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Sorption and Desorption of Endosulfan Sulfate and Diuron to Composted Cotton Gin Trash

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This paper investigates the potential use of composted cotton gin trash (CCGT) as a pesticide sorption medium in remediation of contaminated tailwater. CCGT was found to contain a large organic matter fraction (25.22%). Sorption of endosulfan sulfate and diuron, using the batch equilibrium method, was rapid but not limited for the range of applied concentrations, with diuron failing to reach equilibrium after two days. The partition K_d and organic carbon partition K_{OC} coefficients determined diuron ($K_d = 78$; $K_{OC} = 526$) and endosulfan sulfate ($K_d = 1500$; $K_{OC} = 10\,111$) to reside in the solid phase. Limited desorption of diuron and higher range concentrations of endosulfan sulfate (50−100 μg L^{-1}) were quantified. Sorption and desorption resulted from hydrophobic and hydrophilic interactions with the humic components of the compost. CCGT was concluded to have a superior sorption capacity to other sorbents reported in the literature, an assessment that requires field substantiation.

KEYWORDS: Composted cotton gin trash; sorption; desorption; diuron; endosulfan sulfate

INTRODUCTION

Pesticide concentrations currently detected in irrigation tailwater of cotton farms are sometimes high enough for concern regarding exposure (*1*). It is common practice that irrigation tailwater be retained on-farm in holding dams to protect vulnerable surface waterbodies, such as lakes and rivers (*2*). Exposure of biota to contaminated water, however, is still possible through contact with collected tailwater and overflow of holding dams. This has justified the need to investigate methods for removing pesticides from runoff to reduce human and wildlife exposure.

Methods of contaminated tailwater remediation involve exploiting degradation mechanisms commonly observed in the environment. Most involve microbial and phytobiological degradation pathways (*1, 3*), while other technologies aim to limit the transport potential of pesticides from the soil by filtration and sorption (*4–7*).

The most effective sorbent of organic pollutants is activated carbon, but its high cost makes it an unattractive means of treating large volumes of water on cotton farms. It has been widely demonstrated, however, that soil organic matter and other organic amendments offer enhanced pesticide sorption capacity (*8, 9*). Aerobically composted organic material, in particular, produces negatively charged polyphenolic compounds, with a high binding affinity for hydrophobic organic pesticides (*8, 9*). Composted cotton gin trash (CCGT), the composted waste material representing 15−20% of harvested cotton, currently provides no economic value in world cotton production (*10*) and has not been investigated for its pesticide sorption ability.

This paper addresses the binding of diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea) and endosulfan ((1,4,5,6,7,7-hexachloro-8,9,10-trinorborn-5-en-2,3-ylenebismethylene) sulfite), which are two pesticides with contrasting chemical and physical properties widely used in the irrigated cotton industry, to CCGT via batch equilibrium studies. Diuron is a soil applied pre-emergent herbicide used to control a number of broad-leaf weeds (*11*), as well as the defoliation of cotton. Diuron functions as a photosynthesis inhibitor in plants. Diuron is characterized by having a highly polar urea functional group, contributing to its solubility in water (36.4 mg L^{-1}; (*12*)), and a nonpolar, highly stable chlorinated aromatic ring, capable of hydrophobic interactions, as indicated by its octanol/water partition coefficient (log K_{OW}) of 2.85 (*12*). Endosulfan is a broad spectrum insecticide that exists as two isomers, α- and β-endosulfan. In contrast to diuron, endosulfan is relatively insoluble in water ($\alpha = 0.32$ mg L^{-1} and $\beta = 0.33$ mg L^{-1}; (*12*)) and hydrophobic (log $K_{OW} = 4.74$ and 4.79 for α- and β-endosulfan, respectively; (*12*)). Endosulfan isomers readily undergo microbiological oxidation, at the sulfite functional group, to produce endosulfan sulfate (*2, 13–16*). Endosulfan sulfate is more commonly detected in irrigation tailwater and is more toxic to fish than its parent isomers (*14*), therefore making it a compound of interest in this investigation over its parent isomers.

