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Pesticide Residues in Soil and Quality of Potato Grown with Sewage Sludge

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Soil erosion reduces productivity by decreasing soil depth, removes nutrients required for plant growth, and alters soil physical properties resulting in less water infiltration, poorer crop establishment and root penetration (Littleboy et al. 1992). Yield decline due to erosion is masked by advances in technology such as use of fertilizers, higher yielding crop varieties, improved planting technology, and use of pesticides. Intensive use of pesticides in many parts of the United States raises the potential for serious non-point source contamination of soil and receiving water. One of the major problems with the application of pesticides is targeting the chemicals to the pest. Often, less than 0.1% of the pesticides applied to crops under field conditions reach the target pests (Pimentel and Levitan 1986). The remaining 99.9% can have a number of adverse effects including health risks to both humans and wildlife. Occurrence of pesticides in runoff and infiltration water (Antonious 1999; 2000; 2003) and on treated vegetables (Antonious et al. 1998; 2001a; Antonious 2002) increases their potential transport into rivers and streams. Knowledge of how pesticide residues reach the edge of the field and streams and how these residues can be minimized is essential for reducing the quantity of pesticides reaching surface water and the nation's water resources. Minimizing soil erosion is vital to long-term crop production. Therefore, a proper soil management practice is an important key element in reducing soil erosion and pesticide movement. Composting provides an organic amendment useful for improving soil structure and nutrient status (Burriuso et al. 1997). Compost also increases pesticide sorption (Martinez and Almendros 1992; Guo et al. 1993; Antonious et al. 2001a; Patel 2002), and decreases pesticide leaching (Zsolnay 1992).

The use of sewage sludge in land farming provides not only a means for sludge disposal, but can also improve soil fertility and physical properties of soils (Garcia et al. 1995; Logan and Harrison 1995). Addition of lime to sewage sludge is an effective and low-cost method for treating sewage sludge to reduce the number of pathogens and availability of heavy metals (Allievi et al. 1994) for safe utilization of sewage sludge in agriculture. The proportion of sewage sludge recycled for agricultural use is growing steadily in the US (Beck et al. 1995). Nutrients in sludge are used to replace a supplement commercial fertilizer, while sludge organic matter has been reported to improve soil structure, reduce soil erosion, and improve crop

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yield (Tester 1990; Bevacqua and Mellano 1993). Sewage sludge processed with alkaline additives such as lime, and pasteurized at high temperature at the waste water plant facility provides a media suitable for plant growth (Logan and Harrison 1995; Wong 1995).

Trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl) benzenamine), a pre-emergence herbicide, is widely used for control of annual grasses and broadleaf weeds. Diazinon (O,O-diethyl O-(6-methyl-2-(1-methylethyl)-4-pyrimidinyl) phosphorothioate, a non-systemic insecticide and acaricide, is used to control sucking and chewing insects and mites on a wide range of crops including potatoes (Anonymous 1995). The objectives of this investigation were 1) to study the effect of mixing soil with municipal sludge and yard waste compost on trifluralin and diazinon residues in soil, and 2) to study the impact of municipal sludge and yard waste compost on potato yield and quality of tubers. Soil amendments that mitigate environmental degradation while maintaining agricultural productivity and profitability are explored in this study.

