Summer Cover Crops and Soil Amendments to Improve Growth and Nutrient Uptake of Okra

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Additional index words. **sunn hemp, velvetbean, sorghum sudangrass, cowpea, biosolids, co-compost, N-Viro Soil, yard waste compost, coal ash, *Abelmoschus esculentus***

Summary. **A pot experiment with summer cover crops and soil amendments was conducted in two consecutive years to elucidate the effects of these cover crops and soil amendments on 'Clemson Spineless 80' okra (*Abelmoschus esculentus*) yields and biomass production, and the uptake and distribution of soil nutrients and trace elements. The cover crops were sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*), velvetbean (*Mucuna deeringiana*), and sorghum sudangrass (*Sorghum bicolor* x *S. bicolor* var. *sudanense*) with fallow as the control. The organic soil amendments were biosolids (sediment from wastewater plants), N-Viro Soil (a mixture of biosolids and coal ash, coal ash (a combustion by-product from power plants), co-compost (a mixture of 3 biosolids : 7 yard waste), and yard waste compost (mainly from leaves and branches of trees and shrubs, and grass clippings) with a soil-incorporated cover crop as the control. As a subsequent vegetable crop, okra was grown after the cover crops, alone or together with the organic soil amendments, had been incorporated. All of the cover crops, except sorghum sudangrass in 2002–03, significantly improved okra fruit yields and the total biomass production (i.e., fruit yields were enhanced by 53% to 62% in 2002–03 and by 28% to 70% in 2003–04). Soil amendments enhanced okra fruit yields from 38.3 to 81.0 g/pot vs. 27.4 g/pot in the control in 2002–03, and from 59.9 to 124.3 g/pot vs. 52.3 g/pot in the control in 2003–04. Both cover crops and soil amendments can substantially improve nutrient uptake and distribution. Among cover crop treatments, sunn hemp showed promising improvement in concentrations of calcium (Ca), zinc (Zn), copper (Cu), iron (Fe), boron (B), and molybdenum (Mo) in fruit; magnesium (Mg), Zn, Cu, and Mo in shoots; and Mo in roots of okra. Among soil amendments, biosolids had a significant influence on most nutrients by increasing the concentrations of Zn, Cu, Fe, and Mo in the fruit; Mg, Zn, Cu, and Mo in the shoot; and Mg, Zn, and Mo in the root. Concentrations of the trace metal cadmium (Cd) were not increased significantly in either okra fruit, shoot, or root by application of these cover crops or soil amendments, but the lead (Pb) concentration was increased in the fruit by application of a high rate (205 g/pot) of biosolids. These results suggest that cover crops and appropriate amounts of soil amendments can be used to improve soil fertility and okra yield without adverse environmental effects or risk of contamination of the fruit. Further field studies will be required to confirm these findings.**

Summer cover crops have shown promise for improving soil fertility and crop yields in tropical and subtropical regions (Melendez, 2004; Triomphe and Sain, 2004; Wang et al., 2002, 2003a; Wildner et al., 2004). Large quantities of water and soil nutrients can be conserved by growing summer cover crops, since heavy rainfall events cause significant soil erosion and nutrient leaching during the rainy season in southern Florida, where Krome gravelly loam soil is dominant, consisting of up to 60% rocks (Wang et al., 2005).

Municipal solid wastes, such as biosolids, yard wastes, and coal ash, as soil amendments have shown considerable potential to improve soil fertility and crop production (Eriksen et al., 1999; Li et al., 2000, 2003). According to the U.S. Environmental Protection Agency (USEPA, 1994), 30% to 60% of a community's municipal solid wastes can be processed into useful composts. The agricultural industry is the largest consumer of composts, and has the potential to consume up to about 800 million m^3 annually, or more than 10 times the current U.S. production (Slivka et al., 1992; USEPA, 1993).

A number of studies have demonstrated that the application of composts can increase soil organic matter (Cortellini et al., 1996; Maynard, 1995), cation exchange capacity (Paino et al., 1996), soil water holding capacity (Serra-Wittling et al., 1996; Turner et al., 1994), the pH of acidic soils (Maynard, 1995), and soil microbial (Cameron et al., 2004) and enzymatic activities (Serra-Wittling et al., 1996) and decrease soil bulk density (Turner et al., 1994).

However, crop response to different composts varies widely, from yield increases of 22% for snap bean (*Phaseolus vulgaris*) and 38% for tomato (*Lycopersicon esculentum*) (Maynard, 1995) to induced N deficiency in pepper (*Capsicum annuum*) (Clark et al., 1995). Also, the application of composts may lead to the immobilization of soil mineral N (Beloso et al., 1993; Duggan, 1973), cause N deficiencies in plants, and depress crop yields (Clark et al., 1995) because of immaturity or a high ratio of carbon (C) to nitrogen (N) in the compost.

A major concern is that long-term application of composts may cause heavy metal contamination of soil,

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	$g\cdot kg^{-1}$	0.1
0.0283	ft^3	m^3	35.3147
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg\cdot ha^{-1}$	0.8922
1	mmho/cm	$mS\cdot cm^{-1}$	1
28.3495	oz	g	0.0353
1	ppm	$mg\cdot kg^{-1}$	1
2.2417	ton/acre	$t\cdot ha^{-1}$	0.4461
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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edible crops, and groundwater (Li et al., 2000, 2003; Wang et al., 2001, 2003b). In addition, precautions pertaining to human pathogens and phytotoxicity should be considered when developing production systems amended with composts (Stoffella and Li, 2001). Therefore, the main objectives of this experiment were to elucidate 1) the effects of summer cover crops and soil amendments on subsequent vegetable crop production, and 2) the influences of summer cover crops and soil amendments on uptake and distribution of soil nutrients and trace metals in different components of okra plants.

Materials and methods

Soil properties and experimental design. The experiment was conducted in pots of 8.3 L each, 23 cm in diameter, and 20 cm high with a soil capacity of 8 kg/pot. The soil was a Krome very gravelly loam (loamy-skeletal, carbonatic, hyperthermic Lithic Udorthents) collected from a field in the Tropical Research and Education Center, University of Florida, Homestead. The soil contained 58.8% gravel (>2-mm sieve), and had a distribution of soil particles of 48.4% sand, 30.3% silt, and 21.3% clay. Also, the soil contained 60% calcium carbonate ($CaCO_3$), pH 7.8 (water), 28 g·kg^{-1} soil organic C, 1.1 g·kg^{-1} total N, 22.7 mg·kg^{-1} phosphorus (P) [ammonium bicarbonate-diethylene triaminepentaacetic acid (AB-DTPA)-extractable], and 129 mg·kg^{-1} AB-DTPA-extractable potassium (K).

A split plot design was used in which the main plots were four summer cover crops and fallow, and the subplots were five organic soil amendments along with a no-amendment control. When the cover crop, sunn hemp, reached the optimum stage for termination (flowering), the stems of all the cover crops were cut off at ground level and cut into pieces about 2 cm long and thoroughly mixed into the soil together with the appropriate organic amendment, if any. After these soil amendments were applied, the materials in the pots were allowed to equilibrate for 10 d before the okra was seeded. The experiment was carried out in a screen house from June 2002 to Feb. 2003 of the first year (2002–03), and June 2003 to Feb. 2004 of the second year (2003–04).

The main treatments were summer cover crops, sunn hemp, cowpea, velvetbean, and sorghum sudangrass and a weedy natural fallow as the control. The subplot treatments were soil amendments: biosolids, N-Viro Soil (N-Viro International Corp., Toledo, Ohio), coal ash (a by-product from power plants in Florida), co-compost (3 biosolids : 7 yard waste from West Palm Beach, Fla.), yard waste compost (mainly from leaves and branches of trees and shrubs, and grass clippings), and a control (soil-incorporated cover crop residues but without any organic amendment). Each soil amendment was applied at 205 g/pot of dry weight equivalent, which was equivalent to 50 Mg·ha^{-1}. The composition and properties of the various organic amendments were determined and are summarized in Table 1.