MATERIALS AND METHODS

All chemical reagents and solvents were of analytical grade. Diuron (98.6% w/w, donated by Nufarm, Australia) and endosulfan sulfate

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Table 1. Diuron and Endosulfan Sulfate Sorption and Desorption Kinetic Models, Showing Parameter Estimates and Adjusted Coefficient of Determination (Adj. R^2)[a]

		kinetic exponential model parameters					
pesticide	model	y_0	a	b	c	d	adj. R^2
sorption							
endosulfan sulfate	$y = a(1 - e^{-bx})$		0.48 (±0.01)	0.17 (±0.03)			0.96
diuron	$y = a(1 - e^{-bx}) + c(1 - e^{-dx})$		0.89 (±0.05)	0.09 (±0.02)	0.49 (±0.08)	0.0006 (±0.0001)	0.96
desorption							
diuron	$y = y_0 + ae^{-bx}$	1.00 (±0.02)	0.44 (±0.06)	0.02 (±0.01)			0.90

[a] Numbers in brackets are standard errors of the parameter estimates as calculated by SigmaPlot v9.0.

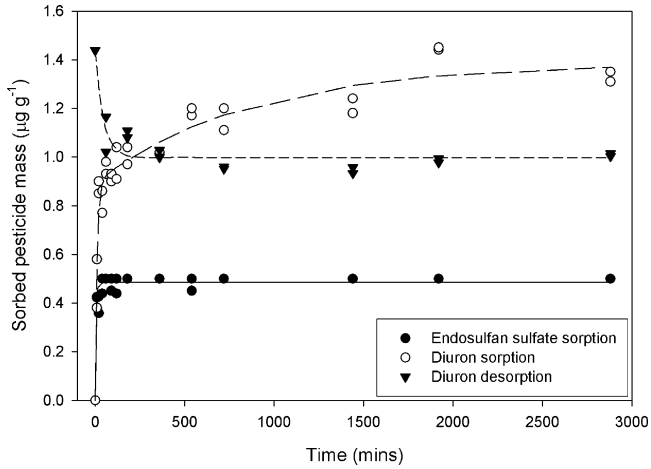

Figure 1. Endosulfan sulfate and diuron sorption and desorption kinetics showing observed and fitted results for sorbed mass of each pesticide (μg g^{-1}) against time (min). (Endosulfan sulfate sorption, adj. $R^2 = 0.96$; diuron sorption, adj. $R^2 = 0.96$; and diuron desorption, adj. $R^2 = 0.90$).

(>99% w/w, purchased from Hoescht, Germany) standards (1000 and 100 mg L^{-1}) were prepared in acetone and stored in 200 mL amber glass bottles in a freezer (<−4 °C).

CCGT was collected from a large stockpile located at Auscott Ltd., Narrabri, northwestern New South Wales, Australia. Except for organic matter determination, the CCGT was air-dried, sieved (<2 mm), and then dried (105 °C) for 24 h to homogenize the media (*17*). Once dried, the CCGT was stored in a sealed glass jar and kept at room temperature.

The organic matter and mineral content of the CCGT was determined using the weight loss-on-ignition (WLOI) method (*18*). Four replicates of 10 g (±0.1 mg) of fresh CCGT were weighed out into clean dry 20 mL crucibles (of known weight). The samples were dried (105 °C) for 24 h. The dried samples were then cooled to room temperature in a desiccator containing $CaCl_2$ pellets, weighed, and placed in a muffle furnace (500 °C) for 24 h. The samples were allowed to cool in a desiccator at room temperature and weighed. The fraction of organic matter (%OM) was calculated by difference as a ratio of the oven dry weight.

Batch Sorption and Desorption Experiments. Sorption and desorption batch experiments were performed on the CCGT. The methodology used, consisting of kinetic and isotherm experiments, was optimized from OECD (*17*) as follows.

Sorption. Following partition coefficient K_d estimation techniques, a sorbent/sorbate ratio of 1:50 was devised. Oven-dried CCGT (2 ± 0.001 g) was weighed and 100 mL of 0.01 M $CaCl_2$ solution was decanted into each 250 mL conical flask. The flasks were stoppered with aluminum foil lined rubber stoppers and left to equilibrate for 12 h at 120 rpm using an orbital shaker (Braun, Germany). To each flask, set aliquots of stock solution (100 mg L^{-1}) were added to give final concentrations of 50 μg L^{-1} of diuron and 10 μg L^{-1} of endosulfan sulfate. All flasks were agitated at 120 rpm, and 50 mL aliquots were extracted from duplicate flasks for each pesticide at 10, 20, 40 min, 1, 1.5, 2, 3, 6, 9, 12, 24, 32, and 48 h. Single blank flasks, without sorbate (pesticide), and duplicate controls, without sorbent (compost), were extracted after 9, 24, and 48 h.

