soil covers could lead to an acceptable plant cover to improve the esthetics of these sites, representing an environmentally and economically acceptable issue for the community. Under the humid and cool conditions of Eastern Canada, the combined paper sludge and black bark can be a valuable tool for re-vegetation of degraded soils presenting limitations in water retention,



acidity, nutrient retention and availability, and bulk density. Soil cover consisting of 2.5 cm of combined paper sludge on top of 2.5 cm of black bark, and adequately fertilized in P and K, enhanced plant growth and yield by improving the limiting conditions prevailing in the biomass park. Long term research should assess the viability of the system.

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Table 1. Granulometry of various bark types.

Type of material	Bark size					
	>19 mm	<19 to >9.5 mm	<9.5 to >6.3 mm	<6.3 to >4.0 mm	<4.0 to >2.0 mm	<2.0 mm
	------(%)-----					
Fresh Bark	54.74 ± 7.27	16.02 ± 4.33	9.14 ± 1.12	6.79 ± 0.39	6.21 ± 1.01	7.16 ± 0.95
Young Bark	22.56 ± 4.73	15.25 ± 3.32	12.31 ± 1.32	11.00 ± 1.39	13.94 ± 0.83	24.94 ± 4.13
Light Brown	16.11 ± 2.24	29.38 ± 3.54	15.77 ± 0.98	12.66 ± 0.32	11.17 ± 0.73	14.89 ± 0.76
Brown Bark	5.13 ± 0.77	13.05 3.12	13.95 ± 1.90	15.67 ± 1.99	20.29 ± 1.42	31.99 ± 6.00
Black Bark	5.17 ± 0.97	12.27 ± 2.46	11.63 ± 1.82	13.07 ± 1.65	21.38 ± 1.18	36.45 ± 4.07

Mean of 4 replicates and their standard deviation (Mean ± standard deviation).

Table 2. Some physical and chemical characteristics of bark of various ages and combined paper sludge.

Type of material	Dry Bulk Density	pH	Electrical Conductivity	Plant Available Nutrient						Total Plant Nutrient				
				NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	P	K	Ca	Mg	N	P	K	Ca	Mg
	(g/cm <sup>3</sup> )		---(μS/cm)---	-----( <i>mg/kg dry matter</i> )-----										
Fresh Bark	0.12 ± 0.01	4.1 ± 0.0	278 ± 144	12 ± 1	N.D. <sup>z</sup>	18 ± 1	722 ± 2	2743 ± 61	297 ± 5	2207 ± 70	184 ± 16	977 ± 21	7469 ± 287	384 ± 6
Young Bark	0.17 ± 0.00	4.7 ± 0.5	110 ± 10	113 ± 12	N.D.	15 ± 1	396 ± 33	3032 ± 61	236 ± 10	2410 ± 216	179 ± 15	959 ± 5	9625 ± 102	1214 ± 21
Light Brown Bark	0.16 ± 0.01	4.5 ± 0.1	106 ± 42	25 ± 1	N.D.	7 ± 0	144 ± 9	4432 ± 107	230 ± 2	3607 ± 350	216 ± 18	299 ± 5	11185 ± 413	393 ± 1
Brown Bark	0.22 ± 0.01	5.0 ± 0.4	75 ± 11	12 ± 1	6 ± 4	10 ± 1	396 ± 33	4878 ± 166	177 ± 9	3743 ± 497	168 ± 6	1149 ± 15	14817 ± 121	771 ± 1
Black Bark	0.24 ± 0.01	5.5 ± 0.2	78 ± 37	19 ± 0	N.D.	6 ± 1	240 ± 6	5469 ± 557	179 ± 14	3477 ± 156	99 ± 11	806 ± 10	15190 ± 269	532 ± 33
Combined Paper Sludge	0.19 ± 0.00	6.5 ± 0.1	868 ± 215	387 ± 19	23 ± 3	1409 ± 24	1380 ± 0	7515 ± 80	1005 ± 8	16100 ± 290	5585 ± 78	2937 ± 14	18171 ± 47	2179 ± 37

<sup>z</sup> Not detected

Mean of duplicates or triplicates and standard deviation.

Table 3. Effect of soil cover on plant growth of various plant species, seeded alone or mixture.

Mixture name	5.0 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge + 2.5 cm Black Bark	5.0 cm Black Bark
	<i>Plant Growth Index (1 to 10 Scale)</i>			
Savoureux + Birdsfoot trefoil	6.4 a-e	5.0 e-g	7.0 ab	3.8 gh
Lab 02 + MR-77	6.8 a-c	6.8 a-c	7.2 a	3.6 gh
Lab01	5.0 e-g	4.2 f-h	5.2 d-g	3.4 h
Birdsfoot trefoil + MR-77	5.2 d-g	3.8 gh	5.4 c-f	3.2 h
Birdsfoot trefoil	5.6 b-f	3.6 gh	5.0 e-g	3.4 h
Birdsfoot trefoil + bromegrass	6.8 a-c	5.2 d-g	6.6 a-d	3.2 h

Mean of 5 replicates.

Values followed by the same letters across rows and columns do not differ significantly from one another according to the LSD test; Soil cover\*Plant Mixture  $P < 0.01$ .

