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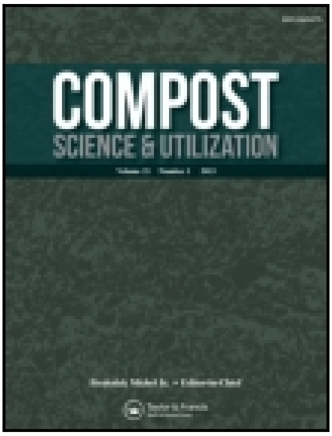

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Effect of Deinking Paper Sludge Compost On Nutrient Uptake and Yields of Snap Bean And Potatoes Grown in Rotation

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The paper industry in Canada faces a challenge of economically sound and environmentally safe disposal of massive amounts of residues. A field study was conducted in 1996 and 1997 to evaluate the effects of application of a compost derived from a mixture of deinking paper residues and poultry manure (DSPC) on P and K uptake, and yields of snap bean (*Phaseolus vulgaris* L. cv. Centralia), and potato (*Solanum tuberosum* L. cv. Gold Rush). The experiment was conducted on a Tilly silt loam (Gleyed Humo-Ferric Podzol) located in Sainte-Croix de Lotbinière, Québec, Canada. The DSPC was applied in the spring 1996 at 0, 14, 28 and 42 Mg ha^{-1} on a dry matter basis, and supplemented or not with mineral fertilizer (MF) at 0, 60, 120 and 180 kg P_2O_5-K_2O ha^{-1}. In 1997, P fertilizer was applied in subplots at 0, 100, 200 and 300 kg P_2O_5 ha^{-1}. Snap bean yield increased significantly with DSPC and MF application. Apparent P and K recoveries from MF by snap bean decreased with DSPC or MF rate. In combination with DSPC, P and K recoveries from MF by snap bean were smaller at all rates than those with no DSPC. Based on nutrient uptake, P and K in DSPC were more available than in MF. Potato yield in the following year was not significantly influenced by the previous treatments nor by supplemental P fertilizer added in the second year. This experiment indicates that compost derived from a mixture of deinking papermill sludges and poultry manure is a potential source of P and K for crops and will increase crop yields in the application year.

Introduction

Paper mills produce large quantities of residues which pose a serious disposal problem for the paper industry. Deinking sludge is derived from the newsprint recycling process. In the province of Québec, Canada, about 160,000 Mg yr^{-1} of deinking sludge and 475,000 Mg yr^{-1} of secondary sludge from the deinking and paper making processes are generated (Trépanier *et al.* 1996). Until recently, those residues were landfilled or burned. Although burning produces energy, more stringent regulations concerning atmospheric emissions increase cost (Cournoyer *et al.* 1997). Landfilling is expensive and is recognized as a waste of natural resources. It also generates greenhouse gases such as CH_4 and N_2O (Vinten *et al.* 1997).

Deinking sludges are composed of cellulose and lignin fibers, clay fillers and coating agents used in the papermaking processes (Bellamy *et al.* 1995, Norrie and Gosselin 1996). Deinking sludges easily meet the guidelines for land application in Québec (Ministère de l'Environnement et de la Faune du Québec 1997). Interest in the application of deinking paper to agricultural land is growing in Québec (Cournoyer *et al.* 1997), where loss of organic matter, structure and compaction are recognized degradation problems for horticultural soils (Tabi *et al.* 1990). The DSPC high C:N and C:P ratios, however, result in N and P immobilization by the microbial biomass and a subsequent nitrogen deficiency and depressed growth (Aitken *et al.* 1998; Simard *et al.* 1998a). Nitrogen immobilization may be reduced by using supplementary N fertilizer, a N_2-fixing plant, and/or a fallow period before planting a crop on the amended soil (Bellamy *et al.* 1995).

Composting deinking sludge could potentially reduce sludge C:N ratio, sludge volume and potential N immobilization in amended soils, thus producing a marketable material suitable for agricultural and horticultural uses. It also produces a material that does not have the bad odor characteristic of fresh residues. There is a large surplus of manure in many watersheds in the province of Quebec, Canada (Simard 1996). Manure, by providing N and P, can be combined with paper mill residues which act as a C source to produce composts with a more balanced composition (Stratton *et al.* 1995). Compost products are more stable or less biologically active, and generally have higher C:N and C:P ratios than manures and, therefore, may act as a slow-release source of N and P (Gagnon and Simard 1999). Presently, composting is used to manage 12% of all papermill biosolids in Québec (Désilets 2000). There is little information on compost made from deinking paper sludge mixed with manure (Simard *et al.* 2000). Cocomposting with P- and K-rich organic material such as poultry manure may be a way to produce compost of higher P and K contents than with other types of manure. While the effect of compost on soil N availability has been studied extensively, other nutrients such as P and K have received little attention. Gagnon and Simard (1999) observed that the P potential nutrient value of composts is dependent upon compost source materials and manure management, and should be based on their inorganic P content. Plant available K was positively affected by compost addition (Schlegel 1992; Warman 1995; Chen *et al.* 1996). Conversely, in his review, Barker (1997) concluded that compost could not be expected to be a good source of K for plant nutrition. Simard *et al.* (1998b) found no changes in P and K contents of cabbage heads grown in soil amended with compost of deinking paper sludge and cattle manure.