The flasks were then removed from the orbital shaker. Endosulfan sulfate slurries were vacuum filtered through 1.2 μm GF/C glass microfiber filters (Whatman, U.K.). The supernatant was collected into amber glass bottles (200 mL), capped with foil-lined lids, and refrigerated for later extraction and analysis. Diuron aliquots (2 mL) were drawn directly from the slurry and filtered through a 0.22 μm regenerated cellulose membrane (Sartorius, Germany) prior to analysis.

By using the same compost/0.01 M $CaCl_2$ solution ratio and following 12 h slurry equilibration, duplicate flasks (total 14 for each pesticide) were spiked with relevant volumes of 1000 mg L^{-1} (diuron) and 100 mg L^{-1} (endosulfan sulfate) stock solutions to make final concentrations of 500, 250, 100, 50, 25, 10, and 5 μg L^{-1} of diuron and 100, 75, 50, 10, 5, 2.5, and 1 μg L^{-1} of endosulfan sulfate. Duplicate control flasks containing 250 and 25 μg L^{-1} of diuron and 75 and 5 μg L^{-1} of endosulfan sulfate in 100 mL of 0.01 M $CaCl_2$ (without sorbent) were also prepared. All flasks were gently shaken at 120 rpm until equilibration, as indicated by the sorption kinetics experiment for diuron and endosulfan sulfate (*17*). Samples were extracted and filtered as above.

Desorption. Oven-dried CCGT (2 ± 0.001 g) was added to 0.01 M $CaCl_2$ solution (100 mL) in a series of 200 mL Pyrex centrifuge bottles. The bottles were capped with foil-lined lids and allowed to equilibrate for 12 h via gentle agitation at 30 rpm on an end-over-end rotary shaker (400 mm diameter). Individual centrifuge bottles were spiked with relevant volumes of 100 mg L^{-1} diuron and endosulfan sulfate pesticide stocks to make final concentrations of 50 μg L^{-1} and 10 μg L^{-1}, respectively. The centrifuge bottles were then allowed to equilibrate with the slurry for a time indicated by the sorption kinetics experiment. All bottles were centrifuged at 368*g* for 10 min, and the supernatant discarded. The discarded supernatant was replaced with 100 mL of 0.01 M $CaCl_2$ solution. The bottles were then mixed on a rotary shaker, and replicate bottles were centrifuged for 10 min at 368*g* after 1, 3, 6, 12, 24, 32, and 48 h from supernatant replacement. Duplicate controls did not have their supernatant replaced following equilibration, except that they were centrifuged and supernatant collected after 1, 12, 24, and 48 h from supernatant replacement of spiked CCGT slurries. The supernatant was decanted into 200 mL amber glass bottles and refrigerated before extraction and analysis.

A desorption isotherm experiment was run for the same pesticide concentrations used in the sorption isotherm experiment. The same compost/0.01 M $CaCl_2$ ratios were prepared in 200 mL Pyrex centrifuge bottles and allowed to equilibrate on a rotary shaker (30 rpm) for 12 h. Individual duplicate bottles (total of 14 for each pesticide) were spiked with relevant volumes of 1000 mg L^{-1} of diuron or 100 mg L^{-1} endosulfan sulfate stock solutions. The bottles were allowed to equilibrate on a rotary shaker (30 rpm), centrifuged at 368*g* for 10 min, and the supernatant was discarded. The compost was resuspended in 100 mL of fresh 0.01 M $CaCl_2$ and gently shaken on a rotary shaker. Following equilibration, the samples were centrifuged at 368*g* for 10 min, and the supernatant was decanted into 200 mL amber glass bottles for later extraction and analysis.

