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PERFORMANCE AND TRACE METAL CONTENT OF CRAMBE AND KENAF GROWN ON SEWAGE SLUDGE-TREATED STRIPMINE LAND

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ABSTRACT

Crambe Crambe abyssinica *and kenaf* Hibiscus cannabinus *were grown for 3 years on stripmine land in three replications of the four treatments: control (no soil amendment); added commercial fertiliser; and two levels of digested sewage sludge (42% solids at the rate of 112 and 224 metric tons ha^{-1}). Favourable growth responses to sludge and commercial fertiliser were observed with both crops, although performance of crambe on the sludge-treated plots was adversely affected by weed competition. The yield of kenaf increased with sludge amendment of the soil. Concentrations of eight metals (Fe, Zn, Mn, Cu, Pb, Cr, Cd, and Hg) in crambe seed were unaffected by plot treatment, but kenaf stems appeared to accumulate higher metal concentrations with soil amendment by sewage sludge. Neither crambe seed nor kenaf stalks accumulated unusual quantities of these metals, and thus neither crop would be expected to remove significant quantities of metals from soils. Metal concentrations of both soil and sludge samples were determined to evaluate translocation of metals to both crops.*

INTRODUCTION

Crambe *Crambe abyssinica* Hochst ex R. E. Fries and kenaf *Hibiscus cannabinus* are two potential industrial crops studied extensively by the US Department of Agriculture. Kenaf's value as a source of fibre for newsprint and other types of paper is well documented (Bagby, 1977; Cunningham *et al.*, 1979). Crambe oil can be a domestic replacement for imported high-erucic acid rapeseed oil. The erucic acid in

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these oils is the raw material for production of erucamide, an antiblock slip-promoting additive in polyolefin films (Molnar, 1974), and for other prospective chemicals and products (Nieschlag & Wolff, 1971; Carlson *et al.*, 1977; Nieschlag *et al.*, 1977). Production of either crop on stripmine lands would not disturb the area under current food production, and the probable lower land costs would favourably affect the economics of producing the two experimental crops. Since neither crop would directly involve the food chain, they are attractive prospects for utilising sewage sludge as a fertiliser on stripmine soils. However, information about translocation of metals from sludge and soil into the useful parts of these plants is important because products made from kenaf fibres (paper) or crambe oil (plastic films) could conceivably come in contact with food (e.g., food wraps), and defatted crambe seed meal could enter feed rations as a protein supplement (Perry *et al.*, 1979). Also, total harvest of kenaf (stalks and roots) would mean that all metals accumulated by the plant would be removed from the field to the pulping facilities and might then be distributed in fibre products or be discharged in wastes into streams or groundwaters. Crambe, by contrast, would be harvested only for its seeds, with about half the mature plant weight being returned to the soil with each crop. Thus, only those quantities of metals present in the seed would leave the sludge disposal site.

Our studies on growing crambe and kenaf on sewage sludge-treated stripmine land were initiated to examine translocation of heavy metals from amended soil into the useful plant parts, and to evaluate the potential of sewage sludge as a fertiliser for these two crops. We report here the results of preliminary studies carried out in cooperation with the Greater Peoria Sanitary District, who provided sewage sludge, and Midland Coal Company, who provided stripmine land, personnel, and equipment to prepare and seed the plots.

MATERIALS AND METHODS

Description of plot areas

Experimental crambe and kenaf plots were established on land stripped of its coal reserves and levelled in anticipation of further reclamation activities. The original plots (1975) provided meaningful qualitative results, but physical aspects of their location proved to be unsatisfactory; therefore, new plots were established in 1976 and used in 1977. A variable depth of B-horizon soil (clay) had been spread over the mine spoils at the second site, and some rocks, shale, and coal debris were in evidence. Soil drainage was adequate, but thin crusting occurred during protracted dry periods after heavy rains. Plot dimensions were 7·6 × 30·5 m, totalling 0·6 ha for the two crops. Trenches, 46 cm deep × 61 cm wide, were cut between adjoining plots to prevent cross drainage. Soil samples (0–15 cm) were taken from the centre of each crambe plot in May 1976 (pre-treatment sample) and again in July 1977 after

two crop seasons of designated treatment (final sample). The latter samples, collected from around the roots of harvested crambe plants, are thus characteristic of the root environment. Soil composites representing each treatment were prepared by combining equal portions (300 g) of well-mixed, air-dried soil from each of the three appropriate plot replicates. A portion of each composited soil sample was then dried (2 h, 130 °C) and finally 100 g was ground (c. 100 mesh) with a mortar and pestle before being subjected to trace metal analyses. All other soil analyses were made on the air-dried treatment composites.

Experimental design and plot treatment

The randomized complete block design utilized twelve plots each for crambe and kenaf, representing three replications of four treatments. The four treatments may be briefly summarized:

- C Control: Soil without specific amendment,
- CF Commercial fertiliser amendment: N:P:K applied at a rate of 112:67:67 kg ha^{-1} as a 'positive control',
- S_1 Low level sludge amendment: 112 metric t ha^{-1} of anaerobically digested sewage sludge, 42 % solids as applied (47 metric t ha^{-1} dry basis),
- S_2 High level sludge amendment: 224 metric t ha^{-1} of anaerobically digested sewage sludge, 42 % solids as applied (94 metric t ha^{-1} dry basis).