Nowadays, management plans for raw or composted organic material use are usually based on N availability (Lucero *et al.* 1995). Organic materials generally have a lower N:P ratio than crop plants, thus when composts are applied to meet crop N needs, more P is applied than is required by the plants, this may result in substantial increases in soil P and K (Robinson and Sharpley 1996; Mazzarino *et al.* 1998). Several reports indicate that P and K will be in excess for many forage and field crops when fresh or composted poultry manure is used to supply their N requirement (Edwards and Daniel 1992; Shepherd and Withers 1999; Warman and Cooper 2000). Simard *et al.* (2000) also indicated that composted deinking sludges increase the soil Mehlich-3 extractable P at potato harvest. The knowledge of P and K availability for compost is an important factor to evaluate if composting is a viable option for disposal of deinking paper sludge under the cool and humid conditions of eastern Canada. The objective of this study was to assess the impact of deinking paper sludge and poultry manure compost (hereafter referred to as DSPC) on P and K uptake and yield of snap bean (*Phaseolus vulgaris* L. cv. Centralia), and its residual P effect on potato (*Solanum tuberosum* L. cv. Gold Rush) yield.

Materials and Methods

The experiment was conducted in 1996 and 1997 at the Joseph Rhéaume experimental farm of Laval University located in Sainte-Croix de Lotbinière (46° 39' latitude north and 72° 06' longitude west), province of Québec, Canada. The soil is a Tilly loam (Gleyed Humo-Ferric Podzol) with a pH of 5.8 in 0.01 M $CaCl_2$ and contained 26.9 g kg^{-1} organic matter expressed on a dry weight basis. The two-years old compost (raw deinking paper sludge and poultry manure) was obtained from Les Composts du Québec Inc. (Québec, Canada).

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The treatments included three rates of DSPC (14, 28 and 42 Mg ha^{-1} on a dry matter basis) alone or in combination with mineral fertilizer (MF), three rates of MF (60, 120 and 180 kg P_2O_5- K_2O ha^{-1}), and an untreated control. The field plot design was a randomized complete block design with three replicates of 10 treatments. Experimental units (plots) were 7.5 m x 10 m. All treatments with MF received 45 kg N ha^{-1} as ammonium nitrate (Conseil des Productions Végétales du Québec 1996). The DSPC and MF were applied on 26 May 1996. The soil was tilled with a disk harrow to a depth of 10 cm after treatment application to incorporate the DSPC and MF. The plots were seeded with snap bean (*Phaseolus vulgaris* L. cv. Centralia) on 27 May 1996. Seeds were placed 4 cm deep at a seeding rate of 45 kg ha^{-1}. Each plot consisted of 10 rows, 70 cm apart, and each of 10 m in length. Weed, disease and insect control were applied as described in local crop growth guides (Conseil des Productions Végétales du Québec 1993, 1994). Bean pods were hand harvested on 19 September 1996, and grain yield was determined. Bean grains and stubble were collected for chemical analysis at harvest.

In May 1997, plots were divided into four subplots with an area of 3.66 m x 4.55 m. The main plots received 150 kg N ha^{-1} (ammonium nitrate), and 215 kg K_2O ha^{-1} (50% as K-Mg-sulfate and 50% as KCl), and subplots were four rates (0, 100, 200 and 300 kg P_2O_5 ha^{-1}) of P fertilizer as 0-46-0. The fertilizers were applied in two bands located 5 cm to each side of tubers. Potato (*Solanum tuberosum* L. cv. Gold Rush) tubers were hand planted in open furrows on 26 May 1997 at a spacing of 90 cm between rows and 35 cm within the row. Individual subplots consisted of four rows, with the middle two rows designated as harvest rows. Tubers were harvested on 20 September 1997, and total and marketable yields, and specific gravity of fresh tubers for each plot were recorded. Potato above-ground biomass at 10% flowering stage (mid-season) and tubers at harvest were taken for chemical analysis.