Extraction and Analysis of Pesticides. Filtered diuron samples were analyzed untreated using an Applied Biosystems 3200 Q Trap LC/MS/MS, equipped with a Shimadzu SIL-20A autosampler, Shimadzu LC-20AD liquid chromatograph, and Shimadzu DGU-20A$_3$ degasser. A standard curve was prepared with stock standards redissolved in 50:

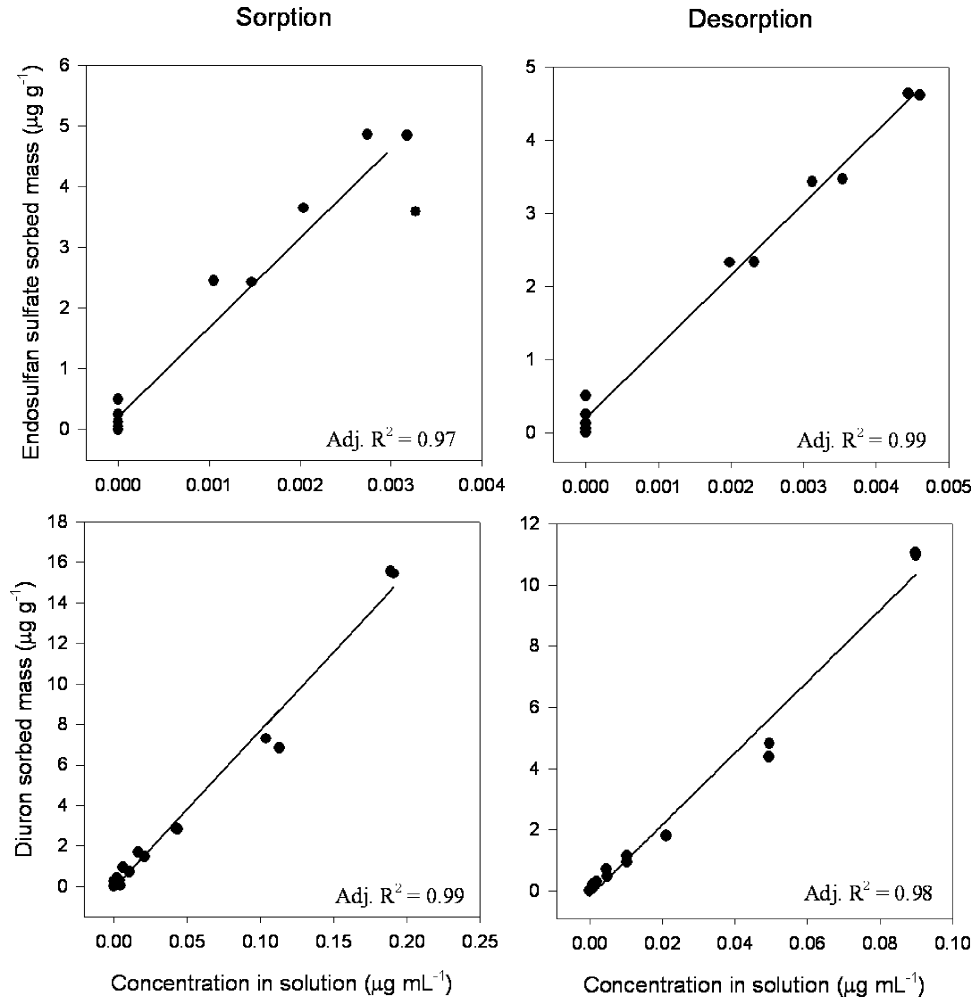

Figure 2. Sorption and desorption isotherms for endosulfan sulfate (**top left** and **top right**, respectively) and diuron (**bottom left** and **bottom right**, respectively) depicting observed and fitted results of sorbed pesticide mass (μg g^{-1}) against pesticide concentration in solution (μg mL^{-1}) and their respective coefficients of determination (adj. R^2).

Table 2. Summary of Linear Fits for Endosulfan Sulfate and Diuron Sorption Isotherms, Showing the Intercept (y_0), Partition (K_d), Organic Carbon Partition (K_{OC}), Desorption (K_{des}) Coefficients, and Adjusted Coefficient of Determination (Adj. R^2)[a]

	sorption				desorption		
pesticide	y_0	K_d (mL g^{-1})	adj. R^2	K_{OC} (mL g^{-1})	y_0	K_{des} (mL g^{-1})	adj. R^2
endosulfan sulfate	0.2 (±0.1)	1500 (±100)	0.97	10111	0.19 (±0.07)	980 (±30)	0.99
diuron	−0.1 (± −0.1)	78 (±4)	0.99	526	0.2 (±0.3)	117 (±7)	0.98

[a] Numbers in brackets are standard errors of the parameter estimates as calculated by SigmaPlot v9.0.

50 acetonitrile/water. Triplicate spikes of 50 μg L^{-1} diuron into 0.01 M $CaCl_2$ (100 mL) solution were filtered through 0.22 μm regenerated cellulose membranes (Sartorius, Germany) and then analyzed to validate the analytical method, yielding 95 ± 1% recovery.