Okra seeds were sown on 20 and 25 Aug. in 2002 and 2003, respectively, and thinned at the three-leaf stage to six plants per pot. Drip irrigation was installed and adjusted to deliver 2 L·h^{-1} of water. A clock timer was used to control the irrigation automatically. The period and frequency of irrigation were adjusted according to needs of the successive plant growth stages. Okra fruit were harvested twice each week for 7 weeks starting on 5 Jan. 2003, and 10 Jan. 2004, respectively. At the end of the experiment, to obtain the total biomass, the remaining fruit, shoots, and roots, washed free of soil, were harvested. Plants were separated into fruit, stems, and roots, and random samples of these plant parts were taken for chemical analysis to determine concentrations of B, C, Cd, Cu, Fe, K, Mg, manganese (Mn), Mo, N, P, and Pb. Carbon and N were analyzed with a carbon–nitrogen–sulfur (CNS) auto-analyzer (vario Max Elementar, Hanau, Germany), and all the other elements were analyzed via inductively coupled plasma optical emission spectroscopy [ICP–OES (Ultima 2C; Horiba Jobin Yvon Inc., Edison, N.J.) after the samples had been digested with concentrated nitric acid–hydrogen peroxide–hydrochloric acid (HNO_3–H_2O_2–HCl) according to USEPA method 3050A (USEPA, 1990).

After the okra plants were harvested and removed, sorghum sudangrass was grown in the same pots to study the residual effects of the cover crops and soil amendments. Twenty-five sorghum sudangrass seedlings were grown in each pot and irrigated as above. The sorghum sudangrass was grown from Nov. 2002 to Jan. 2003, then removed from the pots, dried at 70 °C for 72 h, and weighed to obtain the aboveground dry biomass.

Sampling and analysis. The cover crops were sampled for biomass determination at the time of their termination. Also, a representative okra plant from each pot was sampled at the visible bud (pre-flowering) stage to determine the dry weight of its biomass. Okra fruit, shoots, and roots (washed free of soil) were sampled. Soil

Table 1. Chemical characteristics of soil amendments that were used in a pot experiment conducted at Homestead, Fla.

	Soil amendments^z				
	Biosolids	N-Virosoil	Co-compost	YW-compost	Coal ash
	[mg·kg^{-1} (ppm)]				
pH^y	6.1	9.2	6.7	7.7	11.8
EC (mS·cm^{-1})^y	16.1	6.4	1.0	1.7	5.4
Extractable nitrogen	1461.2	13.8	145.9	29.0	6.4
Extractable phosphorus	236.6	209.1	130.3	85.9	8.9
Total phosphorus	29,080	5,430	13,433	729	156
Total calcium	43,179	115,122	44,133	153,614	161,294
Total magnesium	3.774	1,814	2,452	2,027	1,781
Total iron	8,387	9,094	13,210	5,559	6,985
Total zinc	1,254	168	347	598	69
Total molybdenum	11.4	12.0	6.0	3.4	18.7
Total cobalt	2.8	16.6	2.6	4.5	41.5
Total cadmium	3.6	1.7	1.8	1.8	1.6

^{z}Biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (combustion by-product from power plants).

^{y}EC = electrical conductivity; 1 mS·cm^{-1} = 1 mmho/cm.

samples were collected before and after growing the cover crops and also after the okra harvest.

The plant samples were dried at 70 °C for 72 h and ground to pass through a 1-mm sieve. Soil samples were air-dried, plant materials were removed, and the samples were gently ground by hand to pass through a 2-mm sieve. Soil samples were extracted with AB-DTPA for P, K, Ca, Mg, and micronutrient element analysis via ICP–OES. Total N and C in both soil and plant samples were determined via a CNS auto-analyzer. Soil organic carbon was determined by the weight loss-on-ignition (WLOI) method (Schulte and Hopkins, 1996).

The data were subjected to the analysis of variance (ANOVA) and Duncan's multiple range tests for significant differences using SAS (version 8.1; SAS Institute, Cary, N.C.).

Results and discussion

BIOMASS, TOTAL CARBON, NITROGEN, AND PHOSPHORUS ACCUMULATED BY DIFFERENT COVER CROPS. All of the cover crops, except cowpea in 2002–03, produced significantly higher quantities of biomass and organic carbon than weedy fallow; sunn hemp and sorghum sudangrass produced the most (Table 2). The approximate amounts of N accumulated in the 2 years were 1.3 to 1.6 g/pot by sunn hemp, 0.9 to 1.0 g/pot by velvetbean, and 0.4 to 0.6 g/pot by cowpea. These amounts of N were significantly higher than those accumulated by the non-leguminous cover crop sorghum sudangrass, 0.3 to 0.4 g/pot. All of the cover crops contributed significantly higher total P than did the weedy fallow. Sunn hemp and velvetbean contributed 0.9–1.2 g/pot of total P compared to 0.5–0.6 g/pot by cowpea, and 0.3 g/pot by the weedy fallow treatment (Table 2). These very different N and P contributions relate directly to differences in quantities of biomass produced.

Among these cover crops, sunn hemp produced the greatest amounts of biomass and total C, N, and P, which made a substantial contribution to soil organic matter and plant nutrients to the subsequent crop. Sorghum sudangrass also produced significantly greater amounts of biomass and total C than either velvetbean or cowpea. However, the total N content of sorghum sudangrass was the lowest among these cover crops (i.e., 6.9 g·kg^{-1} in sorghum sudangrass vs. 27.4 g·kg^{-1} in velvetbean, 26.0 g·kg^{-1} in cowpea, and 25.1 g·kg^{-1} in sunn hemp).

Sunn hemp displayed consistently greater biomass production in field experiments in southern Florida. About 12–14 Mg·ha^{-1} of biomass usually can be produced, which is equivalent to 204–350 kg·ha^{-1} of N (Li et al., 1999; Wang et al., 2002). Under open field conditions, velvetbean produced more biomass than did sorghum sudangrass. For example, Wang et al. (2002) observed that velvetbean in the field produced 11 Mg·ha^{-1} of biomass, while sorghum sudangrass produced only 5 Mg·ha^{-1}; the respective amounts of N were 280 and 48 kg·ha^{-1}. These discrepancies in biomass production between pot and field experiments may be attributed to different growing periods of these cover crops. For example, velvetbean requires a longer growth period than sorghum sudangrass or sun hemp. In subtropical regions of southern Florida, indeterminate cultivars of velvetbean are usually grown from early June through September, which allows vegetative growth to be completed. However, the relatively short period (about 2 months) of growth allowed in this study was insufficient for complete development in the vegetative growth of velvetbean.

OKRA FRUIT YIELDS AND TOTAL BIOMASS AS INFLUENCED BY DIFFERENT COVER CROPS. Fruit yields in the cover crop treatments were significantly higher than those in the fallow treatment (Table 3), except in the sorghum sudangrass treatment in 2003–04. The sunn hemp treatment increased okra fruit yield from 41.7 (fallow) to 45.2 g/pot in 2002–03, and from 46.5 to 79.2 g/pot in 2003–04, which are 57% and 70% more than the control, respectively. The corresponding increases in the velvetbean treatment were 58% and 48% greater than the control. Even though cowpea and velvetbean produced significantly lower quantities of cover crop biomass than sunn hemp and sorghum sudangrass (Table 2), yields of okra fruit were statistically the same among all of the cover crop treatments in 2002–03 (Table 3). The amount of aboveground okra biomass was increased significantly by application of all the cover crops, except sorghum sudangrass in 2002–03, compared to the fallow treatment (Table 3). The sunn hemp treatment increased okra biomass over that in the fallow treatment by 45% in 2002–03 and 88% in 2003–04, and the corresponding increases in the velvetbean treatment were 54% and 98% over the control.