The N, P, K, Ca and Mg contents in plant tissues were determined following a wet digestion in H_2SO_4 and H_2O_2 whereas the content of other elements was determined after dry ashing at 450°C and recovery in 2 M HNO_3 (Richards 1993). The compost was characterized in triplicate as follows: dry matter content from weight loss by oven drying at 105°C, pH in 0.01 M $CaCl_2$ in 1:2 compost:solution ratio, total C by loss on ignition, total N by dry combustion (CNS-1000, LECO Corporation, St. Joseph, Michigan), total P, K, Ca and Mg by wet digestion in H_2SO_4-H_2O_2 , total Zn, Mn, Cu, Pb and Cd by dry ashing and recovery in 2 M HNO_3 (Richards 1993). Water-soluble elements were extracted in duplicate for 30 min in a 1:1 soil:water ratio followed by filtration through 0.2 m filter paper. The soil pH was measured in 0.01 M $CaCl_2$ (1:2 soil:solution), P, K, Ca, Mg and metals were extracted by the Mehlich-3 solution (Tran and Simard 1993). The P content in the extracts was determined by colorimetry (Hitachi U-1000, Tokyo, Japan) using the molybdate reaction (Murphy and Riley 1962) whereas the other elements were determined by flame (K) or atomic absorption spectroscopy (Perkin-Elmer 503, Überlingen, Germany). The NH_4^+ content in the extracts was determined by the colorimetric reaction with nitroprusside (Nkonge and Ballance 1982). The NO_3^- was measured by ion chromatography at 210 nm on a Dionex 4000i apparatus equipped with VDM- II UV-Vis and CDM-II conductivity detectors (Dionex Corporation, Sunnyvale, California). Water-soluble Cl^- and SO_4^{-2} contents were determined by ion chromatography/conductivity detection.

The agronomic use efficiency, in terms of yield produced per unit applied P or K for selected treatments, was calculated as the difference between yield from treatment and yield from untreated control divided by the total amount of nutrient applied. Total and grain nutrient uptake was obtained by multiplying dry matter yield by tissue nutrient content. Apparent recovery of total P and K from DSPC and MF was calculated as the increase in crop nutrient uptake over the untreated control, divided by the total amount of P or K applied as DSPC or MF. In addition, apparent recovery of applied fertilizer P or K by snap bean at various DSPC rates was calculated as the increase in P or K uptake over plots receiving only DSPC, divided by fertilizer P or K applied. Fertilizer P and K equivalencies of DSPC were calculated according to Sullivan *et al.* (1998).

Data transformation was carried out when needed to improve the normality of the distribution of studied variables. An analysis of variance for a randomized complete block design in 1996 and for split-plot in 1997 was used to test for significant differences among treatments, and means were compared using a Fisher's protected least-significant-difference (LSD) procedure. The standard error is presented as a measure of the variability of the data. All statistical analysis were performed with the SAS statistical package (Statistical Analysis System Institute 1990).

Results and Discussion

Compost Characteristics

The relevant characteristics of the DSPC used are given in Table 1. The DSPC had 643 g water kg^{-1} and was slightly alkaline (pH 7.6). Its C:N ratio was 32.2 which should normally result in soil N immobilization (Sullivan *et al.* 1998). Water-soluble mineral N (NO_3-N + NH_4-N) was only 17% of total N. The molybdate reactive water-soluble P was 250 mg kg^{-1} which represent 14% of total P. The DSPC had a C:P ratio of 259, suggesting a net immobilization of P shortly after addition to soils (Lindo *et al.* 1993; Barker 1997). The N:P ratio of DSPC was approximately 8:1. Considering the N:P uptake ratio of most crops which ranges from 4 to 8 (Mazzarino *et al.* 1998), the application of this material as the only plant nutrient source to meet the N requirement may not result in a soil P-buildup over time. The total K content was 910 mg kg^{-1}, 34% of which in water-soluble form. This compost contained significant amounts of Ca and Mg of which little was in water-soluble form. The contents of heavy metals were below that for the quality AA criteria for compost in Canada (Canadian Council of Ministers of the Environment 1997).

TABLE 1.
Chemical composition of DSPC and soil used

		DSPC		
Property	Units	Total	Water-Soluble	Soil[1]
Electrical conductivity	dS m^{-1}	5.9		
pH $CaCl_2$		7.6		5.7
Water	g kg^{-1}	643		
Organic matter	g kg^{-1}	785		26.9
Total N	g kg^{-1}	14.4		
C/N		32.2		
NO_3-N	mg kg^{-1}		1120	
NH_4-N	mg kg^{-1}		1290	
P	mg kg^{-1}	1790	250	39.1
K	mg kg^{-1}	910	310	91.3
Ca	mg kg^{-1}	6930	350	1283
Mg	mg kg^{-1}	280	40	68.4
Fe	mg kg^{-1}	621		
Mn	mg kg^{-1}	83		39.0
Zn	mg kg^{-1}	25		2.11
Cu	mg kg^{-1}	2.44		19.9
B	mg kg^{-1}	2.56		0.96
Cd	mg kg^{-1}	0.02		0.71
Co	mg kg^{-1}			0.61
Cr	mg kg^{-1}	0.23		0.97
Ni	mg kg^{-1}	0.13		1.18
Pb	mg kg^{-1}	0.2		2.83
Cl-	mg kg^{-1}		25.3	
SO_4^{2-}	mg kg^{-1}		14.3	

[1]pH in 0.01 M $CaCl_2$ and Mehlich-3 extractable elements for the 0-20 cm soil layer.