Sludge was applied to the S_1 and S_2 plots with a manure spreader. Annually all plots received a dressing of potassium chloride at the rate of 112 kg ha^{-1}. All plots were thoroughly disced and harrowed at appropriate points in the plot preparation work. Kenaf (1976, 1977) and crambe (1976) plots were treated with Treflan (trifluralin, Elanco Div., Eli Lilly & Co.) at the rate of 1·1 kg ha^{-1} prior to planting. In 1977, crambe plots were treated with a 5·6 kg ha^{-1} combination of Dacthal (DCPA, Diamond Shamrock Corp., 3·4 kg ha^{-1}) and Ramrod [Propachlor, Monsanto Co., 2·2 kg ha^{-1}].

Planting dates were 6 May 1975; 28 May 1976; and 25 April (crambe) and 4 May (kenaf) 1977. Planting depth was 1·3 cm and row width was 53 cm each year (except crambe in 18 cm rows in 1977). The seeding rate for each crop was eight to twelve seeds per 30·5 cm or 11–18 kg ha^{-1}. Crambe seed was treated with Maneb Fungicide (Black Leaf Products Co.) (0·3 %, by weight) before the 1977 planting to help control *Alternaria* infections (Mills & Wallace, 1972; Leppik & White, 1975; Kilpatrick, 1976).

Harvest procedures

Severe *Alternaria* infection led to a very poor quality crambe seed (many empty pods and shrivelled seed) in both 1975 and 1976, and no harvest was made either year. In 1977, twenty whole, mature crambe plants were harvested on day 89 by selecting four sets of five plants each from the central area (4·6 × 18·3 m) of each

plot. Roots were clipped from the plants at soil level and, except for one set (five plants), were discarded. Above-ground parts of the plants were sealed as sets in double-wall paper bags (31 × 80 × 18 cm). The roots from the one set of five plants, together with the surrounding soil, were sealed in 20 × 20 cm plastic bags for later analyses. Seeds and stem material were separated, and their weights were recorded. Roots were carefully washed to remove soil, oven dried (130 °C, 5 h), and weighed. Plot composites (twelve) were prepared by combining one-half the harvested weight (seeds or stems) from each subplot. Treatment composites (four) were prepared by mixing equal weights (seeds or stems) from the three appropriate plot composites.

Kenaf was harvested in 1976 and 1977 1 month after the first killing frost. Three 5 row × 3 m areas, representing about 10 % of the plot area, were harvested from each plot by cutting the naturally defoliated kenaf stalks at ground level. Any remaining leaves were removed before further sampling. Plant material from each subplot was weighed before representative stalks were sectioned (c. 15–30 cm) and dried at 105 °C to constant weight for dry matter yield determinations. For metal analyses, sections (c. 5 cm) were taken from the lower, middle, and upper regions of representative stalks.

Analytical procedures

Moisture, oil, and protein contents of crambe seed were determined by standard techniques (AOCS, 1970). Oil was extracted from ground whole seed with petroleum ether. Protein content was determined on the defatted seed meal (Kjeldahl N × 6·25). Erucic acid content of the seed oil was estimated by gas chromatography of the fatty acid methyl esters prepared from the oil by treatment with BF_3/MeOH solution (Kleiman *et al.*, 1969). Glucosinolate content of the defatted seed meal was determined by measuring glucose released by thioglucosidase hydrolysis (Van Etten *et al.*, 1974).

Air-dried, whole crambe seeds and chopped kenaf stalks (10 g) were wet-ashed as described previously for maize grain and maize cobs husks, respectively, before being analysed by atomic absorption (AA) techniques for Zn, Cu, Pb, Cd, Hg, Fe, Mn, and Cr (Garcia *et al.*, 1974*a*, *b*). All crambe seed replicates were subjected to metal analyses, but kenaf stalk replicates were combined into the four appropriate treatment composites, which were then analysed. Background correction for Cd and Pb determinations were made using a hydrogen continuum lamp. Separate 10 g samples (seeds or stalks) were used for the Hg analyses by a non-flame technique. Because of the high oil content of crambe seeds, a comparison with the wet-ash procedure was made with one sample of crambe seeds that was carefully dry-ashed in a platinum dish at 500 °C by alternate heating and dissolution of the residue until complete ashing of organic matter was achieved. Subsequent analyses by AA ($\mu g\,g^{-1}$) for Zn (41·0), Mn (21·6), Pb (0·604), Cd (0·249) and Cu (4·69) were generally lower than results on the corresponding wet-ashed sample (47·2, 26·8, 0·821, 0·314 and 4·45, respectively), suggesting that metal recoveries were better in the wet-ash procedure.

Metal concentrations of soil were determined with a Perkin-Elmer Model 306 AA instrument (ACA 2100 Heated Graphite Furnace, deuterium arc background correction) after digesting 1·0 g of soil with the following acid sequence: HCl, HNO_3, $HClO_4$, HCl/HF and HCl (modified procedure of Pawluk, 1967). Flameless AA analyses for Hg were obtained on separate 1·0 g soil samples after HNO_3 digestion followed by $SnSO_4$ reduction of Hg to the elemental state (modified procedure of Hatch & Ott, 1968).

Sludge analyses were provided by the Greater Peoria Sanitary District, except for metal analyses for sludge beds 1 and 4 (Table 1, 1976 experiment), which were determined according to Garcia *et al.* (1974*b*). Except for Hg (mean and standard deviation for three 0·5 g samples), these metal values are the means and standard deviations for three different sample sizes—0·4, 0·8 and 1·2 g of sludge—run to show that precision is not sacrificed even with smaller, more manageable, sample sizes.