MATERIALS AND METHODS

A field study was conducted on a Lowell silty loam soil (2.8% organic matter, pH 6.99) located at Kentucky State University Research Farm, Franklin County, KY. The soil has an average of 12% clay, 75% silt, and 13% sand. Universal soil loss equation (USLE) standard plots of 22 × 3.7 m (n=18), on a soil of 10% slope were established. Plots were separated using metal borders 20 cm high above the ground level to prevent cross contamination between treatments. Three soil management practices were used 1) sewage sludge (Nicholasville Wastewater Treatment Plant, Versailles, KY) mixed with native soil at 50 t acre^{-1} (on dry weight basis) with a plowing depth of 15 cm, 2) yard waste compost made from yard and lawn trimmings, and vegetable remains (obtained from Kentucky State University Research Farm, Franklin County) mixed with native soil at 50 t acre^{-1} (on dry weight basis) with a plowing depth of 15 cm, and 3) a no-mulch (NM) control treatment (roto-tilled bare soil). Potato (*Solanum tuberosum* cv. Kennebec) seed pieces were planted (10 plants row^{-1}). Plots were irrigated by drip tape (Rainbird Corporation, Glendora, CA) and no fertilizer was applied. Trifluralin (430 g liter^{-1} EC; Treflan) was sprayed on the soil surface at the rate of 0.75 lb acre^{-1} and incorporated into the soil. Diazinon AG500 was sprayed on potato foliage at a height of 15-20 cm above plant canopy at the rate of 0.75 pints acre^{-1} in a total volume of 157.5 L of water acre^{-1}. Spraying was carried out using a 4-gallon portable backpack sprayer (Solo) equipped with one conical nozzle operated at 40 p.s.i. Potato from the three soil treatments were harvested and weighed, tubers with a diameter >1 7/8″ (class-A) and those <1 7/8″(class-B) and total yield were recorded. Twenty-five tubers were randomly selected from each of the 18 plots (six replicates from each treatment) and evaluated for internal and external tuber defects (Snowdon 1991; Antonious et al. 2001b). Soil samples were collected (n=11) from each treatment up to 35d following spraying to a depth of 15 cm from the experimental plots during the growing season using a soil core sampler equipped with a plastic liner tube (Clements Associates, Newton, IA, USA) of 2.5 cm i.d. for maintenance of sample integrity. Samples were air-dried in the dark, sieved to a size of ≤2 mm. Fifty g soil were shaken with 100 mL mixture of acetonitrile-water (99:1 v/v) for 1 h using a Multi-wrist shaker (Lab-Line Instruments, Inc., Melrose Park, IL, USA). The solvent was filtered through Whatman 934-AH glass microfibre discs (Fisher Sci, Pittsburgh, PA) of 90 mm diameter, concentrated by rotary vacuum (Buchi Rotavapor Model 461, Switzerland) and N_2 gas stream evaporation. A Supelco Envi-C_{18} cartridge was placed on a Visiprep solid-phase extraction vacuum manifold (Supelco) and conditioned first with 4 mL of 50% acetonitrile in water and then with isooctane (3 mL). Four mL of the extract were loaded onto the top of the cartridge and passed through at a flow rate of 1-2 mL min^{-1}. Finally, the cartridge was eluted with 3 mL of hexane and 3 mL of isooctane, and the eluate was dried under a gentle stream of N_2 gas (99.99% purity) and reconstituted in isooctane for GC determination. GC analysis of trifluralin and diazinon in soil was performed on a Hewlett-Packard model 5890A Series II gas chromatograph (Hewlett Packard Co., Avondale, PA), equipped with a NP detector and a megabore column of 15 m x 0.53 mm i.d. and 0.5 μm film thickness (DB-5 column) (J & W Scientific Inc., Folson, CA). Operating conditions were 110 ^oC initial temperature (10 ^oC ramp min^{-1} and 230, 250, and 280 ^oC for injector, oven, and detector, respectively. Area units were obtained from 1 μL injections. Linearity over the range of concentrations was determined using regression analysis ($R^2 >$ 0.95). Peak areas were determined on a Hewlett Packard model 3396 series II integrator. Quantification was based on average peak areas from two consecutive injections obtained from external standards. Under these conditions retention times (Rt) of trifluralin and diazinon were 6.88 and 8.18 min., respectively. Peak identity was confirmed by consistent retention time and coelution with standards under the conditions described. Trifluralin technical material of 96.3% purity was obtained from Dow AgroSciences (Indianapolis, IN, USA). Diazinon of 97.3% purity was obtained from Ciba-Geigy Corp. (Greensboro, NC, USA). Standard solutions in isooctane (trifluralin) and in acetone (diazinon) ranging from 0.1 to 15 ng μL^{-1} were prepared for determination by GC/NPD. Standard solutions at 0.15 to 1 $\mu g\ g^{-1}$ soil were used to spike blank soil samples obtained from the three soil treatments for evaluating the reproducibility and efficiency of the analytical procedures used. Recoveries of trifluralin from fortified soil samples ranged 86.3-100 %. Recoveries of diazinon from fortified soil samples ranged 76.5-99 %. Quality control (QC) samples included three field blanks to detect possible contamination during sampling, processing, and analysis. Three sets of duplicate samples and three sample-matrix spikes were used to evaluate potential bias of the data collected and the ability of the analytical procedure to recover the analyte from the soil field samples. The lack of trifluralin and/or diazinon residues in the blank samples suggested that there was no contamination from sampling, processing, or laboratory procedures.