Endosulfan sulfate aliquots (50 mL) were shaken for 1 min with 5 mL of dichloromethane in a Teflon separating funnel three times. The dichloromethane solvent was passed through anhydrous sodium sulfate (about 3 g) suspended by nonadsorbent cotton wool in a glass filter funnel. The combined extracts were collected into a 100 mL pear-shaped flask, evaporated to near dryness on a rotary evaporator (Buchi, Switzerland), and exchanged three times with 5 mL of hexane. After the final evaporation, the volume was made up to 0.5 mL with hexane. The volume was recovered for gas chromatographic (GC) analysis after filtering through 0.45 μm PTFE (Sartorius, Germany).

The extracts were analyzed using a gas chromatograph−mass spectrometer (Agilent 6890 gas chromatograph, with an Agilent 7683 series injector, an Agilent 5973 Network Mass Selective Detector, and a Phenomenex L-32-GGC capillary column). To validate the analytical method, triplicate spikes of 10 μg L^{-1} endosulfan sulfate into 0.01 M $CaCl_2$ (100 mL) solution were extracted and analyzed using the above technique, yielding 100 ± 11% recovery.

Data Analysis. Batch sorption−desorption data were analyzed following the method provided by OECD (*17*). The mass of sorbed pesticide C_s (μg g^{-1}), partition coefficient K_d (mL g^{-1}), and desorption coefficient K_{des} (mL g^{-1}) were calculated for both pesticides. Organic carbon partition coefficients K_{OC} (mL g^{-1}) were also calculated using the organic matter content (%OM) of the sorbent, according to the method of VanLoon and Duffy (*19*).

Sorption and desorption equilibria were deduced by fitting one- and two-rate exponential models using SigmaPlot 9.0 statistical software package. The best fit was determined by adjusted R^2.

RESULTS

Sorption and Desorption Kinetics. The exponential kinetic models used and the parameter outputs for sorption and desorption kinetics of endosulfan sulfate and diuron are sum-

Table 3. Summary of α-, β- Endosulfan, and Endosulfan Sulfate Partition (K_d) and Organic Carbon Partition (K_{OC}) Coefficients for a Range of Media Reported in the Literature

endosulfan sulfate			
substrate	% organic matter	K_d (mL g^{-1})	K_{OC} (mL g^{-1})
composted cotton gin trash	25.22	1500	10111

endosulfan							
			K_d (mL g^{-1})		K_{OC} (mL g^{-1})		
location	substrate	% organic matter	α-endosulfan	β-endosulfan	α-endosulfan	β-endosulfan	reference
Jabiru Lagoon, northern NSW, Australia	sediment	0.50[a]	20[b]	40[b]	3981[b]	7943[b]	(*15*)
India	sandy soil	0.58	8[b]	9[b]	2371[b]	2527[b]	(*28*)
Psamments, Brazil	sand	0.73[a]	92[b]		12600		(*30*)
Boobora Lagoon, northern NSW, Australia	sediment	0.90[a]	72[b]	90[b]	7943[b]	10000[b]	(*15*)
Boobora Lagoon, Nnorthern NSW, Australia	sediment	0.90[a]	90[b]	143[b]	10000[b]	15849[b]	(*15*)
Jabiru Lagoon, northern NSW, Australia	sediment	1.30[a]	130[b]	130[b]	10000[b]	10000[b]	(*15*)
Jabiru Lagoon, northern NSW, Australia	sediment	2.20[a]	88[b]	139[b]	3981[b]	63010[b]	(*15*)
India	clay	2.29	43[b]	75[b]	3200[b]	5568[b]	(*28*)
Ustox, Brazil	medium clay	2.64[a]	166[b]		6280		(*30*)
Boobora Lagoon, northern NSW, Australia	sediment	5.30[a]	266[b]	840[b]	5012[b]	15849[b]	(*15*)
India	compost	9.51	23[b]	50[b]	405[b]	886[b]	(*28*)

[a] Organic carbon (%). [b] Calculated from reported data.

marized in **Table 1**. The initial sorption of both endosulfan and diuron was rapid (**Figure 1**). Endosulfan sulfate attained sorption equilibrium after 41 min; however, diuron did not reach sorption equilibrium and continued to sorb up to the end of the allowed interaction time of 48 h. Endosulfan sulfate desorption kinetics yielded results that were below the limit of detection of the GC-MS; and therefore, the amount desorbed over a period of 48 h was assumed to be negligible and the sorbed mass constant. Diuron, on the other hand, exhibited rapid initial rates of desorption, followed by equilibrium after 4 h (**Figure 1**). Both diuron and endosulfan sulfate controls showed no significant degradation over the course of either sorption or desorption experiments.