TABLE 1
CHARACTERISTICS OF SEWAGE SLUDGE FROM THE GREATER PEORIA SANITARY DISTRICT

Sample date	*15 December 1975*	*15 December 1975*	*28 December 1976*	*6 January 1977*
Experiment year	*1976*		*1977*	
Lagoon (L) or Bed (B) no.	*B1*[a]	*B4*	*L5*	*L4*[a]
pH, 10% slurry	—	—	7·2	6·8
Total solids, %	42·9	—	35·1	41·0
Volatile solids, %	29·4	—	22·7	29·8
Nitrogen, %[b]	1·40	1·98	2·0	2·0
Phosphorus (P_2O_5), %[b]	2·43	0·75	1·9	1·2
Potassium (K_2O), %[b]	0·04	0·03	<0·1	<0·1
Metal content, $\mu g\ g^{-1}$[b,c]				
Cd	28·3 (1·2)	39·3 (2·0)	5·1	15·4
Cr	460 (59)	59·4 (3)	—	—
Cu	1021 (17)	1221 (31)	1293	1223
Fe	14936 (479)	10659 (658)	—	—
Pb	728 (20)	812 (25)	410	556
Mn	480 (38)	327 (17)	—	—
Hg	28·3 (0·5)	22·8 (0·8)	—	—
Zn	2232 (88)	2468 (90)	2066	2362

[a] Source of sludge for plots.
[b] Dry-weight basis.
[c] For sludges B1 and B4, metal values are the mean (SD) of three analyses (0·4-, 0·8- and 1·2 g samples); for Hg the value is the mean (SD) for three 0·5 g samples of sludge.

RESULTS AND DISCUSSION

The overall performance of crambe and kenaf of the stripmine plots was less than desired in terms of germination, plant density, and yields, partly because of adverse weather conditions. In 1975, extensive cross-plot drainage after rains, unexpected incursion of willow saplings into the plot area and the presence of numerous localised areas of residual mine gob in many plots (resulting in poor plant growth) led us to abandon the original plot site. New plots, established at another site in

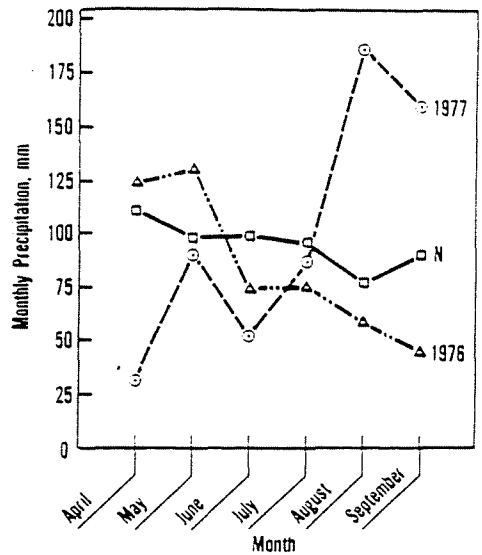
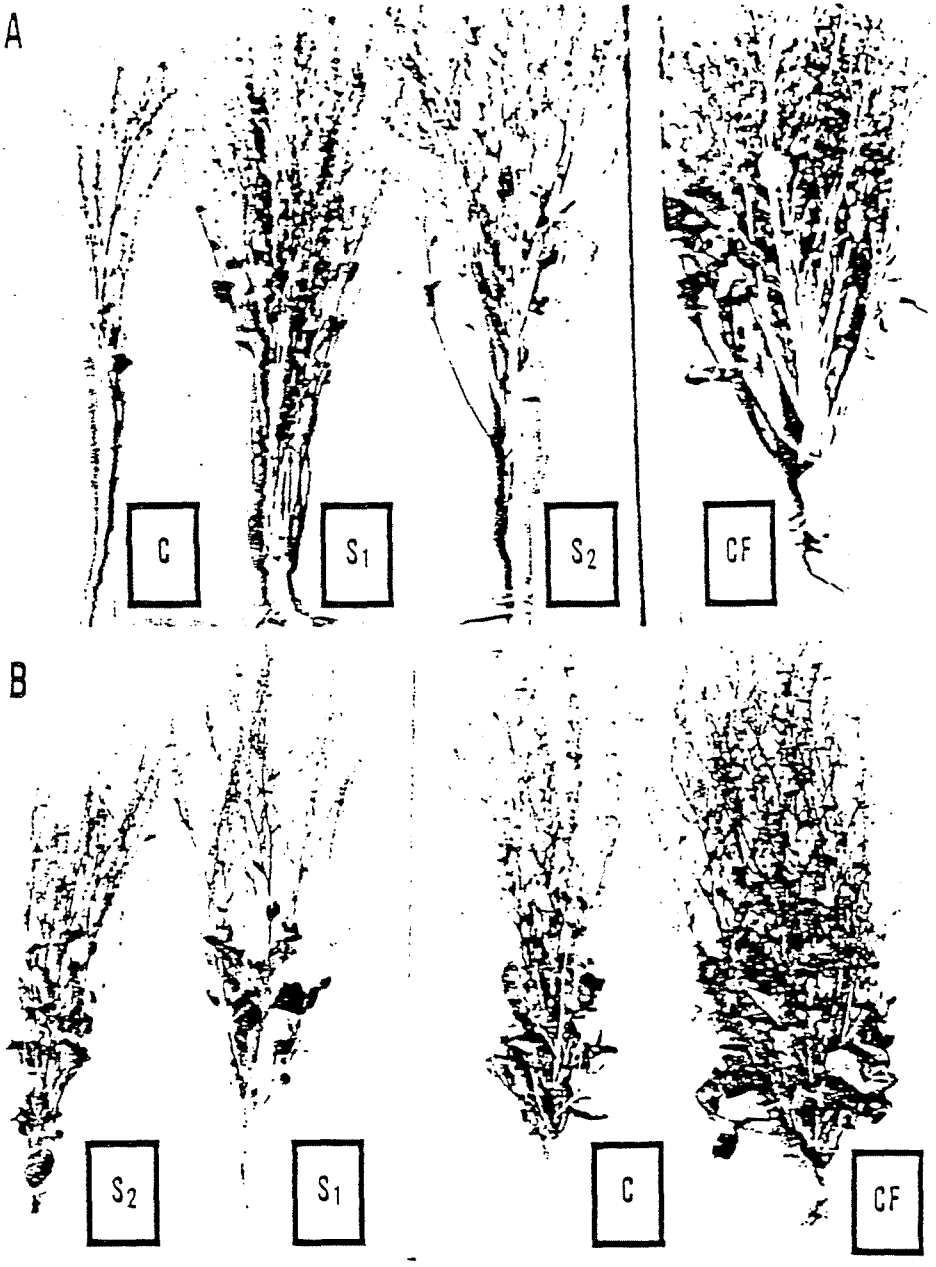