RESULTS AND DISCUSSION

Residues of trifluralin in soil mixed with sewage sludge, yard waste compost, and NM (unamended) bare soil are presented in Figure 1. Residues were significantly higher in sewage sludge treatments compared to yard waste treatments and no-mulch control. Diazinon residues in soil represent the amount that reached the soil as drift during foliar spraying or washed-off residues from the plant surface into the soil following natural rainfall. These residues were also higher in soil treated with sewage sludge compared to other treatments. Previous results have indicated that the sorption of pesticides was highest in soils with greatest content of organic matter (Patel 2002; Zbytniewski and Buszewski 2002). The organic matter contents were not significantly different between soil mixed with sewage sludge and soil mixed with yard waste compost (Table 1). Adsorption of trifluralin and diazinon therefore, could be attributed also to the differences in elemental composition. High concentrations of Ca and Cu were present in soil, where sewage sludge was applied, compared to native soil and yard waste treatments. Calcium, Cu, and Zn are essential elements that may be supplied by sludge addition.

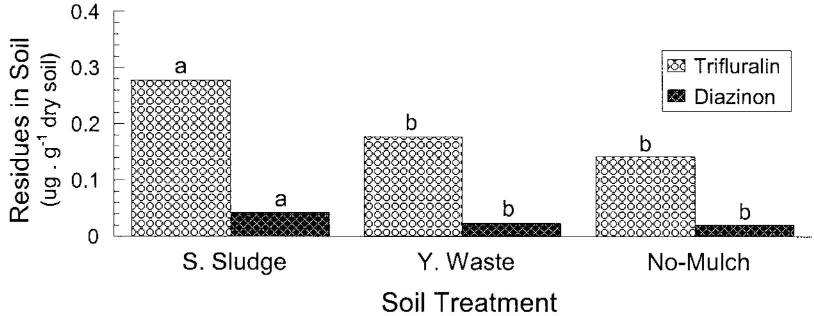

Figure 1. Average concentration of trifluralin and diazinon residues in soil collected during 35 days following pesticide spraying from the rhizosphere of potato grown with drip irrigation under three soil management practices. Statistical comparisons were done between the three soil management practices for each pesticide. Bars accompanied by different letter for each pesticide are significantly different ($P < 0.05$) from each other using the SAS procedure (SAS Institute, 1999, Duncan's multiple range test).

Sewage sludge contains nutrients that plants require. Addition of sludge has also increased the soil pH to about 1.5 units compared to native soil (Table 1). Soil pH affects ion availability (Woodbury 1992). An increase in pH can bring about strong adsorption on soil particles or in some cases, precipitation of Mn, Cu, and Zn among other metals, which in turn allows for lower accumulation of these metals in plant tissues (Stratton and Rechcigl 1998). Application of sewage sludge as a soil management practice may therefore lead to increased retention or removal of hydrophobic compounds like trifluralin and diazinon from runoff water. In addition, application of carbon-rich waste to soils may be useful for reducing pesticide leaching to groundwater (Guo 1993). Average total potato yield was lowest in NM unamended treatments and highest in yard waste compost treatments (Figure 2). Potato grows well at pH range from 4.5 to 7.0 but soil borne diseases such as scab often becomes serious at higher pHs. Urban sewage sludge typically has a higher nitrogen content, and hence a lower C/N ratio, than native soil. Total yield from sludge and yard waste treatments were not significantly different. The use of sewage sludge in land farming must increase profits in order for it to become an accepted practice among vegetable growers.