The results indicate that summer cover crops, especially legumes (e.g., sunn hemp and velvetbean), can significantly improve yields of the subsequent crop by releasing to the soil plant available nutrients through decomposition of plant residues. Marketable tomato yields in southern Florida were improved by growing a cover crop of sunn hemp (Abdul-Baki et al. 2005; Li et al., 1999; Wang et al., 2002, 2003a). There is a paucity of information on the use of cover crops in okra production; however, our results with okra agree

Table 2. Total quantities of biomass, carbon (C), nitrogen (N), and phosphorus (P) accumulated by each cover crop during years 2002–03 and 2003–04, respectively, in a pot experiment conducted at Homestead, Fla.

	Biomass[z]	Total C	Total N	Total P
	(g/pot dry wt basis)[y]			
	2002–03			
Fallow (weeds)	10.6 c[x]	3.9 c	0.1 e	0.3 c
Cowpea	16.1 c	6.5 c	0.4 c	0.5 b
Velvetbean	32.5 b	13.6 b	0.9 b	0.9 a
Sorghum sudangrass	46.5 a	19.2 a	0.3 d	0.9 a
Sunn hemp	50.2 a	20.6 a	1.3 a	0.9 a
	2003–04			
Fallow (weeds)	12.0 d	4.4 d	0.2 e	0.3 d
Cowpea	21.4 c	8.7 c	0.6 c	0.6 c
Velvetbean	38.0 b	15.9 b	1.0 b	1.0 ab
Sorghum sudangrass	52.3 a	21.6 a	0.4 d	1.0 ab
Sunn hemp	65.3 a	26.9 a	1.6 a	1.2 a

[z] 1 g = 0.0353 oz.

[y] Values within a column in 2002–03 or 2003–04 followed by same letters represent no significant differences at $P \le 0.05$ using Duncan's multiple range test.

Table 3. Effects of different cover crops and various organic soil amendments on okra pod yields and biomass quantities in a pot experiment conducted at Homestead, Fla.

	Pod yield		Dry wt of biomass	
	2002–03	2003–04	2002–03	2003–04[z]
	(g/pot)[y]			
Cover crops				
Sunn hemp	45.2 a[x]	79.2 a	35.2 a	13.1 a
Velvetbean	45.5 a	68.8 b	37.3 a	14.3 a
Cowpea	46.7 a	59.5 b	30.9 ab	12.1 ab
Sorghum sudangrass	44.1 a	55.7 bc	28.7 abc	8.7 b
Fallow	41.7 b	46.5 c	20.7 c	6.8 b
Amendments[w]				
Biosolids	81.0 a	124.3 a	60.1 a	18.0 a
N-Viro Soil	48.4 bc	64.6 bc	27.9 c	9.6 cd
Co-compost	49.6 bc	68.0 b	26.3 c	9.6 cd
Yard waste	47.7 bc	61.9 bc	37.3 b	11.0 bcd
Coal ash	38.3 c	59.9 bc	23.5 c	12.6 bc
Control	27.4 d	52.3 d	24.3 c	7.3 d
Cover crops × amendments	$P \leq 0.01$	$P \leq 0.05$	NS	NS

[z] Dry weight of biomass in 2002–03 included stems, leaves and roots but in 2003–04 only stems were included.

[y] 1 g = 0.0353 oz.

[x] Values followed by same letters within a column for either cover crops or amendments represent no significant differences at $P \leq 0.05$ using Duncan's multiple range test.

[w] Biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (combustion by-product from power plants).

well with those obtained in comparable studies with tomatoes. Li et al. (1999) reported that tomatoes grown in a sunn hemp treatment produced significantly higher early and total extra large fruit, and total marketable yields compared to the control. They attributed this improvement in tomato production to improvement in soil physical properties, and increased soil organic carbon and nutrient availability resulting from the mineralization of sunn hemp residues. Moreover, Wang et al. (2002) found that tomato yields were higher in the sunn hemp treatment than in all other cover crop treatments.

Okra fruit yields and total biomass as influenced by various organic soil amendments. All of the organic soil amendments in both years improved the okra fruit yield compared to the control (Table 3). The enhanced production of okra fruit and biomass by biosolids mainly results from its high nutrient concentrations. The concentrations of N, P, and Zn were vastly higher in biosolids than in the other amendments (Table 1), and these high nutrient concentrations in biosolids may be the major factor responsible for the enhanced production of okra fruit and biomass. Vegetable yield improvements by application of composts have also been reported by other researchers (Patterson et al., 2002; Wang et al., 2003a). Some researchers have suggested that composts may serve as a partial substitute for inorganic fertilizer for tomato (Stoffella et al., 1997) and bell pepper (Roe et al., 1997). However, some researchers also found that there was neither a significant difference in fruit yield nor fruit quality characteristics after the application of compost to sweet orange (*Citrus sinensis*) trees (Stoffella et al., 1996). The improvement in okra yields by some cover crops and biosolids in our experiment probably is the consequence of the low fertility of the Krome gravelly loam soil.

Quantities of okra biomass at the visible bud (pre-flowering) stage as influenced by different cover crops and organic soil amendments. The quantity of okra biomass at the visible bud (pre-flowering) stage was significantly increased by the application of cover crops, especially by sunn hemp and velvetbean. For example, compared to the effect of fallow, okra biomass was increased 110.8% by sunn hemp, 80.2% by velvetbean, 63.8% by cowpea, and 34.5% by sorghum sudangrass (Fig. 1). These data indicate that these summer cover crops can provide plant available nutrients for okra growth and development. These plant available nutrients are released during the process of decomposition of the cover crop residues. Leguminous cover crops, such as sunn hemp and velvetbean, can contribute plant available nutrients rapidly because they contain high amounts of N and P (Table 2), and other essential elements for plant growth and development. A suitable C:N ratio in these leguminous cover crops (about 16:1) can provide appropriate nutrition to the soil organisms needed to promote the rapid decomposition of organic matter in the soil. In contrast, a non-leguminous cover crop, such as sorghum sudangrass, has a higher C:N ratio of about 28:1 (Table 2), which would result in a somewhat slower rate of microbial breakdown of cover crop residues.

Okra biomass production was also greatly improved by some soil amendments at the pre-flowering stage, especially by biosolids and co-compost. For example, compared to the control okra total biomass was increased from 19.5 to 32.4 g/pot by application of co-compost, and to 70.5 g/pot by biosolids, respectively, but the other soil amendments did not significantly increase okra biomass production (Fig. 1). The application of biosolids or co-compost, which contained 1461 mg·kg^{-1} and 145.9 mg·kg^{-1} of N, respectively, and significant concentrations of other plant essential elements (Table 1), might be the main reason in the improvement of okra growth and development, especially in the low fertility Krome gravelly loam soil.

Residual effects of cover crops and soil amendments. The residual effect of the sunn hemp treatment increased the aboveground sorghum sudangrass biomass production more than that of any other cover crops (Fig. 2), with a more than 2-fold increase in aboveground biomass in the fallow treatment (control). Among soil amendments, the residual effect of biosolids application increased the aboveground biomass production of sorghum sudangrass more than that of any other amendments. For example, 38 g/pot of aboveground biomass was produced as the residual effect by the application of biosolids, 18.5 g/pot by co-compost vs. only 8.2 g/pot in the control (Fig. 2).