Fig. 1. Monthly precipitation for April to September of 1976 and 1977 (Peoria, Illinois). N, normal. (Data from the National Weather Service Office, National Oceanic and Atmospheric Administration, US Department of Commerce, Greater Peoria Airport.)

1976, were free of these previous difficulties, but crop performance on these plots was affected by a late planting date in 1976 and by much below normal precipitation (Fig. 1) during the critical early growth periods in both 1976 and 1977. *Alternaria* infection in the crambe produced many empty seed pods in both 1975 and 1976 and prevented harvest of useful plant material either year. Also, severe weed competition plagued the sludge-treated crambe plots, particularly in 1977 when plant density was low due to very hot, dry weather. In our experiments the sludge appeared to promote weed growth (Berry, 1977; Berry & Marx, 1977) and/or was a good source of weed seeds. Indeed, sludge-treated plots could be visually distinguished from other plots both by type and quantity of weeds. In spite of these difficulties, meaningful analyses of plant material were obtained from two harvests of kenaf (1976, 1977) and one harvest of crambe (1977). Both crops responded positively to the sludge and fertiliser treatments—kenaf in all 3 years and crambe in 1975 and 1976. For example, in 1975 crambe plants increased in number, height, and fullness in the treatment order $C < S_1 < S_2 < CF$, as illustrated in Fig. 2A. This visual ranking was also observed in 1976 but not so dramatically, because control plants performed better on the soil of the new plots whereas performance of sludge-treated crambe plants was undoubtedly affected by serious weed competition. The severity of the weed problem was so great in 1977 on sludge-treated plots that these plants were typically smaller and less branched than the control plot plants (Fig. 2B: $S_1 \sim S_2 < C < CF$). Past experience shows that a dense stand of crambe, irrespective of herbicide treatments, is effective against weeds under normal crambe cultivation



g. 2. Typical crambe plants at full bloom from sludge (S_1 and S_2), commercial fertiliser (CF), and control (C) plots. (A) Plants from 1975 plots. (B) Plants from 1977 plots.

(Papathanasiou & Lessman, 1966; Christmas *et al.*, 1968). In contrast to crambe, the taller kenaf plants with dense summer foliage were able to compete more successfully with the weeds even on the sludge-treated plots.

Yields of kenaf stalks (kg ha^{-1}, dry basis) harvested in 1976 and 1977 were determined for each replicate, and treatment means were then determined for each year and for the 2 year period (Table 2). The sludge treatments were beneficial in both years compared with the C (1976) and CF treatments (1977). Yield differences between treatment means by years (1976 vs 1977) were not significant. The 2 year mean yield of the C plots is significantly lower ($p < 0{\cdot}10$) than the yields of the S_1 or S_2 plots. The apparent yield trend ($C < CF < S_2$ and S_1) is consistent with the visual observations, such as stalk height, made over the 2 years.

TABLE 2
YIELDS OF CRAMBE AND KENAF ON STRIPMINE PLOTS WITH AND WITHOUT SEWAGE SLUDGE

	Crambe, 1977, g per plant[a]				*Kenaf stalks, dry basis, kg ha^{-1}*[b]			
Treatment[c]	*Root wt (dry basis)*	*Plant wt*[d] *(air-dry)*	*Seed wt (air-dry)*	*Seed by wt, %*	*Treatment*[c]	*1976 mean*	*1977 mean*	*2-Year mean*
S_2	0·84	16·47	8·61	52·13	C	2981	3313	3147
S_1	0·96	15·81	7·91	49·84	CF	4202	2571	3387
C	1·27	22·50	11·25	49·94	S_1	4555	4842	4698
CF	1·70	37·07	17·74	47·82	S_2	4999	4047	4523
	LSD = 0·49 ($p < 0{\cdot}05$)	LSD = 7·56 ($p < 0{\cdot}01$)	LSD = 4·04 ($p < 0{\cdot}01$)	LSD = 2·72 ($p < 0{\cdot}05$)		LSD = 1342 ($p > 0{\cdot}05 < 0{\cdot}10$)		

[a] Each value is the mean of data from three plot replicates: twenty plants per plot, sixty plants per treatment (except roots, five plants per plot and fifteen plants per treatment). LSD = least significant difference.
[b] Each value is the mean of data from three plot replicates; three subplots per plot were harvested (c. 10% of plot area).
[c] See text for description of control (C), commercial fertiliser (CF), and sludge (S_1 and S_2) treatments.
[d] Above-ground parts (stems and seeds).

