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FERTILITY AND TOXICITY OF POTTING SOILS PREPARED FROM GINNING AND DAIRY WASTES ANAEROBIC DIGESTATE

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Abstract

Methane gas resulting from combining cotton gin trash and dairy manure in a two phase anaerobic digester is easily marketed. Digestate solids are not. This study was conducted to determine anaerobic digestate toxicity and its potential as a soil amendment. The same mixture of dairy manure and cotton gin waste was digested anaerobically in solid phase piles leached daily, and composted conventionally. Lettuce was planted in pots filled with different proportions of anaerobic digestate or conventional compost mixed with washed sand or native soil. Emergence was used as an indication of germination. Dry leaf mass was used to measure yield. Emergence was greater in anaerobic digestate mixtures, indicating that it is not toxic. Potting soil mixtures made with various amounts of conventional compost had one to two orders of magnitude greater nitrate (NO_3-N) and produced one to two orders of magnitude greater yields. Anaerobic digestate may be needed where carbon is preferred over nutrients.

Introduction

Alone, cotton gin trash and dairy manure can be costly byproducts to dispose of. But combining cotton ginning and dairy wastes potentially converts these two liabilities into two assets. Cotton gin trash provides carbon, energy and disinfecting properties while dairy manure provides nitrogen and the different species of microbes needed to break down cellulose and convert the resulting volatile fatty acids into methane (Riordan et al., 2005). This methane can be used in an internal combustion engine to produce electricity or as a heating fuel to maintain the temperature of greenhouses. Rising energy prices make it easier to market renewable energy products such as methane. Marketing the resulting anaerobic digestate (solid residue) from this novel two-phase fermentation process is potentially more challenging. Acceptance of anaerobic digestate as a soil amendment requires demonstrating that it does not hinder seed germination and plant growth (it is not toxic) and determining its impact on yield.

Antecedents

Chile and Bermuda grass seed germination tests were performed using liquid extracts from various New Mexican composts (Flynn and Hurtado, 2003). Dairy compost was shown to be saline enough in some cases to inhibit germination. Compost tea made from a mixture of gin trash and dairy manure exhibited no deleterious effects. In a separate study, cotton plant emergence, growth and fruiting were improved by low to moderate applications of garment washing sludge (cellulose solids) to potting soil (Porter and Porter, 1996).

Objectives

This study was conducted to find out which of two possible outcomes the gin and dairy waste anaerobic digestate might have both in terms of potential toxicity and potential soil nutrition. There are therefore two hypotheses:

Hypothesis 1: Anaerobic digestate is non-toxic.

This hypothesis was tested by planting lettuce seeds in mixtures of anaerobic digestate or conventional compost and native Brazito sandy loam soil or washed sand. If emergence in pots containing anaerobic digestate is not statistically less than germination in pots containing compost, anaerobic digestate is non-toxic. Decreases in germination in either material may be caused by sodium from the dairy cows' dietary salt.

Hypothesis 2: Anaerobic digestate is beneficial as a soil amendment.
This hypothesis was tested by growing a lettuce crop in mixtures of anaerobic digestate or compost and native Brazito sandy loam soil or washed sand. It is true if yields increase with increasing amounts anaerobic digestate. In either material nitrogen may be unavailable because microorganisms have it tied up in their cell protein.

Materials and Methods

A series of experiments were conducted supporting design of a demonstration and research pilot plant (currently under construction near Vado, NM) (Funk et al., 2005, and Macias-Corral et al., 2005). Dairy and ginning wastes were mixed in a two-phase anaerobic digester to optimize operating temperature and quantify residence time. Unfortunately, the methanogenic column (second phase) was missing during these experiments. Leachate from the first (solid) phase was replaced with fresh water (hyperleached) instead of being returned from an upflow anaerobic filter (second phase). At the end of the anaerobic digestion process, the solid residue was windrowed for one month. At the same time, portions of these two materials were conventionally composted (aerobically) for nine months as a control treatment by turning wetted windrows using commercial technology at Sierra Vista Growers, La Union, NM.

Sixteen combinations resulted from mixing either washed sand or native Brazito sandy loam soil with either anaerobic digestate or conventional compost in proportions that were 1:0, 2:1, 1:2, 5:1 and 0:1 respectively (Table 1). Appropriate quantities of the soil mixes were prepared and soil samples were collected before the start of and at the end of the experiment. Four replicates of each combination resulted in 64 pots, each with drain holes, sitting in saucers. The saucers were to collect leachate for measurement of pH, TDS (Total Dissolved Solids) and NaCl (salt) using hand-held electrical conductivity meters (Oakton Instruments pHTestr 3+, TDSTestr 2 and SaltTestr). Each pot was placed on a table in a lath house, blocked by replicate but randomly assigned within each block (Figure 1).

Table 1. Experimental design and initial soil leachate properties.