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Snap Bean Yields

The application of MF and DSPC significantly (P<0.05) increased grain bean yield compared with the untreated control (Figure 1). The increase in grain yield in the DSPC-amended soil over the untreated control ranged from 17 to 24%. On average, bean grain yields for the DSPC treatments were similar to those for MF treatments P>0.05). Ozores-Hampton and Bryan (1993) reported that municipal solid waste compost at 90 and 135 Mg ha^{-1} did not affect yield of snap bean seeded immediately after application. In that study, compost had lower P (0.09%) and Ca (0.26%) contents compared to compost used in the present study. In addition, the study of Ozores-Hampton and Bryan (1993) was carried out on a calcareous soil whereas the Tilly soil is acidic (pH = 5.8).

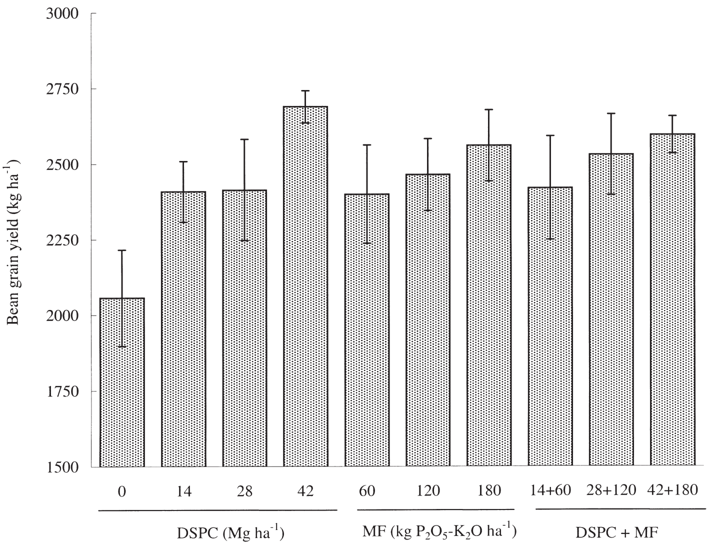

Figure 1. Snap bean yield in 1996 as influenced by DSPC and MF application.

The joint application of DSPC and MF did not result in a significant additional increase in grain bean yield compared to MF or DSPC alone. Robinson (1983) observed a synergistic effect of compost and inorganic N fertilizer on bean yield. A synergistic effect of deinking sludge compost and MF was reported for winter cabbage (*Brassica oleracea* var. Capitata L.) and potatoes (Simard *et al.* 1998b, 1999). The lack of a synergistic effect in our study indicates that DSPC provides for the immediate needs of bean crops like MF. The agronomic efficiency from DSPC, calculated in term of grain bean pro-

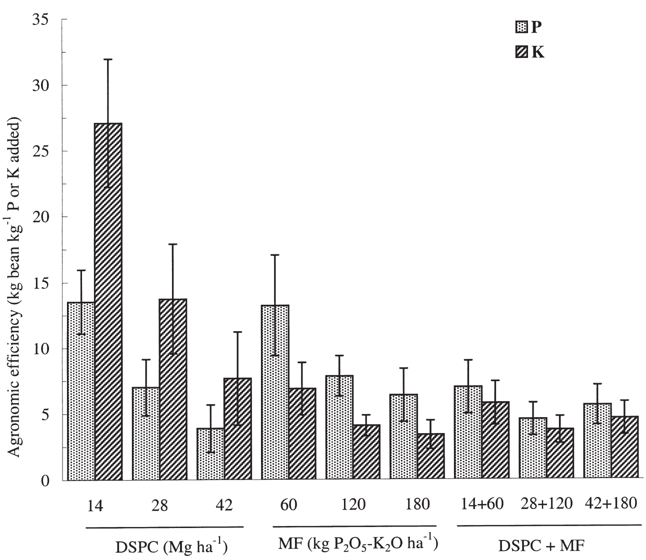

Figure 2. Agronomic efficiency of P and K from DSPC and MF by snap bean.

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duced per kg P added, was equal to that from MF (Figure 2). Based on K applied, the agronomic efficiency decreased with DSPC or MF rate, but was higher with DSPC than with MF. These results clearly demonstrate the availability of P and K from DSPC to snap bean or its positive effect on the availability of the soil pools of these elements.