Trace metal analyses on kenaf stalks are shown in Table 3. Metal concentrations in kenaf stalks decreased in the order Zn ~ Fe > Cu ~ Mn > Pb ~ Cd ~ Cr ≫ Hg, and do not appear unusual for this type of plant material (Kirkham, 1977). Copper, Mn, Fe and Zn concentrations were in the range of 5–100 μg g^{-1}, whereas Cr, Pb and Cd were present at less than 1 μg g^{-1} and Hg was under 10 ng g^{-1} of stalk. Kenaf stalk tissues appear to concentrate more of these metals than do edible onion, radish, and tomato tissues, but kenaf stalks accumulate similar quantities of Zn and Cd and lower concentrations of Pb and Hg than do more comparable tissues, such as vegetative parts of wheat and field maize, when grown under similar conditions of soil metal concentrations and pH (Garcia *et al.*, 1981).

In 1976, metal concentrations in stalks from all soil-amended treatments were elevated relative to control (C) stalks. Even stalks from the CF plots (positive control) had higher concentrations of Zn, Cu, Pb, Cd and Hg than the control stalks. Stalks from the high sludge (S_2) plots contained the highest levels of Zn, Cu

TABLE 3

METAL CONTENT OF KENAF STALKS GROWN ON STRIPMINE PLOTS, $\mu g\ g^{-1}$ (DRY WEIGHT)

Treatment[a]	*Zinc*			*Copper*			*Lead*			*Cadmium*			*Mercury*			*Iron*[c]	*Manganese*[c]	*Chromium*[c]
	1976	*1977*	*Ratio 1977/1976*	*1976*	*1977*	*Ratio 1977/1976*	*1976*	*1977*	*Ratio 1977/1976*	*1976*	*1977*	*Ratio 1977/1976*	*1976*	*1977*	*Ratio 1977/1976*	*1977*	*1977*	*1977*
C	12.2	58.8	4.81	3.24	9.50	2.93	0.16	0.46	2.88	0.065	0.556	8.55	0.0024	0.0060	2.50	32.6	11.19	0.47
CF	19.9	41.3	2.08	7.96	5.40	0.68	0.34	0.49	1.44	0.164	0.147	0.90	0.0041	0.0053	1.29	22.5	7.05	0.41
S_1	16.9	127.5	7.54	4.99	14.88	2.98	0.38	0.78	2.05	0.186	0.842	4.53	0.0049	0.0102	2.08	81.3	9.80	0.86
S_2	26.2	24.1	0.92	9.12	7.60	0.83	0.32	1.01	3.16	0.293	0.215	0.73	0.0047	0.0077	1.64	34.7	10.51	0.44
CCF[b]	16.1	50.1	3.11	5.60	7.45	1.33	0.25	0.48	1.90	0.115	0.352	3.06	0.0033	0.0057	1.73	27.6	9.12	0.44
S_1S_2[c]	21.6	75.8	3.51	7.06	11.24	1.59	0.35	0.90	2.56	0.240	0.529	2.20	0.0048	0.0090	1.88	58.0	10.16	0.65
S_1S_2 CCF[d]	1.34	1.51	1.13	1.26	1.51	1.20	1.40	1.88	1.35	2.09	1.50	0.72	1.45	1.58	1.09	2.10	1.11	1.48

[a] See text for description of control (C), commercial fertiliser (CF), and sludge (S_1 and S_2) treatments.
[b] CCF = mean of C and CF values
[c] S_1S_2 = mean of S_1 and S_2 values
[d] S_1S_2 CCF = ratio of S_1 and S_2 mean and C and CF mean
[e] Data for 1977 only

and Cd, but they contained about the same concentrations of Pb and Hg as stalks from the CF and low sludge (S_1) plots.

In 1977, metal concentrations of control stalks were elevated to the extent that now these stalks contained about the same (Pb, Hg, Cr) or greater (Zn, Cu, Cd, Fe, Mn) concentrations of metals as their 'positive control' (CF) counterparts. Moreover, low-level sludge treatments, S_1, produced kenaf stalks with more Zn, Cu, Cd, Hg, Fe and Cr than found in stalks from the high-level sludge plots (S_2). Only concentrations of Pb and Mn were slightly higher in the S_2 stalks relative to S_1 stalks. S_2 stalks also had lower concentrations of Zn, Cu, Cd, Mn and Cr than the C stalks.

Thus, comparison of the 1977 and 1976 data (Zn, Cu, Pb, Cd and Hg) shows that there is parallel behaviour between the C and S_1 plots on the one hand, and between the CF and S_2 plots on the other. For example, metal concentrations in C stalks increased in 1977 by factors ranging from 2·5 (Hg) to 8·55 (Cd), while S_1 stalks showed similar large increases in concentrations of the five metals ranging from 2·1 (Pb, Hg) to 7·54 (Zn). In contrast, second year metal accumulations by CF stalks increased for Hg (1·29), Pb (1·44) and Zn (2·08) but decreased for Cu (0·68) and Cd (0·90), a pattern similarly shown by S_2 stalks where Pb (3·16) and Hg (1·64) concentrations increased the second year but Cu (0·83), Cd (0·73) and Zn (0·92) decreased.