Table 4. Effect of soil cover on the plant appearance of various plant species, seeded alone or in mixture.

Mixture name	5.0 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge + 2.5 cm Black Bark	5.0 cm Black Bark
	<i>Plant Appearance Index (1 to 10 Scale)</i>			
Birdsfoot trefoil + Savoureaux	5.4 ab	3.8 b-e	6.0 a	3.0 c-e
Lab 02 + MR-77	5.0 a-c	4.4 a-e	6.0 a	2.4 de
Lab01	3.2 c-e	3.0 c-e	4.2 a-e	2.8 de
Birdsfoot trefoil + MR-77	3.8 b-e	2.4 de	4.6 a-d	2.6 de
Birdsfoot trefoil	4.0 b-g	2.2 e	4.2 a-e	3.2 c-e
Birdsfoot trefoil + bromegrass	5.6 ab	3.8 b-e	5.6 ab	2.4 de

Mean of 5 replicates.

Values followed by the same letters across rows and columns do not differ significantly from one another according to the LSD test; Soil cover\*Plant Mixture  $P < 0.01$ .



Table 5. Effect of soil cover on the yield (kg/ha) of various plant species, seeded alone or in mixture.

Mixture name	5.0 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge	2.5 cm Combined Paper Sludge + 2.5 cm Black Bark	5.0 cm Black Bark
Birdsfoot trefoil + Savoureux	1357 a	232 c-e	1436 a	52 f-h
Lab 02 + MR-77	564 a-c	308 a-e	1184 ab	21 h
Lab01	205 c-f	112 d-g	467 a-d	52 f-h
Birdsfoot trefoil + MR-77	246 c-e	74 e-h	324 a-e	21 h
Birdsfoot trefoil	262 b-e	40 gh	310 a-e	38 gh
Birdsfoot trefoil + bromegrass	552 a-c	253 b-e	771 a-c	37 gh

Mean of 5 replicates.

Values followed by the same letters across rows and columns do not differ significantly from one another according to the LSD test; Soil cover\*Plant Mixture  $P < 0.01$ .

Table 6. Effect of soil cover on birdsfoot trefoil yield and on the above-ground and root yield per plant grown.

Soil Cover	Plant	Plant Biomass			Nodule	
	cover	Yield	Above-ground	Root	Number	Nodulation Index
	%	<i>kg/ha</i>	<i>g/plant</i>	<i>g/plant</i>	<i>Nodule/plant</i>	<i>Ranked nodule/plant</i>
Combined Paper Sludge: 5.0 cm	42 b	358 b	53 a	18 a	2 b	40 b
Combined Paper Sludge: 2.5 cm	30 b	114 c	14 b	7 b	3 b	14 c
Combined Paper Sludge: 2.5 cm + Black Bark: 2.5 cm	65 a	778 a	53 a	18 a	11 a	81 a
Black Bark : 5.0 cm	31 b	134 c	16 b	8 b	7 a	15 c

Mean of 4 replicates.

Yield, above-ground and root plant biomass: Soil cover:  $P < 0.01$ ; N fertilization: NS.

Number and ranked nodule per plant: Soil cover:  $P < 0.01$ ; N fertilization: NS.

Values within a column followed by the same letter do not differ significantly from one another according to the LSD test.

Table 7. Effect of soil cover on ammonium and nitrate content averaged over nitrogen levels, and phosphorus content at three levels of nitrogen.

Soil Cover	Ammonium	Nitrate	Phosphorus		
	Mean averaged over all N levels	Mean averaged over all N levels	Level of nitrogen (kg N/ha)		
			30	60	90
	$\mu\text{g N-NH}_4^+/\text{g d.w.}$	$\mu\text{g N-NO}_3^-/\text{g d.w.}$	$\mu\text{g P-PO}_4^{3-}/\text{g d.w.}$		
Combined Paper Sludge: 5.0 cm	18 a	34 a	127 ab	131 ab	118 ab
Combined Paper Sludge: 2.5 cm	6 b	4 b	77 bc	99 abc	55 c
Combined Paper Sludge: 2.5 cm + Black Bark: 2.5 cm	7 b	10 b	146 a	123 ab	134 ab
Black Bark : 5.0 cm	1 c	1 c	5 d	2 e	6 d

Mean of 4 replicates.

Ammonium, nitrate: Soil cover:  $P < 0.01$ ; N fertilization: NS.

Phosphorus: Soil cover\*Plant Species  $P < 0.01$ .

Values within a column followed by the same letter do not differ significantly from one another according to the LSD test.

Figure 1. Effect of soil cover on the plant growth of birdsfoot trefoil grown at different nitrogen fertilization levels. Values (means of four replicates) followed by the same letters among lines do not differ significantly from one another according to the LSD test; Soil cover\*Plant Species  $P < 0.02$

Figure 2. Effect of soil cover on the plant growth index (A) and yield (B) of birdsfoot trefoil grown at different phosphorus fertilization levels. Values (means of four replicates) followed by the same letters among lines do not differ significantly from one another according to the LSD test; Soil cover\*P fertilization  $P < 0.01$