Residual effects of manure and composts have been investigated by a number of researchers. For example,

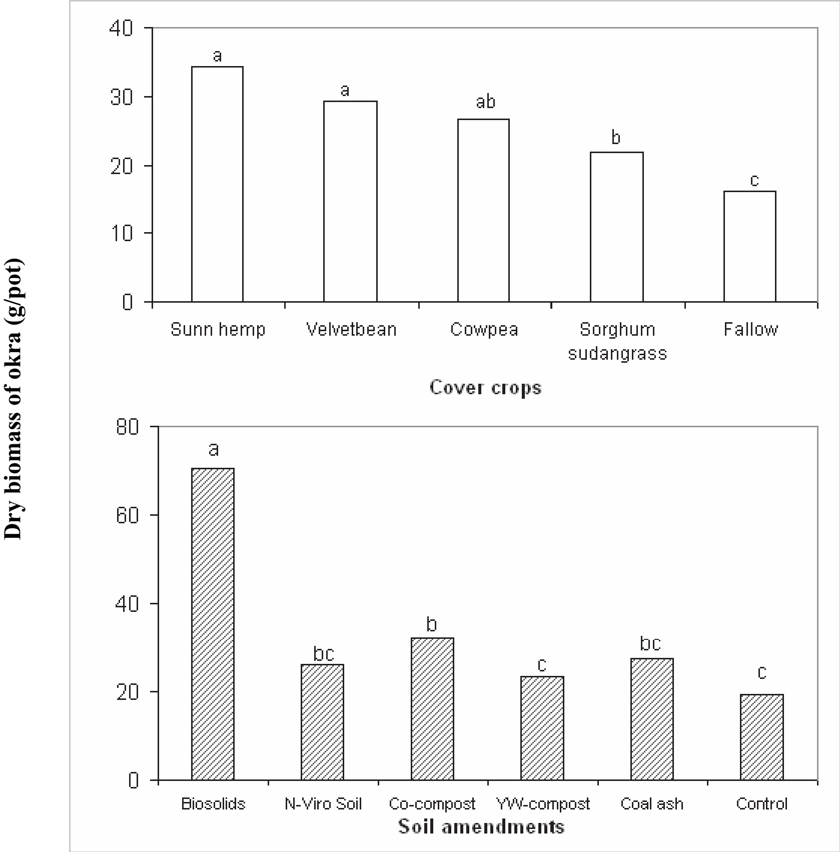

Fig. 1 (*right, top*). Effects of cover crops and soil amendments on aboveground okra biomass at the visible bud (pre-flowering) stage in a pot experiment conducted at Homestead, Fla. Values are the mean of data from 2 years. Same letters above the bars represent no significant difference at $P \leq 0.05$ using Duncan's multiple range tests. The soil amendments were biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (a compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (a combustion by-product from power plants); 1 g = 0.0353 oz.

Bahman et al. (2004) indicated that residual effects of manure or compost application on crop production and on soil properties can persist for several years after the manure or compost application ceases. This is because only a fraction of the N and other nutrients in the manure or compost become plant available in the first year after application (Eghball et al., 2002, 2004; Ginting et al., 2003; Motavalli et al., 1989). Eghball and Power (1999) further found that only 40% of beef cattle feedlot manure N and 20% of compost N were plant available in the first year after application, and this suggests that about 60% of manure N and 80% of compost N became plant available only in succeeding years, assuming little or no loss of N due to nitrate-N leaching or denitrification. Our results also indicate that the residual effect of both

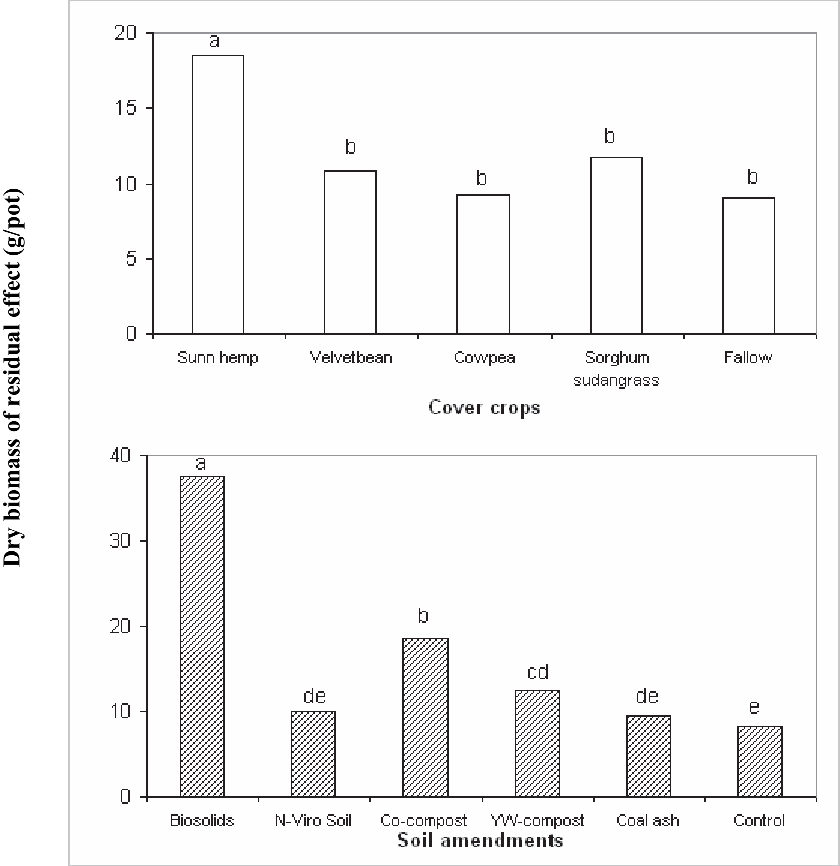

Fig. 2 (*right, bottom*). Effects of cover crops and organic amendments on dry weights of the aboveground sorghum sudangrass biomass as residual effects. Values are the mean of data from 2 years. Same letters above the bars represent no significant difference at $P \leq 0.05$ using Duncan's multiple range tests. The soil amendments were biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (a compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (a combustion by-product from power plants); 1 g = 0.0353 oz.

Table 4. Effects of various cover crops and soil amendments on the distribution of nitrogen (N) and carbon (C) in different parts of okra plants in a pot experiment conducted at Homestead, Fla.

	Pods			Shoots			Roots		
	N (%)	C (%)	C:N ratio	N (%)	C (%)	C:N ratio	N (%)	C (%)	C:N ratio
Cover crops									
Sunn hemp	2.15 ab[z]	41.08 b	19.11 b	0.841 a	38.11 c	45.32 b	1.023 a	39.34 a	38.46 c
Velvetbean	2.24 a	47.03 a	21.00 ab	0.769 a	38.56 bc	50.14 b	0.593 b	39.22 a	66.14 a
Cowpea	1.89 abc	41.24 b	21.82 ab	0.89 a	40.42 ab	45.42 b	0.66 b	38.23 a	57.92 ab
Sorghum sudangrass	2.06 ab	40.64 b	19.73 b	0.937 a	41.39 a	44.17 b	0.899 ab	38.88 a	43.25 c
Fallow	1.81 bc	40.51 b	22.38 a	0.465 b	38.82 bc	83.48 a	0.603 b	39.17 a	64.96 a
Soil amendments[y]									
Biosolids	2.82 a	42.08 a	14.92 d	1.45 a	37.09 d	25.58 d	1.16 b	38.71 ab	33.37 d
N-Viro Soil	2.07 bc	41.76 a	20.17 abc	0.68 bc	37.97 cd	55.84 ab	0.92 bc	38.49 b	41.84 bc
Co-compost	2.21 b	41.86 a	18.94 c	0.66 c	42.16 a	63.88 a	0.70 cd	40.36 ab	57.66 a
YW-compost	1.77 c	40.64 a	22.96 a	0.85 bc	41.47 ab	48.79 c	0.68 cd	40.88 a	60.12 a
Coal ash	1.92 bc	40.92 a	21.31 abc	0.7 bc	39.24 bcd	56.06 ab	1.24 a	39.02 ab	24.70 e
Control	1.9 bc	39.87 a	20.98 abc	0.9 bc	39.44 bcd	43.82 c	0.78 cd	38.93 ab	49.91 bc

[z] Values followed by same letters within a column for either cover crops or amendments represent no significant differences at $P \le 0.05$ using Duncan's multiple tests.