Although no clear explanation is apparent for these contrasting patterns, the higher concentrations recorded on the C plots from 1976 to 1977 do suggest that some phenomenon, perhaps involving soil changes induced by tillage and incorporation of plant residues, altered metal availability to the kenaf stalks above and beyond direct metal addition to the soil (as on the sludge plots). Since no soil samples were collected from the 1977 kenaf plots, no evaluation of physical or chemical changes in the soil was possible; however, no major pH change was apparent in soils collected from the adjoining crambe plots (Table 4), and thus it seems unlikely that significant pH changes occurred in the kenaf plot soils either. As expected, sludge-treated soil of the crambe plots contained higher concentrations of Cd, Cr, Pb and Zn and lower concentrations of Fe and Mn than the soils of plots not treated with sludge (C and CF), a pattern also expected in the unanalysed soils of the kenaf plots. The abundant precipitation from July to September 1977, compared with below normal precipitation after mid-May in 1976 (Fig. 1), may also have affected metal accumulations by the kenaf.

Conclusions applicable for all eight metals can be derived from the calculated ratio of metal concentrations in stalks from sludge-treated plots (S_1, S_2) to metal concentrations in stalks from plots not treated with sludge (C, CF). Results for all eight metals in 1977, and for both years for five metals, show that the mean metal concentrations in stalks from the two types of sludge treatments (S_1, S_2) are higher than the mean metal concentrations in stalks from the two non-sludge treatments (CCF) (Table 3). Thus, in 1976, the ratio S_1S_2:CCF ranged from a low of 1·26 (Cu)

TABLE 4
SOIL CHARACTERISTICS OF CRAMBE PLOTS BEFORE (1976) AND AFTER (1977) 2 YEAR EXPERIMENTS

Sample date	*27 May 1976*[a]				*22 July 1977*[b]			
Experiment year	*1976*				*1977*			
Plot type[c]	*C*	*CF*	S_1	S_2	*C*	*CF*	S_1	S_2
Parameters								
pH	7·5	7·6	7·6	7·4	7·8	7·7	7·6	7·5
P $\mu g\,g^{-1}$	94	180	205	175	185	285	345	345
K $kg\,ha^{-1}$	116	129	125	116	125	175	197	175
Metals, $\mu g\,g^{-1}$								
Cd	1·1	≤0·5	≤0·5	0·8	1·1	≤0·5	2·7	2·6
Cr	54	44	50	48	46	43	60	62
Cu	29·9	30	26·6	30	30	30	97·5	115
Pb	10	9·6	10	10	7·2	7·2	19	24
Mn	1110	1020	1020	939	1120	819	839	679
Hg	≤0·2	≤0·2	≤0·2	≤0·2	≤0·2	≤0·2	≤0·2	≤0·2
Zn	69·3	66·4	67·8	67·5	70·5	67·3	205	192
Fe ($mg\,g^{-1}$)	28·1	28·0	29·8	29·6	29·6	28·8	27·6	26·8

[a] Prior to addition of soil amendments (i.e., commercial fertiliser, sludge).
[b] After two soil amendments and two crambe crops. C plots received no amendment.
[c] Each is the composite soil sample from three plot replicates. See text for description of control (C), commercial fertiliser (CF), and sludge (S_1 and S_2) treatments.

to a high of 2·09 (Cd) with an average of 1·51 (i.e. 51% higher mean metal concentrations in stalks from sludge-treated plots). In 1977 the ratio of sludge to non-sludge stalks ranged from 1·11 (Mn) to 2·1 (Cd, Fe) and averaged 1·58, or 58% higher mean metal concentrations in sludge-treated stalks.

This type of comparison is carried a step further in Fig. 3 where, for each metal, the 2 year mean for each treatment (CF, S_1 and S_2) is normalised against the 2 year control mean; i.e. the ratios CF:C, S_1:C and S_2:C were determined. Only the S_1 treatment gave stalks with elevated ratios of all five metals (S_1:C = 1·56 (Cu) to 2·03 (Zn)), although means of the combined sludge treatments were also elevated relative to the C stalks (S_1S_2:C > 1). Except for Pb, the high-rate sludge amendment (S_2) did not result in higher metal accumulations compared with the S_1 amendment. However, like the CF stalks, S_2 stalks had higher Cu, Pb and Hg ratios (S_2:C > 1) but lower Zn and Cd ratios (S_2:C < 1) compared with the control stalks.

The 2 year mean metal concentrations in the kenaf stalks and soil concentrations, given in Table 4, were used to compute a stalk metal:soil metal ratio (Fig. 4). In computing this ratio, the metal concentrations in C and CF stalks were compared with the mean metal concentrations in the C and CF soils (both years), and the metal concentrations in S_1 and S_2 stalks were compared with the mean metal concentrations in the S_1 and S_2 soils (1977). Not surprisingly, a much higher proportion of soil Zn was accumulated by the kenaf stalks than any other metal and the stalk concentration was c. 50% of the soil concentration for C, CF and S_1 treatments. In contrast, Cu and Cd concentrations were accumulated in stalks at a level of 8–28% of the soil concentrations, with the sludge-treated soils producing stalks with lower