Sorption and Desorption Isotherms. The sorption isotherms for endosulfan sulfate and diuron are shown in **Figure 2**. A linear association between the sorbed mass of pesticide and dissolved concentration was observed for both pesticides (**Table 2**). The organic matter content of CCGT was found to be 25.22 ± 2.92%, using the weight loss-on-ignition method. Calculated K_d and K_{OC} partition coefficients were much greater than 1 mL g^{-1} for both pesticides (**Table 2**).

Desorption isotherms of endosulfan sulfate and diuron show a linear association between sorbed mass and dissolved concentration (**Figure 2**). For the applied concentration range 1−10 μg L^{-1}, desorption of endosulfan sulfate was not detected, and only small fractions desorbed for higher applied concentrations. Diuron, however, exhibited some desorption over the applied pesticide concentrations.

DISCUSSION

Understanding physicochemical interactions responsible for environmental partitioning can provide insights into pesticide mobility (*20–26*). The process of desorption is understood to act concomitantly with sorption, with the relative rates describing the equilibrium of the system. The concentrations of endosulfan sulfate (1−100 μg L^{-1}) and diuron (5−500 μg L^{-1}) used in this study reflect those found in irrigation tailwater and storm runoff on Australian cotton farms (*2, 27*).

Sorption of Endosulfan Sulfate and Diuron. The strong hydrophobic interaction of endosulfan sulfate and diuron with humic compounds in the compost material, on account of their respective low solubilities in water (0.117−0.22 mg L^{-1} and 36.4 mg L^{-1}) and strong preferences for hydrophobic phases (log K_{OW} = 3.66 and 2.85), was believed to be the mechanism driving the rapid rate of sorption (*28*). Rate-determining mechanisms were operating in the case of diuron sorption; however, both compounds have a high binding affinity for CCGT for the applied concentrations.

Limited comparative data was available from the literature for endosulfan sulfate sorption; however, assessments for its parent isomers, α- and β-endosulfan, were made on the basis that they exhibit similar chemical and physical properties (*12, 29*). Kumar and Philip (*28*) observed similar rapid rates of endosulfan sorption, with equilibrium reached in a short period of time in sandy soils (1.5 h), and slightly longer for clay and composted soils (4 h). Partitioning in the soils studied was most pronounced for the clay and composted soils that contained 2.29 and 9.51% organic matter, respectively, compared to 0.58% for sand (**Table 3**). Laabs and Amelung (*30*) reported limited partitioning of α-endosulfan on sand and medium clay soils. Peterson and Batley (*15*) observed strong partitioning of α- and β-endosulfan ($K_{d\alpha\text{-endo}}$ = 266 and $K_{d\beta\text{-endo}}$ = 840) in river sediments containing 5.3% organic matter. They also found a positive correlation between the extent of sorption and organic matter content in a number of different lagoon sediments.

Similarly, the extent of diuron sorption is correlated with soil organic matter (**Table 4**). Sheng et al. (*5*), Nkedi-Kizza et al. (*23*), Gaillardon (*31*), Lennartz et al. (*32*),and Oliver et al. (*33*) reported limited partitioning for a range of soils that contained much less organic matter (1.06−2.56%) than CCGT. Failure for the sorption to reach equilibrium in other studies, as occurred in ours, has been attributed to intraorganic matter diffusion (*31, 34*). Although diffusion increases the total sorption capacity because it allows more diuron to move into the organic matter, the rate of diffusion limits the rate of sorption. Sheng et al. (*5*) found that sorption of diuron onto clay minerals was hindered by large substituents on the aromatic ring (two chlorines and *N*,*N*-dimethylurea) and that the electroneutrality of diuron enhanced this outcome. Competition with other polar molecules and ions in solution (such as Ca^{2+} and Cl^- in 0.01 M $CaCl_2$ solution) for surface functional groups may also limit diuron sorption.