[y] Biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (combustion by-product from power plants).

cover crops and soil amendments can greatly benefit the following vegetable crop. Conversely, these results also indicate that if the soil and crops are improperly managed (e.g., leaving land fallow or with a sparse stand of plants, there is a high risk that nutrients can be leached). This phenomenon has been observed by several researchers (Linville and Smith, 1971; Wang et al., 2003b).

Effect of cover crops and amendments on concentrations of N and C in okra plant parts. The concentration of N in okra fruit (Table 4) was obviously higher than that in shoots or roots. Also, N concentrations in the various okra plant parts were increased by incorporation of some cover crops. For example, in comparison to N levels from the control (fallow), velvetbean enhanced okra fruit N by 24%, sunn hemp enhanced okra root N concentration by 70%, and all these cover crops enhanced okra shoot N concentrations (Table 4). The C concentration in okra plant parts was relatively constant, but it was increased significantly in the fruit and shoots by the incorporation of velvetbean and sorghum sudangrass cover crops, respectively. Also, the C:N ratio in okra plant parts was influenced by the incorporation of some cover crops. Compared to the control, the C:N ratio was decreased significantly in okra fruit, shoots, and roots by the incorporation of sunn hemp and sorghum sudangrass. In contrast, the only significant effect of the cowpea and velvetbean treatments was to decrease the C:N ratio in the okra shoots (Table 4).

The application of biosolids significantly increased N concentrations in okra fruit, shoots, and roots. However, the highest N concentration in the roots was observed in the coal ash treatment (Table 4). The highest C concentration in the roots was found in the yard waste compost treatment. The C:N ratio in different plant parts was also influenced by the application of some soil amendments. For example, the lowest C:N ratio in okra fruit occurred in the biosolids treatment followed by the co-compost treatment, but the lowest C:N ratio in okra roots occurred in the coal ash treatment (Table 4).

The distribution of N and C in different plant components indicates that the incorporation of certain summer cover crops and the addition of some soil amendments can change the status of N and C concentrations and the C:N ratio of the subsequent crop. Among soil amendments, the biosolids treatment generally enhanced the N concentration in plant components because of the high N content in the biosolids. Leguminous summer cover crops, such as sunn hemp or velvetbean, which produce great quantities of biomass with high N concentrations, can also induce significant enhancement of N uptake and influence the distribution of C and N in plant parts. In some cases, however, nitrogen deficiency in plants appears following the application of organic amendments mainly derived from a material with a low N concentration or with a high C:N ratio (Clark et al., 1995). In addition, N immobilization may induce N deficiency in plants, and this may occur when immature compost is applied. Immature compost can immobilize N and cause phytotoxicity (Li et al., 2000). However, if the soil amendment has a C:N ratio lower than 25–30:1, N immobilization is unlikely to occur.

The rate of mineralization of organic soil amendments or composts depends on their composition, maturity, and soil conditions (e.g., moisture, temperature, etc.). For instance, about 50% of organic N is mineralized from biosolids, 25% from municipal solid waste composts, and less than 25% from yard waste composts in southern Florida (He et al., 2000; Stoffella et al., 1997). Weggler-Beaton et al. (2002) compared the effects of biosolids and chemical fertilizer applications on wheat and barley yields, and found that an application of 2 Mg·ha^{-1} biosolids increased dry matter production and yields to the same extent as a mineral fertilizer application of 20 kg·ha^{-1} of N, 20 kg·ha^{-1} of P, and 1.8–2.8 kg·ha^{-1} of Zn. In the present experiment, the high N concentration in some amendments, especially in biosolids (Table 1) and the leguminous cover crops (Table 2), not only improved the availability of soil N but also promoted the uptake and accumulation of N in okra plants.

Table 5. Effects of various cover crops and soil amendments on plant nutrients and trace metals in okra fruit in a pot experiment conducted at Homestead, Fla.

	Nutrients[z]				Trace metals[y]								
	P	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**Fe**	**B**	**Cd**	**Mo**	**Ni**	**Pb**
	$g \cdot kg^{-1}$				$mg \cdot kg^{-1}$ (ppm)								
	Cover crops												
Sunn hemp	5.64 a[x]	22.08 a	13.77 a	4.99 a	59.58 a	18.06 ab	11.64 a	33.63 a	125.44 a	0.44 b	1.14 a	3.34 a	3.77 a
Velvetbean	5.04 ab	19.74 b	12.08 ab	4.89 a	49.56 bc	21.46 a	9.70 b	28.03 b	107.68 b	0.72 a	0.55 b	0.64 a	3.03 a
Cowpea	4.69 b	19.79 b	11.46 b	4.88 a	44.73 b	21.73 a	8.69 b	26.99 b	100.12 b	0.81 a	0.43 b	1.50 a	4.20 a
Sorghum sudangrass	5.52 ab	22.29 a	10.62 b	4.31 b	55.95 ab	12.59 c	9.65 b	28.71 ab	96.01 b	0.55 b	1.20 a	0.85 a	3.91 a
Fallow	4.91 ab	21.17 ab	10.60 b	4.53 ab	44.20 c	16.44 ab	8.48 b	26.41 b	100.48 b	0.78 a	0.43 b	0.72 a	3.61 a
	Soil amendments[w]												
Biosolids	5.84 ab[x]	20.72 bc	10.15 a	4.72 a	70.35 a	18.17 ab	13.14 a	35.48 ab	117.18 a	0.24 e	1.70 a	1.42 a	5.67 a
N-Viro Soil	5.51 ab	22.01 bc	11.16 a	4.48 a	54.57 bc	14.31 c	10.50 b	30.54 abc	109.60 a	0.61 bc	1.10 b	1.64 a	4.27 ab
Co-compost	6.21 a	25.48 a	12.29 a	4.66 a	60.33 b	8.78 d	9.92 b	36.18 a	108.24 a	0.35 de	1.51 a	0.61 a	2.72 b
YW-compost	5.15 bc	19.96 c	11.81 a	4.59 a	52.57 bcd	15.31 c	9.99 b	28.77 c	102.11 a	0.61 bc	0.55 c	0.58 a	3.10 b
Coal ash	5.78 ab	22.79 b	12.29 a	4.82 a	51.98 bcd	18.26 ab	10.32 b	29.08 bc	104.59 a	0.44 cd	1.67 a	1.63 a	4.67 ab
Control	4.89 c	20.61 bc	12.34 a	4.76 a	48.00 cd	19.68 ab	9.19 b	27.07 c	107.66 a	0.77 ab	0.47 c	0.89 a	3.40 b

[z] P =phoshorus, K = potassium, Ca = calcium, Mg = magnesium, 1 g kg^{-1} = 0.1%.

[y] Zn = zinc, Mn = manganese, Cu = copper, Fe = iron, B = boron, Cd = cadmium, Mo = molybdenum, Ni = nickel, Pb = lead.

[x] Values followed by same letters within a column for either cover crops or amendments represent no significant differences at $P \leq 0.05$ using Duncan's multiple tests.