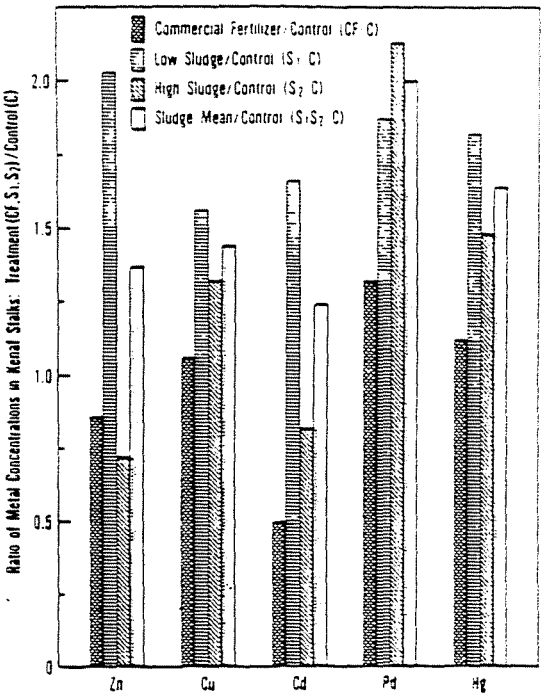


Fig. 3. Ratio of metal concentrations in kenaf stalks: treatment (CF, S_1, S_2): control (C). Computed from the 2 year mean metal concentrations (1976 and 1977).

concentrations of both metals compared with stalks produced on control soils. Since Pb and Hg are relatively unavailable, stalk concentrations are only 2–4 % of the soil concentrations, and differences as a result of treatments are very small. Compared with controls, adding sludge to the soil at the level of the S_2 treatment greatly reduced relative uptake of Zn, and to a lesser extent Cu and Cd, whereas the S_1 treatment level decreased the relative uptake of Cu and Cd without affecting the relative Zn accumulation. Garcia *et al.* (1981) have reported decreases in the relative proportion of soil metals (Pb, Hg, Zn, and Cd) accumulated by several vegetables and wheat when brown loam, clay, or black topsoil were amended with sludge and minimal or no pH change occurred in the amendment. In our studies, sludge added to soil at the higher rate constituted 5 % (dry basis) of the resultant soil–sludge mixture, and 2 years of sludge treatment resulted in modest increases in amended-soil concentrations of Cd and Cr, and two- to threefold increases in Cu, Pb and Zn (Table 4). At the same time the pH of the plot soils did not change significantly with time (2 years) or with sludge addition (2 years and 2 levels), remaining on the slightly alkaline side (pH 7·4–7·8). Thus, it is apparent that translocation of particular metals to the kenaf stalks is not dependent entirely on either pH or metal concentrations of the soils.

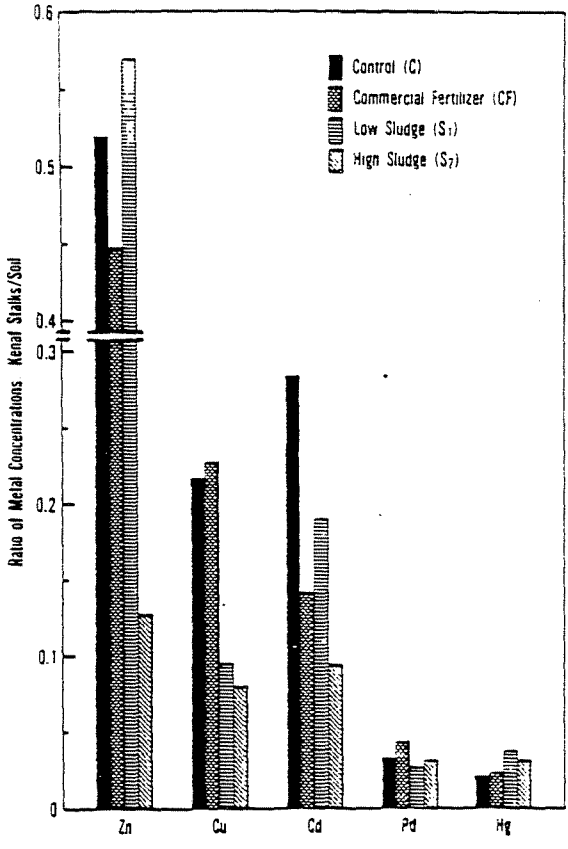


Fig. 4. Ratio of metal concentrations: kenaf stalks: soil. Computed from the 2 year (1976 and 1977) treatment means for stalks and for soil metal concentrations (Table 4).

The Cd:Zn ratio in untreated soil (c. 0·0156) decreased slightly with sludge addition to c. 0·0133 in the amended soil (Table 4), reflecting the relatively lower ratio in the added sludges (c. 0·0127–0·0065, Table 1). In 1976 kenaf stalks the Cd:Zn ratio increased from c. 0·0053 in the control plants to c. 0·0111 in the two types of sludge-treated plants, a trend not repeated in 1977 stalks where the control plants had the higher ratio. There is no difference in the Cd:Zn ratio (0·0087) based on the 2 year means for the control and two types of sludge-treated plants.

Crambe root, seed, and plant weights (Table 2) appear to increase in the order $S_1 \sim S_2 < C < CF$; statistically, seed and plant weights on the CF plots are different from those of the other three plot types ($p < 0{\cdot}01$). Plants receiving the high sludge level produced a higher percentage (by weight) of seed ($p < 0{\cdot}05$). We believe that the relatively poor performance of crambe on the sludge plots in 1977, in contrast to the 1975 and 1976 observations (Fig. 2), was due primarily to severe sludge-promoted weed competition and probably not to particular chemical constituents in the

sludge–soil medium. Our current studies should provide evidence as to whether crambe is sensitive to sludge constituents and elevated levels of microelements in neutral or slightly alkaline stripmine soils. Apparently, sludge applications to soils seldom cause crop yield reductions in field studies when good management practices (e.g., pH > 6·5) are maintained (Chaney & Giordano, 1977). The estimated yield of crambe seed on the plots ranged from a low of 1028 kg ha^{-1} (S_1 plots) to a high of 2306 kg ha^{-1} (CF plots). Generally, crambe plants readily adapt to available space by branching and setting more seed, and thus plant density and row spacing often have minimal effect on seed yield. Under normal conditions, narrow row spacing and high plant density are more important as means of effectively controlling weeds than for determining yield.