Nutrient Uptake and Fertilizer Equivalency

The application of DSPC and MF at low and intermediate rates increased the P concentration of grain and stubble of snap bean (Table 2). Compared to the untreated control, however, this increase was not statistically significant. DSPC and MF treatments resulted in larger total P uptake than in the untreated control plots. However, P uptake was not significantly different among the DSPC rates, suggesting that enough P was available in the lowest DSPC rate treatment whereas additional P from higher rates was excessive. On average, DSPC treatments resulted in similar total P removal to those from MF treatments. The percentage of P from MF and DSPC recovered by snap bean was inversely related to the application rate, varying from 15 to 4.2 % for MF, and from 12.5 to 5.3 % for DPSC. In combination with DSPC, the apparent P recovery of applied fertilizer varied from 1.4 to -3.6 %, suggesting that P uptake from MF was not improved by DSPC addition. In a greenhouse study, Browaldh (1992) found that P use efficiency by snap bean was inversely related to the compost and chicken manure rates. The lower P use efficiency in manure- or compost-amended plots was generally attributed to the lower recovery of P from the organic P source and the larger amount of nutrients applied with it (Motavalli *et al.* 1989). The second hypothesis is highly probable in the present study. Gagnon and Simard (1999) indicated that the P potential value of compost was strongly related to their total P content. Another reason for this low P recovery may be the greater capacity of the compost-amended soil to provide large amounts of plant available P.

TABLE 2.
Effect of deinking sludge compost (DSPC) and mineral fertilizer (MF) on P content and uptake by snap bean

Treatment[1]		P content[2]		P uptake		Recovery[3]
DSPC ($Mg\ ha^{-1}$)	MF (P_2O_5-K_2O) ($Mg\ ha^{-1}$)	Grain	Stubble	Grain	Total	
		$g\ kg^{-1}$		$kg\ ha^{-1}$		(%)
0	0	5.73 a	0.88 a	11.9 b	13.1 b	
14	0	6.31 a	0.95 a	15.2 ab	16.3 ab	12.5
28	0	6.16 a	0.92 a	14.8 ab	16.7 a	7.0
42	0	5.71 a	1.01 a	13.3 ab	17.1 a	5.3
0	60	6.31 a	1.09 a	15.3 ab	17.0 a	15.0
0	120	6.05 a	1.05 a	14.9 ab	16.6 a	6.7
0	180	5.81 a	0.96 a	14.8 ab	16.4 ab	4.2
14	60	5.73 a	1.00 a	13.8 ab	15.4 ab	4.4 (-3.6)
28	120	6.19 a	1.04 a	15.7 a	17.5 a	4.2 (1.4)
42	180	5.60 a	0.87 a	16.6 a	16.1 ab	1.9 (-1.4)

[1]Treatments including MF received 45 kg N ha^{-1} as ammonium nitrate.
[2]Means within a column with the same letter are not significantly different at P = 0.05 according to LSD test.
[3]Numbers in parentheses are apparent recoveries of fertilizer P and K applied.

Apparent nutrient recovery can be used to roughly calculate the fertilizer equivalency assuming that nutrients from organic materials and MF have the same uptake efficiency by the crop (Motavalli *et al.* 1989; Cogger *et al.* 1999). In this study, it was not possible to establish a standard curve since fertilizer P uptake was the same over three

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inorganic P application rates. Furthermore, each increment of MF rate provided the same amount of P as each increment of DSPC. Therefore, fertilizer P equivalency of DSPC for snap bean was calculated as the ratio of apparent recovery of the DSPC to the apparent recovery of MF (Sullivan *et al.* 1998; Wen *et al.* 1997). From data in Table 2, fertilizer P equivalency of DSPC ranged from 83 to 126%. We found no reports concerning fertilizer equivalency of compost of deinking sludge and chicken manure. Nevertheless, fertilizer P equivalency in this study is in the range of that reported by Motavalli *et al.* (1989) for dairy manure for a corn crop, and are much higher than those in use in the local recommendation guide for chicken manure (Beaudet 1995).

TABLE 3.
Effect of deinking sludge compost (DSPC) and mineral fertilizer (MF) on K content and uptake by snap bean

Treatment[1]		K content[2]		K uptake		Recovery[3]
DSPC	MF (P_2O_5-K_2O)	Grain	Stubble	Grain	Total	
(Mg ha^{-1})	(Mg ha^{-1})	g kg^{-1}		kg ha^{-1}		(%)
0	0	15.1 a	15.7 abc	31.2 c	53.0 b	…
14	0	15.7 a	14.1 bc	37.8 abc	60.5 ab	57.5
28	0	15.6 a	16.4 ab	37.5 abc	63.9 ab	42.0
42	0	15.4 a	14.9 abc	36.2 bc	68.3 a	39.1
0	60	15.3 a	16.5 ab	36.9 bc	63.9 ab	21.9
0	120	15.4 a	13.5 bc	37.9 abc	60.0 ab	7.0
0	180	15.2 a	13.0 c	38.9 ab	61.3 ab	5.5
14	60	15.4 a	14.5 bc	37.2 bc	61.0 ab	12.8 (1.1)
28	120	15.7 a	14.2 bc	39.7 ab	63.7 ab	8.5 (-0.2)
42	180	15.4 a	18.0 a	44.9 a	71.1 a	9.6 (1.9)

[1]Treatments including MF received 45 kg N ha^{-1} as ammonium nitrate.
[2]Means within a column with the same letter are not significantly different at P = 0.05 according to LSD test.
[3]Numbers in parentheses are apparent recoveries of fertilizer P and K applied.