[w] Biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (combustion by-product from power plants).

Uptake and distribution of other soil nutrients and metal elements as influenced by cover crops and soil amendments

CONCENTRATIONS OF VARIOUS ELEMENTS IN OKRA FRUIT. Potassium concentration in okra fruit was enhanced more by the use of sunn hemp and sorghum sudangrass (Table 5) than by velvetbean and cowpea. The concentration of Ca in okra fruit was enhanced significantly by sunn hemp compared with fallow, cowpea, or sorghum sudangrass. The Mg concentrations in okra fruit were greater in the legume treatments than the non-legume (sorghum sudangrass) treatment (Table 5). Concentrations of Zn, Cu, Fe, B, and Mo in okra fruit were significantly enhanced by the sunn hemp treatment. Concentrations of Zn and Mo in okra fruit were also increased by the sorghum sudangrass treatment. The concentrations of Zn in okra fruit in all cover crop treatments were higher than in the fallow treatment, and the Mn concentration in okra fruit was lower in the sorghum sudangrass treatment than in all other cover crop treatments (Table 5).

With respect to environmentally hazardous metals, such as Cd and Pb, sunn hemp and sorghum sudangrass treatments reduced the concentrations of Cd compared to the other cover crops or fallow; however, none of the cover crop treatments had a significant effect on the Pb concentration in okra fruit (Table 5).

Various organic amendments had differential effects on the concentrations of certain elements in okra fruit (Table 5). The P concentrations in okra fruit were significantly enhanced by co-compost, biosolids, coal ash, and N-Viro Soil compared to the control. Concentrations of Ca and Mg in okra fruit were not affected by any of the organic amendments, but the micronutrients Zn and Cu in okra fruit were greater with biosolids; Fe was higher with co-compost; and Mo was greater with biosolids, co-compost, and coal ash compared to the control (Table 5). Application of co-compost also enhanced concentrations of Zn, Fe, and Mo but decreased Mn. Also, Mn concentrations in okra fruit were significantly reduced by application of N-Viro Soil and yard waste compost. Application of coal ash strongly enhanced the concentration of Mo in okra fruit; however, the concentration of the toxic trace metal Cd in okra fruit was abated significantly by application of biosolids, co-compost, and coal ash, but unfortunately, the Pb concentration in okra fruit was enhanced by the application of biosolids (Table 5).

The extent of uptake of plant nutrients and other elements from the treatments of cover crop and soil amendments is not directly related to their concentrations in the applied materials, since such uptake is usually controlled by complicated mechanisms of availability and need. For example, although biosolids contained 237 $mg \cdot kg^{-1}$ of extractable P (Table 1), which is about 27-fold greater than in coal ash (8.9 $mg \cdot kg^{-1}$), the amounts taken up in these two treatments were essentially the same (Table 5). The Zn concentration in the biosolids (1255 $mg \cdot kg^{-1}$) was 18-fold greater than in coal ash (69 $mg \cdot kg^{-1}$), yet the Zn concentration in okra fruit were only 1.4-fold higher in the biosolids than in the coal ash treatment. The concentrations of Mo in soil amendments in decreasing order were: coal ash (18.7 $mg \cdot kg^{-1}$), N-Viro Soil (12 $mg \cdot kg^{-1}$), biosolids (11.4 $mg \cdot kg^{-1}$), co-compost (6 $mg \cdot kg^{-1}$), and yard waste compost (3.4 $mg \cdot kg^{-1}$) (Table 1), yet Mo concentrations in the okra fruit (Table 5) in decreasing order by treatment were: biosolids > coal ash > co-compost > N-Viro Soil > yard waste compost.

CONCENTRATIONS OF VARIOUS METAL ELEMENTS IN OKRA SHOOTS. Concentrations of various metal elements in okra shoots were affected by different cover crop treatments relative to the fallow control as follows: Mg was significantly enhanced by sunn hemp (Fig. 3); Zn was enhanced by

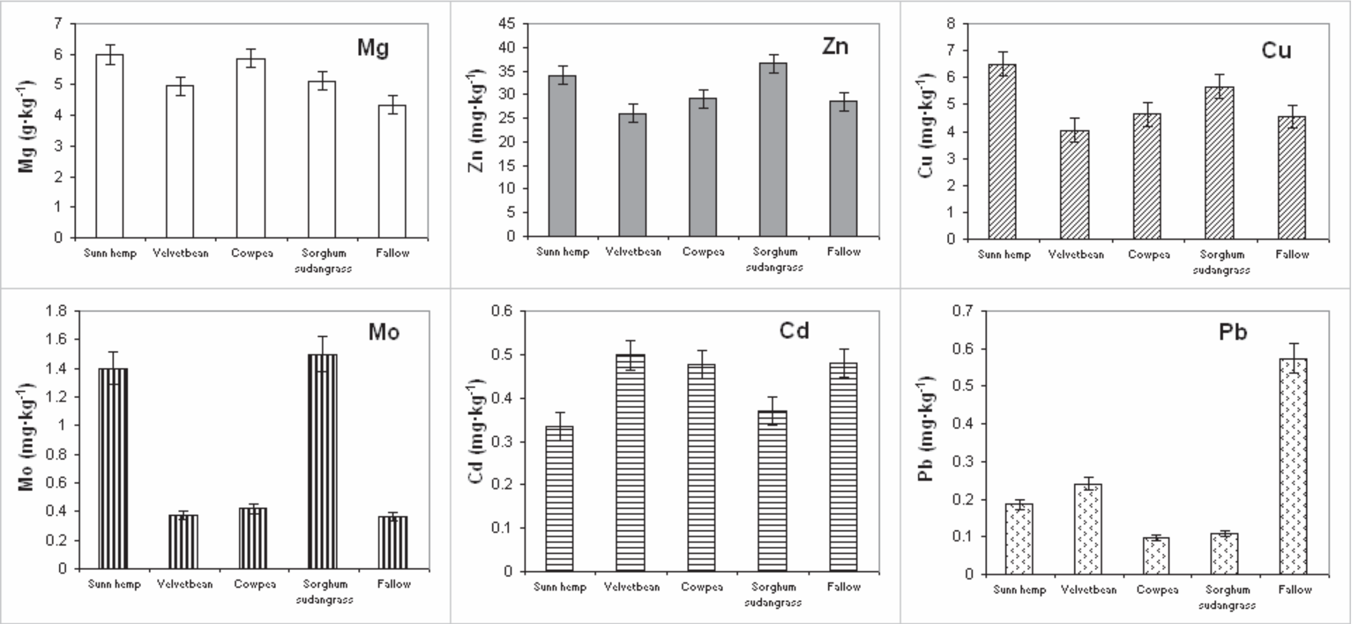

Fig. 3. The effect of various cover crops on the distribution of elements magnesium (Mg), zinc (Zn), copper (Cu), molybdenum (Mo), cadmium (Cd), and lead (Pb) in okra shoots. Vertical bars represent SD (n = 3); 1 g·kg^{-1} = 0.1%, 1 mg·kg^{-1} = 1 ppm.

sorghum sudangrass and sunn hemp, but not by velvetbean (Fig. 3); Cu was higher with sunn hemp and sorghum sudangrass but lower with velvetbean (Fig. 3); Mo was strongly enhanced by sunn hemp and sorghum sudangrass, but unaffected by the other cover crop treatments (Fig. 3); Cd was abated by sunn hemp and sorghum sudangrass, but little affected by cowpea and velvetbean (Fig. 3); Pb was strongly abated by all of the cover crops, but remained relatively high in the fallow treatment (Fig. 3).