TABLE 5

ANALYSES OF CRAMBE SEEDS GROWN ON STRIPMINE PLOTS WITH AND WITHOUT SEWAGE SLUDGE (1977)[a]

Treatment[b]	*Bulk density,*[c] *g 100 cm*$^{-3}$	*Seed wt, g per 1000*	*Oil, %* *(db)*[d]	*Erucic acid in oil, %*	*Protein, %* *(ff, db)*[d]	*Glucosinolates, %* *(ff, db)*[d]
S_2	29·07	6·23	32·45	57·04	32·89	6·82
S_1	28·65	6·26	32·37	55·37	34·75	8·02
C	27·36	6·12	31·49	57·58	32·03	6·97
CF	28·87	6·02	31·18	56·73	35·38	8·09
			LSD = 0·92 (P < 0·05)		LSD = 1·81 (P < 0·01)	

[a] Each value (except bulk density) is the mean of data from three plot replicates; seed harvested from twenty plants per plot, sixty plants per treatment. LSD = least significant difference.
[b] See text for description of control (C), commercial fertiliser (CF), and sludge (S_1 and S_2) treatments.
[c] Single determination on treatment composite samples.
[d] Dry basis (db) and fat free (ff).

Compositional data on crambe seed from the stripmine plots (Table 5) are within normal ranges (Earle *et al.*, 1965). Only differences in oil ($p < 0·05$) and protein ($p < 0·01$) contents are statistically significant.

Plot treatment did not affect metal concentrations in whole crambe seed (Table 6) even though our treatments resulted in as much as fourfold differences in some soil metal concentrations. Compared with kenaf stalks, crambe seeds accumulated approximately twice as much Mn, possibly because the crambe planting seed had been treated with an Mn-containing fungicide. Otherwise, similar levels of the other seven metals were accumulated. As in kenaf stalks, Hg, Cd, Cr and Pb were well below 1 $\mu g\, g^{-1}$ in crambe seed. Iron and Cu concentrations in the seed are the only elements significantly correlated ($p < 0·05$; $R = 0·61$) between plots. Iron and Zn concentrations may be of nutritional significance in using the defatted seed meal as animal feed, assuming that they are bioavailable and the meal is used in ruminant feeds. The Cd:Zn ratio in crambe seed, which did not change with plot treatment, is

TABLE 6

METAL CONCENTRATIONS IN WHOLE CRAMBE SEEDS GROWN ON STRIPMINE PLOTS WITH AND WITHOUT SEWAGE SLUDGE (1977)[a]

Treatment[b]	*Metal content (dry weight basis) μg g⁻¹*							
	Iron	*Zinc*	*Manganese*	*Copper*	*Lead*	*Chromium*	*Cadmium*	*Mercury*
S_2	79·0	39·9	19·4	5·16	0·525	0·299	0·362	0·0039
S_1	76·5	40·2	19·8	5·39	0·595	0·299	0·277	0·0016
C	75·6	38·1	24·9	4·80	0·706	0·321	0·327	0·0017
CF	74·3	42·6	23·6	4·66	0·760	0·289	0·323	0·0020
Overall mean, SD,	76·3	40·2	21·9	5·00	0·646	0·302	0·322	0·0023
(between plots)[c]	10·9	2·2	3·0	0·36	0·125	0·036	0·104	0·0011

[a] Each value is the mean of data from three plot replicates; seed harvested from twenty plants per plot, sixty plants per treatment.
[b] See text for description of control (C), commercial fertiliser (CF), and sludge (S_1 and S_2) treatments.
[c] Standard deviation (SD) based on eight degrees of freedom; least significant difference = 1·88 SD.

low (c. 0·008) and similar to the ratio in kenaf stalks. We currently have no data on metal contents of crambe stems or roots, which would be of interest in assessing whole-plant metal accumulations. However, it is apparent that neither crambe seeds nor kenaf stalks remove large amounts of microelements from the soil. For example, a yield of 2000 kg ha^{-1} of crambe seed would represent only 0·1 to 0·2 kg ha^{-1} of seven metals (Table 6, Fe excluded), compared with nearly 600 kg ha^{-1} of the seven added annually with sludge and the nearly 2600 kg ha^{-1} present originally in the soil. Since the seed pod of crambe constitutes 25–40 % of the seed weight (Earle *et al.*, 1965), it will be of interest to determine what proportion of the whole-seed metal accumulation resides in the pod and could therefore be readily removed prior to processing the seed for oil and meal.

Data obtained in these experiments suggest that both crops can be produced on disturbed lands using sewage sludge as a soil amendment. Neither crop appears to concentrate unusual quantities of metals, but the short-term nature of the study precludes conclusions about metal accumulations in the crops when sludge applications occur at sustained high annual rates. The fate of the accumulated metals when kenaf stalks or crambe seed are subjected to processes appropriate to their uses has not been determined. Weed control was a difficult problem directly associated with the sludge treatments and adversely affected crop performance, especially with the short-statured crambe.

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