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Grain K concentration was not affected by DSPC and MF application (Table 3). Addition of 42 Mg DSPC ha^{-1} alone or combined with MF significantly increased the total K uptake as compared with the untreated control. On average, there was no significant difference between inorganic K fertilizer and DSPC in K uptake (P>0.05). The K uptake was slightly increased by the combination of DSPC and MF as compared with each K source alone. Apparent K recovery decreased with increasing DSPC or MF rates. The mean K recovery was 46% (range 57.5-39.1%) for DSPC and 11.5% for MF (range 5.5-21.9%). In combination with DSPC, the apparent recovery of applied inorganic K varied from 1.9 to -0.2%. These results agree with those of Browaldh (1992) who obtained an increase in K uptake by snap bean from compost and chicken manure, and a decrease of K use efficiency with application rate. Similarly to P, the low values of K use efficiency suggest that amounts of K applied through DSPC and MF were largely in excess to plant needs. Using the same approach as for P, the fertilizer K equivalency calculation indicated that K in DSPC was 1.8 to 2.6 times more available than K in fertilizer. These high values may be related to lower amounts of K applied with DSPC as compared to MF. These results agree with those of Wen *et al.* (1997) who found that the K applied with sewage sludge, and sludge and manure compost to snap bean was equally as available as K fertilizer.

Although snap bean is a N_2-fixing crop, addition of DSPC at the 42 Mg ha^{-1} rate slightly increased the N concentration of grain and stubble of snap bean (Table 4). Grain N concentration was significantly increased by joint application of DSPC at 14 Mg ha^{-1} and MF. Nitrogen removal was increased significantly with an application of 42 Mg DSPC ha^{-1}

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TABLE 4.
Effect of deinking sludge compost (DSPC) and mineral fertilizer (MF) on N content and uptake by snap bean

Treatment[1] DSPC ($Mg\ ha^{-1}$)	MF (P_2O_5-K_2O) ($Mg\ ha^{-1}$)	N content[2] Grain ($g\ kg^{-1}$)	Stubble	N uptake Grain ($kg\ ha^{-1}$)	Total
0	0	35.3 b[1]	3.51 ab[1]	71.5 c	76.2 c
14	0	36.2 b	3.52 ab	87.1 abc	86.1 bc
28	0	33.5 b	3.37 ab	80.2 bc	93.4 abc
42	0	37.8 ab	3.90 ab	89.0 abc	108.9 a
0	60	37.6 ab	3.52 ab	90.6 ab	96.1 abc
0	120	37.4 ab	3.68 ab	91.4 ab	97.6 ab
0	180	35.6 b	2.53 b	90.8 ab	95.2 abc
14	60	41.6 a	4.05 ab	100.1 a	106.7 ab
28	120	35.3 b	3.41 ab	89.0 abc	94.7 abc
42	180	34.0 b	4.81 a	98.6 ab	96.3 abc

[1]Treatments including MF received 45 kg N ha^{-1} as ammonium nitrate.
[2]Means within a column with the same letter are not significantly different at P = 0.05 according to LSD test

TABLE 5.
Snap bean Ca, Mg, Mn, Zn, Pb, Cd, Cr, Co and Ni contents as influenced by DSPC and MF