Concentrations of various metal elements in okra shoots were affected by different organic soil amendment treatments relative to the unamended control as follows: Mg was strongly enhanced by the biosolids treatment and little affected by other amendment treatments (Fig. 4); Zn was greater with biosolids, co-compost, and yard waste compost treatments (Fig. 4); Cu was greater with biosolids and unaffected by the other amendments (Fig. 4); Mo was greater with biosolids, co-compost, coal ash, N-Viro Soil, and yard waste compost (Fig. 4); Cd was lower with co-compost, biosolids, coal ash, yard waste compost, and N-Viro Soil (Fig. 4); and Pb was not detectable with biosolids and coal ash, substantially decreased with N-Viro Soil, but obviously increased with the co-compost treatment (Fig. 4). The low concentration of Pb in okra shoots with all of the soil amendments other than co-compost might be related to the differential translocation of this metal into plant parts, since the Pb concentration in okra fruit was higher with biosolids, coal ash, and N-Viro Soil treatments (Table 5).

CONCENTRATIONS OF METAL ELEMENTS IN OKRA ROOTS. Concentrations of various metal elements in okra roots were affected by different cover crop treatments relative to the control as follows: Mg levels were higher with all of the cover crop treatments (Fig. 5); Zn was higher with sorghum sudangrass, sunn hemp, and velvetbean treatments (Fig. 5); Cu was higher with sorghum sudangrass treatment (Fig. 5); Mo was higher with sorghum sudangrass and sunn hemp treatments (Fig. 5); Cd was significantly higher in the fallow and velvetbean treatments than in the other cover crop treatments (Fig. 5); and Pb was higher in the sorghum sudangrass, cowpea, and velvetbean treatments than in the sunn hemp and fallow treatments (Fig. 5).

Concentrations of various metal elements in okra roots were affected by different soil amendments relative to the unamended control as follows: Mg was higher with biosolids (Fig. 6); Zn was higher with biosolids and co-compost (Fig. 6); Cu was higher with N-Viro Soil (Fig. 6); Mo was higher with biosolids, co-compost, coal ash, and N-Viro Soil (Fig. 6); Cd levels were the lowest with biosolids, followed by co-compost, coal ash, yard waste compost, and N-Viro Soil (Fig. 6); Pb was lower with coal ash and co-compost (Fig. 6). The application of soil amendments did not increase concentrations of Cd and Pb in okra roots.

Zinati et al. (2004) discussed the possibility that compost may contribute heavy metals, which may accumulate in treated soils and be taken up and concentrated in the edible parts of crop plants. However, Ozores-Hampton et al. (1997) found no significant changes in concentrations of Cd, Cu, Pb, Ni, and Zn in tomato and squash fruit grown in a compost amended field. Stoffella et al. (1996) measured N, P, K, Ca, Mg, Zn, Cu, Mn, barium (Ba), and silicon (Si) in citrus leaves for 42-year-old trees with and without application of municipal solid waste compost (MSW), and found no significant differences among treatments. In a tomato field in southern Florida equipped with zero-tension pan lysimeters, Li et al. (2003) investigated the possibility that trace metals might accumulate as a result of applications of different composts, biosolids, and coal ash. Their data indicated that appropriate applications of coal ash or other soil amendments should not lead to detrimental contamination of soil, food, or groundwater.

Notwithstanding, major concerns persist regarding the possible dangers

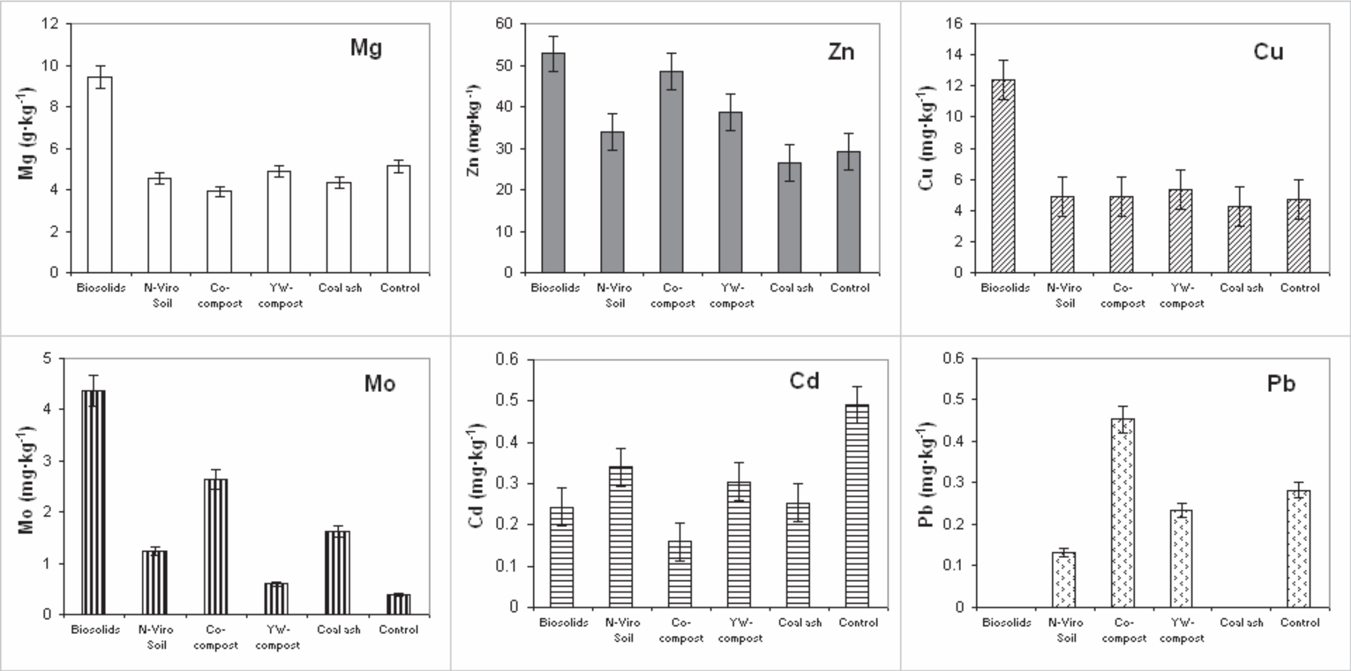

Fig. 4. The effect of soil amendments on the distribution of elements magnesium (Mg), zinc (Zn), copper (Cu), molybdenum (Mo), cadmium (Cd), and lead (Pb) in okra shoots. Vertical bars represent SD (n = 3). The soil amendments were biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (a compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (a combustion by-product from power plants); 1 g·kg^{-1} = 0.1%, 1 mg·kg^{-1} = 1 ppm.