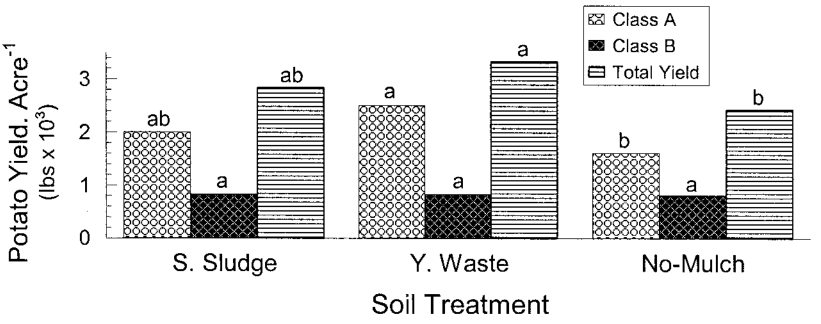

Figure 2. Yield of potato grown with drip irrigation under three soil management practices. Statistical comparisons were done between the three soil management practices for each tuber class or total yield. Bars accompanied by different letter(s) in each class or total yield are significantly different (P< 0.05) from each other using the SAS procedure (SAS Institute, 1999, Duncan's multiple range test).

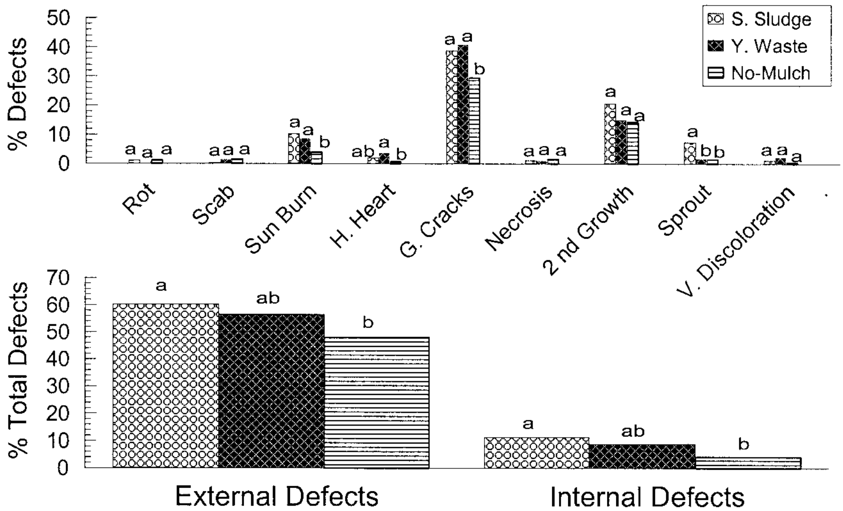

Figure 3. Potato tuber defects (upper graph) and total external and internal defects (lower graph) identified in potato grown under field conditions with drip irrigation under three soil management practices. Statistical comparisons were bone between three soil management practices. Bars accompanied by different letter(s) in each tuber defect or total are significantly different (P< 0.05) from each other using the SAS procedure (SAS Institute, 1999, Duncan's multiple range test).

Potato tubers diagnosed for rot, scab, sun burn, hollow heart, growth cracks, necrosis, second growth, sprout, and vascular discoloration are presented in Figure 3 (upper graph). Four of the tuber defects (sun burn, hollow heart, growth cracks, and sprouts) were significantly different among treatments. Sun burn is caused by tuber exposure to light during the growing season. Deeper planting and better hilling help to prevent this effect. Hollow heart is caused primarily by growing

Table 1. Effects of sewage sludge and yard waste compost on chemical characteristics of soil in the rhizosphere of potato plants grown under three soil management practices at Kentucky State University Research Farm, Franklin County, Frankfort, KY.