Table 4. Summary of Diuron Partition (K_d) and Organic Carbon Partition (K_{OC}) Coefficients for a Range Sorbing Media Reported in the Literature

		diuron			
location	substrate	% organic matter	K_d (mL g^{-1})	K_{OC} (mL g^{-1})	reference
	composted cotton gin trash	25.22	78	526	
Mont Pellier, France	silt loam	1.06[a]	3[b]	240	(*32*)
Western Australia	variable	1.05[a,c]	6[c]	579[c]	(*33*)
Dijon, France	dispered clay loam	1.36[a]	6 (K_f)		(*31*)
Dijon, France	undispered clay loam	1.36[a]	5 (K_f)		(*31*)
Arkansas	sandy loam	2.10[a]	4	167[b]	(*5*)
Philippines	variable	2.23[a,c]	14[c]	618[c]	(*33*)
Florida	carbonatic sandy loam	2.56[a]	3[b]	127	(*23*)
South Australia	variable	2.83[a,c]	15[c]	536[c]	(*33*)
Florida	noncarbonatic loam	4.60[a]	17[b]	366	(*23*)
Florida	muck soil	44.70[a]	190[b]	424	(*23*)

[a] Organic carbon (%). [b] Calculated from reported data. [c] Average reported in document.

Desorption of Endosulfan Sulfate and Diuron. An important consideration is the desorption characteristics of CCGT. Rapid desorption could limit the use of CCGT as a remedial sorbent; however, high rates were not observed. Rapid yet limited desorption of diuron was observed (**Figure 1**). It is thought that diffusion forces into solution overcame the strong hydrophobic interactions with the compost for both diuron and higher sorbed masses of endosulfan sulfate (*28*). High desorption partition coefficients for both endosulfan sulfate ($K_{des} = 980$) and diuron ($K_{des} = 117$) suggest that both compounds reside in the solid phase.

It is expected that increasing organic matter decreases the desorption potential of endosulfan isomers and diuron *28, 31, 34–37*). Kumar and Philip (*28*) found desorption of endosulfan isomers to be faster in sandy soils (0.57% organic carbon) relative to clay (2.29% organic carbon) and composted (9.51% organic carbon) soils. Gaillardon (*31*) reported rapid desorption of diuron for a clay loam soil containing 1.36% organic carbon that resulted in equilibrium after 1 h. Reddy et al. (*36*) similarly observed 32% desorption of diuron for a range of sandy soils containing 0.50−1.67% organic carbon. It is apparent that low organic matter fractions result in weak binding. Organic carbon is believed to contribute to soil structure. It has been suggested that the higher organic carbon content of a heavy clay soil, reported in Inoue et al. (*37*), resulted in the formation of larger soil aggregates that enhanced the tortuosity of the internal soil porosity thereby physically constraining the extent of desorption. Both diuron and endosulfan sulfate exhibited hysteresis. Therefore, CCGT effectively contained a large proportion of the chemicals.

Need for a Dynamic Study. Although the methods reported conform to OECD (*17*) standards, there is a need for a more dynamic sorption assessment of CCGT. Burgisser et al. (*38*) highlighted the inaccuracies and difficulties in using batch equilibrium methods to assess chemical sorption to soil, including the relatively high solution to sorbent ratio, vigorous shaking, and the large number of samples required to generate an isotherm. Rose (*39*) further highlighted that, although batch studies are useful for comparing sorbents, the data obtained from them is sometimes less reliable and more difficult to use for in situ modeling, as a prerequisite to field trials. Column studies help to overcome these compounding issues.

Returning CCGT to the field as a soil ameliorant may also provide added benefits for soil health. Increasing organic matter in soil enhances soil structural stability (*40, 41*), water holding capacity (*41*), soil biological activity, and pesticide retention for a range of soils. Redistribution of CCGT to the field also provides an alternative to the current practice of stockpiling CCGT, potentially freeing up arable land.

In conclusion, because of its relatively high proportion of organic matter, CCGT can effectively sorb environmentally relevant concentrations of endosulfan sulfate and diuron. The extent of sorption for the range of concentrations studied was not limited for endosulfan sulfate and diuron, as compared to other sorbents reported in the literature. Some desorption of endosulfan sulfate and diuron for a range of environmentally relevant concentrations was observed; however, considering the balance of sorption and desorption, CCGT offers a potential medium for the reduction of endosulfan sulfate and diuron in contaminated tailwater. The limitations of batch equilibrium studies need to be overcome to substantiate the use of CCGT in the field.

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