Treatment DSPC ($Mg\ ha^{-1}$)	MF (P_2O_5-K_2O) ($kg\ ha^{-1}$)	Ca ($g\ kg^{-1}$)	Mg	Mn ($mg\ kg^{-1}$)	Zn	Pb	Cd	Cr	Ni	Co
		Grain								
0	0	2.50 a	1.64 a	14.8 b	27.3 a	2.41 a	1.90 a	2.73 a	5.96 abc	1.38 ab
14	0	1.49 a	1.58 a	15.5 ab	25.2 a	2.34 a	1.86 ab	2.40 a	5.93 abc	1.15 b
28	0	1.45 a	1.55 a	16.5 ab	26.0 a	2.32 a	1.82 ab	1.77 a	5.68 bc	1.16 b
42	0	1.85 a	1.61 a	15.8 ab	25.9 a	2.45 a	1.81 ab	2.00 a	4.34 c	1.25 ab
0	60	1.74 a	1.59 a	18.4 a	25.2 a	2.32 a	1.76 ab	2.61 a	7.24 ab	1.35 ab
0	120	1.69 a	1.56 a	17.4 ab	27.5 a	2.25 a	1.86 ab	2.60 a	8.31 a	1.33 ab
0	180	2.57 a	1.61 a	17.7 ab	27.1 a	2.35 a	1.88 ab	2.58 a	7.89 ab	1.37 ab
14	60	1.83 a	1.59 a	16.7 ab	26.5 a	2.30 a	1.86 ab	2.39 a	7.50 ab	1.46 a
28	120	1.62 a	1.52 a	17.4 ab	24.8 a	2.22 a	1.79 ab	1.73 a	6.58 abc	1.21 b
42	180	1.93 a	1.45 a	17.1 ab	26.3 a	2.26 a	1.72 b	1.82 a	6.19 abc	1.17 b
		Stubble								
0	0	13.0 bc	2.63 ab	28.1 c	14.7 c	2.99 a	1.14 ab	1.62 a	0.73 a	0.92 ab
14	0	12.5 bc	2.40 bc	28.4 c	17.3 abc	2.89 a	1.09 b	1.61 a	0.44 a	0.73 ab
28	0	13.7 bc	2.52 ab	33.2 bc	18.5 abc	2.57 a	1.05 b	1.65 a	0.69 a	0.56 b
42	0	11.5 c	2.20 bc	28.9 c	16.6 bc	2.88 a	1.13 ab	1.72 a	0.64 a	0.93 ab
0	60	17.6 a	2.97 a	32.3 bc	19.5 ab	2.95 a	1.07 b	1.73 a	1.04 a	0.973 a
0	120	11.1 c	2.22 bc	30.0 c	16.3 bc	2.86 a	1.12 ab	1.60 a	0.67 a	0.64 ab
0	180	12.5 bc	2.00 c	33.3 bc	16.2 bc	2.80 a	1.16 ab	1.78 a	0.65 a	0.94 ab
14	60	15.3 ab	2.41 bc	36.1 abc	17.9 abc	2.98 a	1.25 a	1.74 a	0.60 a	0.64 ab
28	120	11.1 c	2.04 c	42.2 abc	19.8 ab	2.74 a	1.05b	1.46 a	0.94 a	0.63 ab
42	180	11.8 c	2.28 bc	45.2 a	21.4 a	2.73 a	1.17 ab	1.61 a	0.45 a	0.71 ab

[1]Means within a column with the same letter are not significantly different at P = 0.05 according to LSD test.

compared to the untreated control. Improved uptake of N by snap bean in soil amended with compost has been reported (Browaldh 1992). In that study, the increase in N uptake induced by compost was due to the stimulating effect of compost on root development in the early stages and nodulation by the higher amounts of nutrient contained in the compost. In addition, DSPC was very high in K and may have enabled the bean plants to utilize the soil N more efficiently. However, care should be taken to apply the right amount, because high soil available N levels reduce the potential of legumes for N fixation (Bowren *et al.* 1995). We did not attempt to calculate apparent N recovery by snap bean because the relative contribution of symbiotic fixation is unknown.

Though Ca and Mg concentrations tended to be lower for the highest rates of DSPC and MF, there was no significant difference between untreated control and DSPC or MF treatments (Table 5). The joint application of DSPC and MF increased significantly Mn and Zn contents of stubble. Compared with untreated control, Pb, Cd, Cr and Ni concentrations in bean tissues were not affected by DSPC treatments. However, Cd contents of grain bean tend to decrease with DSPC rate, with a significant decrease for Cd in plots that received 45 Mg DSPC ha^{-1} combined with MF. Bean grain Ni content was increased by MF while the opposite effect was observed in plots that received DSPC. The decreased concentration of plant Cd and Ni may be due to the added organic matter through DSPC addition. An increased adsorption of Cd by the soil solid phase with increasing organic matter has been reported (He and Singh 1993).

Residual P Effect

No significant interaction was found between treatments applied in the previous year and in the second year P rates for foliar N and P contents of potato (Table 6). Foliar P content increased linearly ($P<0.05$) with second year P rates in mid-season (Figure 3). There was a significant interaction ($P<0.01$) between 1996 treatments and P rates for foliar K concentration in the early growing season (Table 6). Except for untreated control and DSPC combined with MF treatments, the foliar K concentration decreased linearly ($P<0.01$) with increasing P rates (Table 7). Marschner (1986) indicated that accumulation of P in the soil may induce deficiencies of the other nutrients. Potato yields were not significantly ($P>0.05$) affected by the 1996 treatments nor by the P fertilizer applied in spring 1997 (Tables 6). The average yield obtained with the control treatment (53 Mg ha^{-1}) was much greater than the provincial average for 1997 (23 Mg ha^{-1}). Potato tuber specific gravity was increased linearly ($P<0.05$) by P fertilizer applied in spring 1997, whereas previous treatment had no significant effect (Table 6). The lack