Soil Parameters	Sewage Sludge	Yard Waste Compost	Native Soil	Sludge Mixed † with Native Soil	Yard Waste Mixed † with Native Soil
pH*	12.33 ± 0.77 a	7.05 ± 0.17 c	6.99 ± 0.02 c	8.48 ± 0.13 b	7.31 ± 0.22 c
Organic Matter** %	30.26 ± 1.15 a	21.07 ± 0.16 b	2.77 ± 2.77 d	5.95 ± 0.17 c	5.72 ± 0.18 c
Elemental Content ‡					
C %	17.05 ± 0.56 a	13.02 ± 1.36 b	1.59 ± 0.06 d	3.77 ± 0.35 c	3.84 ± 1.03 c
N %	2.16 ± 0.13 a	1.02 ± 0.07 b	0.15 ± 0.01 d	0.39 ± 0.02 c	0.32 ± 0.07 c
C/N ratio	7.90 ± 0.24 d	12.74 ± 0.44 a	10.54 ± 0.53 b	9.54 ± 0.47 c	11.78 ± 0.68 a
P %	1.23 ± 0.32 a	0.66 ± 0.02 b	0.18 ± 0.06 c	0.31 ± 0.13 c	0.24 ± 0.12 c
K %	0.20 ± 0.01 b	0.67 ± 0.16 a	0.25 ± 0.07 b	0.23 ± 0.06 b	0.28 ± 0.10 b
Ca %	19.10 ± 1.28 a	5.18 ± 0.10 b	0.40 ± 0.15 d	2.85 ± 1.19 c	1.04 ± 0.54 d
Mg %	0.38 ± 0.08 b	0.57 ± 0.03 a	0.19 ± 0.08 c	0.22 ± 0.11 bc	0.25 ± 0.09 bc
Zn ppm	497.77 ± 72.45 a	112.13 ± 9.25 b	52.96 ± 8.61 c	121.68 ± 12.83 b	95.50 ± 41.66 b
Cu ppm	685.37 ± 31.79 a	65.17 ± 11.65 b	11.84 ± 4.18 c	92.57 ± 7.56 b	13.41 ± 3.02 c
Mn ppm	412.26 ± 88.88 b	1021.50 ± 61.49 a	720.50 ± 33.59 ab	728.40 ± 82.58 ab	737.20 ± 73.14 ab
Fe ppm	8828.3 ± 289.4 b	18888.6 ± 688.7 a	20071 ± 230.13 a	18064 ± 628.91a	19230 ± 354.52 a

Each value in the table is an average ± SE obtained from analysis of three samples. Values within a row having different letter(s) are significantly different ($P< 0.05$) from each other using SAS procedure (SAS Institute, 1999; Duncan's multiple range test). * pH was determined using a glass electrode in a soil: distilled water slurry (1:5, w/v). ** Soil organic matter was calculated as dry weight minus ash content. † Sewage sludge and yard waste compost were each mixed with native soil at 50t $acre^{-1}$ on dry weight basis.
‡ Nitrogen was determined by Kjeldahl method. All other elements were determined using an Inductively Coupled Plasma Spectrometer after digestion with HCl and H_2SO_4.

conditions and is more common in some varieties than others. Growth cracks are caused by weather conditions that favor excellent growth following a period of very poor growth (Snowdon 1991). Overall tuber defects calculated as external and internal defects (Figure 3, lower graph) showed that no significant differences were found between the two soil management practices, soil mixed with sewage sludge and soil mixed with yard waste compost.

Incorporating compost into the soil provided nutrients needed to sustain vegetation. There is an urgent need to develop long-term, low-energy, biological, self-sustainable systems of farming. The sharply escalating production costs associated with the increasing costs of energy, fertilizers, and pesticides to U.S. farmers and the problems of soil deterioration and erosion associated with intensive farming systems have generated considerable interest in less expensive and more environmentally compatible production alternatives by recycling wastes from several processing operations to produce higher quality organic amendments for soil improvement and plant growth. Our results have indicated that the methods of application of these two waste materials (sewage sludge and yard waste) are simple, inexpensive, energy conserving, and effective for erosion control (data not shown) and nutrient recycling. We suggest that the use of sewage sludge in land farming can become a useful technique for trapping non-polar pesticides such as trifluralin and diazinon and may reduce surface and groundwater contamination by these two pesticides. Further studies are in progress.

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