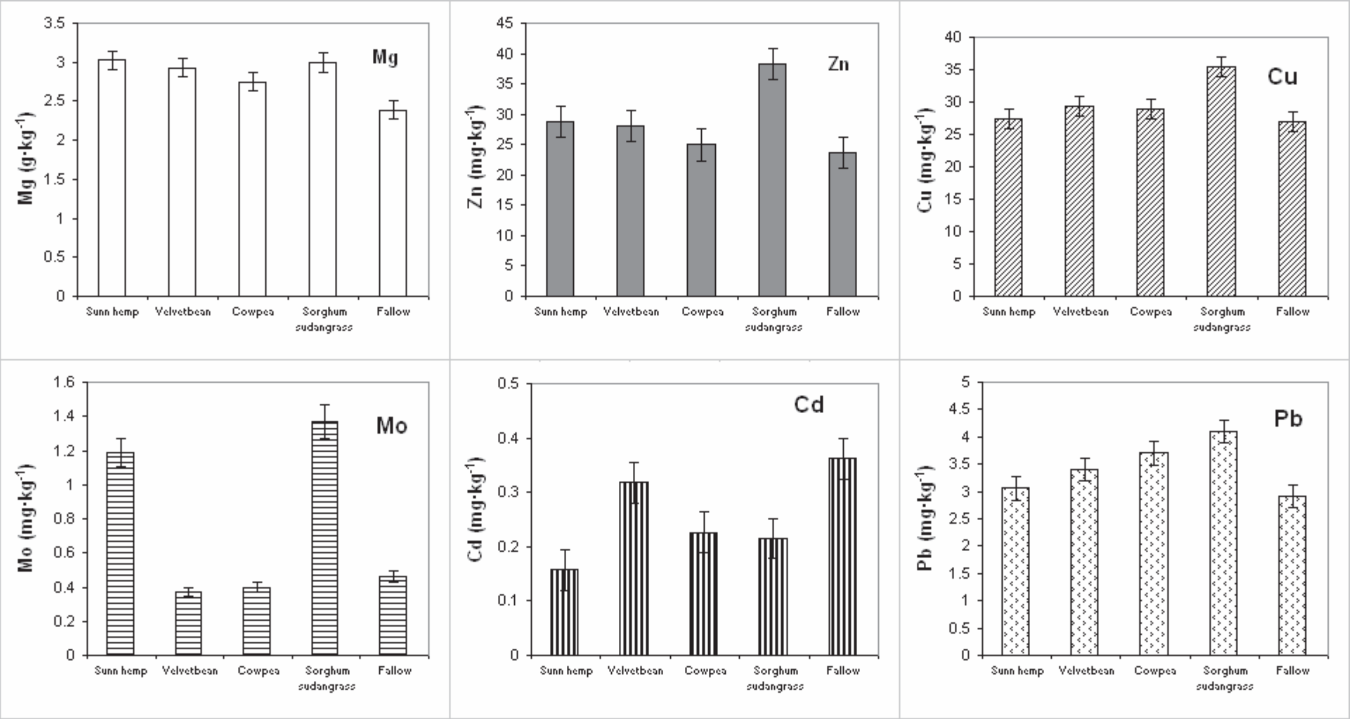

Fig. 5. The effect of cover crops on the distribution of elements magnesium (Mg), zinc (Zn), copper (Cu), molybdenum (Mo), cadmium (Cd), and lead (Pb) in okra roots. Vertical bars represent SD (n = 3); 1 g·kg^{-1} = 0.1%, 1 mg·kg^{-1} = 1 ppm.

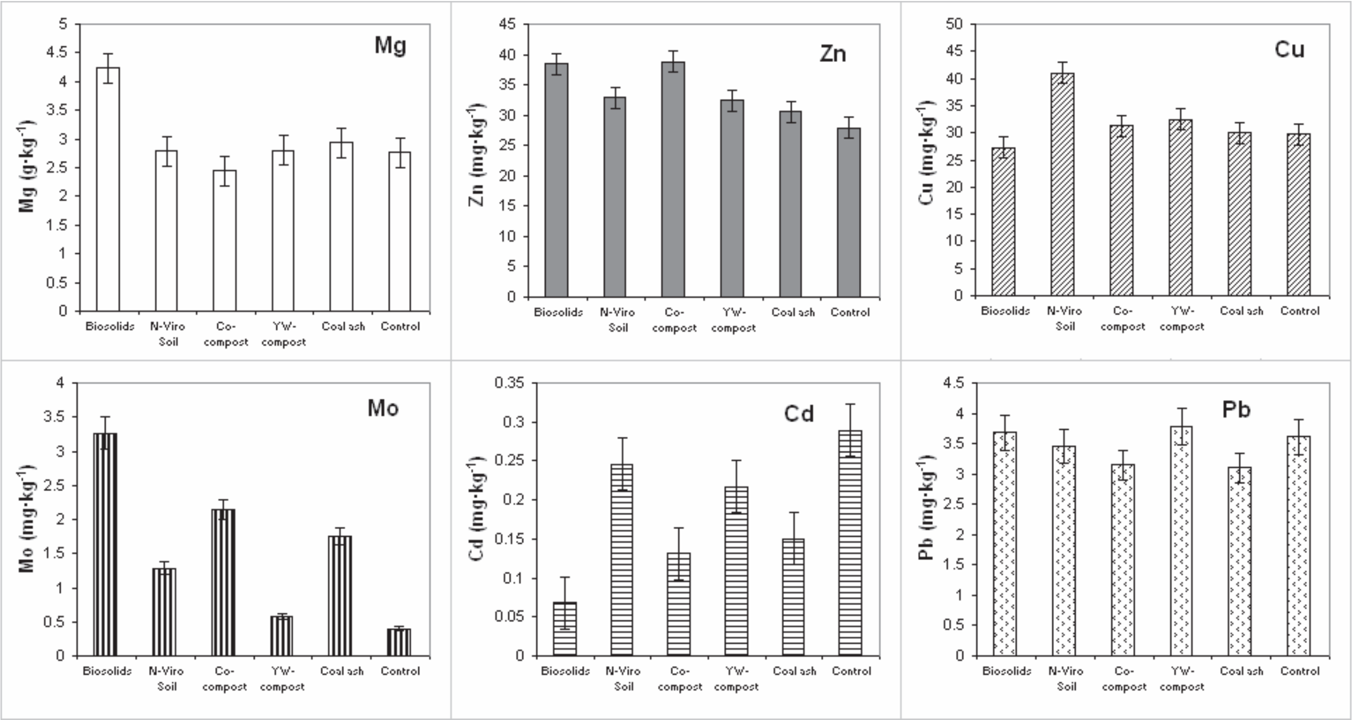

Fig. 6. The effect of soil amendments on the distribution of elements magnesium (Mg), zinc (Zn), copper (Cu), molybdenum (Mo), cadmium (Cd), and lead (Pb) in okra roots. Vertical bars represent SD (n = 3). The soil amendments were biosolids (sediment from wastewater treatment plants); N-Viro Soil (mixture of biosolids and coal ash; N-Viro International Corp., Toledo, Ohio); co-compost (biosolids with yard wastes in the ratio of 3:7 from West Palm Beach, Fla.); YW-compost (a compost of yard wastes, mainly from leaves and branches of trees and shrubs, and grass clippings), and coal ash (a combustion by-product from power plants); 1 g·kg^{-1} = 0.1%, 1 mg·kg^{-1} = 1 ppm.

posed by applications to farm land of organic amendments tainted with toxic metallic elements. Wang et al. (2001) cited a number of cases in which organic amendments had caused serious environmental pollution, and concluded that the level of hazard is determined both by the concentrations of toxic metals in the amendment and the characteristics of the soil to which the amendment is applied. Since the soil used in the present experiment has a high pH and a high concentration of $CaCO_3$, the application of organic amendments with properties similar to those detailed in Table 1 is very unlikely to cause any environmental problem. In the present study, the Cd concentration was actually lower in fruit with several of the soil amendments. The Pb concentration was elevated in okra fruit by application of biosolids; this may have been due to the high application rate equivalent to 50 Mg·ha^{-1}. Therefore, the hazard of toxic metal contamination in plant tissue probably is manageable. These results agree well with those of our previous experiment with these organic amendments at the same loading rate, which showed that these amendments can be used in southern Florida without risk of leaching harmful toxic metals, even with a heavy loading rate (Wang et al., 2003b).

Conclusions

Soil incorporation of leguminous cover crops, especially sunn hemp, and of some organic soil amendments, notably biosolids and co-compost, provides a good source of N and other elements needed by the succeeding crop to produce high yields. Based on these 2-year pot experiments, the residual effects of cover crops and organic amendments can carry over at least one cropping cycle and profoundly improve the physical and chemical properties, as well as fertility, of Krome gravelly loam soil. Further field experiments are needed to confirm these preliminary results.

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