TABLE 6.
Analysis of variance (mean squares) of treatment effects on foliar P, K and N contents, yields of potato and tuber specific gravity in 1997

Source Of Variation	P		K		N		Yield		Specific Gravity
	Mid-Season	Harvest	Mid-Season	Harvest	Mid-Season	Harvest	Total	Marketable	($x10^{-6}$)
Previous treatments (T)	0.977	0.123	1434	371*	67	17.1	51.7	46.8	6.51
Error a	0.462	0.065	110	117	34.9	16.3	29.7	28.8	11.82
P_2O_5	0.342	0.042	623 ***	48	2.4	7.5	23.64	20.8	13.23
T * P_2O_5	0.146	0.055	72 **	32	41.6	17.9	17.4	16.9	5.00
Error b	0.156	0.035	32	42	41.6	11.1	17.0	17.5	6.14
CV (%)	12	12	13	16	11	15	7	8	0.23
Contrasts									
P_2O_5, linear	0.964 *	0.005	1787 ***	126	0.11	17.67	9.12	5.09	36.41*
P_2O_5, quadratic	0.002	0.009	4.7	11	1.65	2.51	7.77	6.69	0.83

*, **, *** significant at P=0.05, 0.01 and 0.001, respectively

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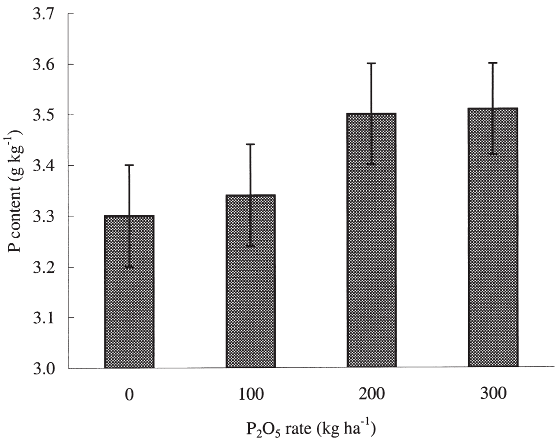

Figure 3. Foliar P contents of potato at 10% flowering stage as influenced by P fertilizer applied in spring 1997.

TABLE 7
Effect of previous treatments and fertilizer P on foliar K content of potato in mid-season

Previous Treatment DSPC ($Mg\ ha^{-1}$)	MF (P_2O_5-K_2O) ($kg\ ha^{-1}$)	P_2O_5 rates ($kg\ ha^{-1}$)[1] 0	100	200	300	P effect[2]
		$g\ kg^{-1}$				
0	0	41.5 a	38.5 c	43.4 b	35.4 a	NS
14	0	51.8 a	51.6 abc	45.0 b	41.3 a	L*
28	0	48.6 a	45.2 abc	42.0 b	40.3 a	L*
42	0	53.2 a	47.8 abc	41.5 b	41.4 a	L**
0	60	49.3 a	50.7 abc	38.9 b	39.7 a	L**
0	120	59.2 a	61.3 abc	36.6 b	36.5 a	L*
0	180	41.6 a	42.8 bc	38.6 b	37.7 a	L*
14	60	43.1 a	43.7 abc	37.1 b	37.9 a	NS
28	120	47.4 a	57.6 abc	58.4 a	41.3 a	NS
42	180	56.3 a	42.0 bc	41.6 b	44.7 a	NS

[1]Means within a column with the same letter are not significantly different at P = 0.05 according to LSD test.
[2]NS, Not significant; *, **significant at P=0.05 and 0.01, respectively; L, linear.

of any significant effect of second year fertilizer P on potato tuber yields is surprising since this soil was low in available P (Conseil des Productions Végétales du Québec 1996). These results corroborate those of Samson (1998), who showed that potato did not respond to fertilizer P on the same soil series with a low soil test P. Simard *et al.* (1991) reported that Mehlich-3 method underestimated the corn and barley available P content for the fine-textured soils.

Summary

The results of this study showed that snap bean yield increased significantly with DSPC and MF application. Snap bean yields produced with DSPC were similar to those produced with MF. Tissue concentrations of P, K and other elements suggest that DSPC may be a sufficient and a balanced source of nutrients for plant growth on the studied soil. Apparent P and K recoveries decreased with increasing DSPC and MF rates. In combination with DSPC, fertilizer P and K use efficiency coefficients by snap bean were lower than those with no DSPC. The fertilizer P and K equivalent values indicate the potential of DSPC to maintain a sufficient supply of nutrients. The yield of potatoes in the following year was not significantly influenced by the previous treatments nor by supplemental P fertilizer added in the second year. Co-composting deinking sludges with poultry manure can produce compost with sufficient amount of available P and K to sustain growth of horticultural crops. This suggest that composting may be considered as a viable approach for recycling deinking paper mill sludges.

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