Lot	Base Material	Amendment	Ratio	pH	TDS	NaCl*
1	Washed Sand	-	1 : 0	8.00	2.55	1.23
2	Washed Sand	Anaerobic	2 : 1	7.68	2.10	1.20
3	Washed Sand	Anaerobic	1 : 2	7.63	1.80	0.90
4	Washed Sand	Conventional	2 : 1	7.68	18.55	5.20
5	Washed Sand	Conventional	1 : 2	7.45	19.95	6.30
6	Brazito Soil	-	1 : 0	7.60	6.30	2.23
7	Brazito Soil	Anaerobic	2 : 1	7.73	3.83	1.73
8	Brazito Soil	Anaerobic	1 : 2	7.73	1.80	0.93
9	Brazito Soil	Conventional	2 : 1	7.60	15.45	4.33
10	Brazito Soil	Conventional	1 : 2	7.65	18.48	5.90
11	-	Anaerobic	0 : 1	7.35	1.75	0.98
12	-	Conventional	0 : 1	7.70	19.83	6.37
13	Washed Sand	Conventional	5 : 1	7.65	13.45	4.65
14	Washed Sand	Anaerobic	5 : 1	7.70	2.98	1.53
15	Brazito Soil	Conventional	5 : 1	7.50	14.93	4.10
16	Brazito Soil	Anaerobic	5 : 1	7.65	4.75	1.95
	Irrigation Water			7.55	0.60	0.35

TDS and NaCl based on calibrated electrical conductivity meter (Oakton Instruments, Inc.)

Ten Black Seeded Simpson leaf lettuce seeds, selected because lettuce is sensitive to salinity, were planted a quarter inch deep after soils were wetted to saturation. Germination was measured by counting emerged seedlings at the dicotyledon stage or above. Counts were recorded at 6, 8, 12, 16, 19 and 21 days after planting. Then each pot was thinned to two plants. Surplus seedlings from other pots were transplanted if there were not two plants. They were wetted daily. Every effort was made to maintain uniform moisture, protect from insects and winds, and in general assure that the experiment was free from confounding influences. After 6 weeks, the plants were cut at soil level, weighed, dried, and weighed again. Plant mass was recorded at the time of cutting (fresh) and after drying at 220 F for 2 hours (dry).

Results and Discussion

Table 2 presents germination results by lot and days after planting. The table presents the sum of four pots, each planted with ten seeds, for each lot. The treatment that was only sand had the slowest emergence, only attaining full seedling count at day sixteen. Emergence was much stronger with the anaerobic digestate, indicating that anaerobic digestate was not toxic. In fact, the anaerobic digestate appears to contribute something that improves germination.

Figure 1. Lettuce growing in pots with various ratios of soil to amendment. The pots with the large plants generally were ones with conventional compost mixed with sand or soil. The small seedlings are in pots with anaerobic digestate. Germination and emergence were greater, but subsequent plant growth was disappointing.

Table 2. Experimental results (ranked by final emergence) showing number of seedlings by days after planting for each treatment and week three emergence.

Lot	Portions in Pots				Days After Planting						Emergence
No.	Sand	Soil	A.D.	C.C.	6	8	12	16	19	21	(% at 21 d)
8		2	4		36	38	39	39	39	39	98
3	2		4		35	38	38	36	38	39	98
11			6		35	35	37	38	38	38	95
7		4	2		28	28	30	32	32	32	80
12	5		1		22	27	30	29	29	29	73
14				6	24	26	27	29	29	29	73
2	4		2		25	27	27	28	28	28	70
10		2		4	20	21	24	27	27	27	68

5	2			4	23	24	25	26	26	26	65
1	4			2	13	14	14	17	16	16	40
4	6				4	4	8	17	15	16	40
16		5	1		7	11	11	11	11	11	28
9		4		2	7	8	7	8	9	8	20
15	5			1	4	5	6	6	6	7	18
13		5		1	5	6	6	6	6	6	15
6		6			2	2	3	4	4	4	10

Note: A.D. signifies anaerobic digestate, C.C. conventional compost.

Tables 3a and 3b present experimental results ranked by dry mass yield, with soil properties and their corresponding correlation to yield. There were differences exceeding two orders of magnitude. The greatest yield (grams dry matter) came from pots with the greatest amount of conventional compost and corresponding high available nitrogen (nitrate) levels. The mid-level (decigrams dry matter) came from pots with smaller amounts of conventional compost. The lowest yields (centigrams dry matter) corresponded to pots with all levels of anaerobic digestate.

Table 3a. Experimental results (ranked by dry mass yield) and final soil properties: EC (electrical conductivity, mmhos/cm), NO_3N (nitrate, ppm), Na (sodium, meq/L), SAR (sodium adsorption ratio), Mg (magnesium, meq/L) where CC is conventional compost, AD anaerobic digestate.

Composition				**Yield**	Soil Properties (ranked by correlation with yield)				
Lot	Base Material	Amend-ment	Ratio	**Dry (mg)**	EC	NO_3-N	Na	SAR	Mg
12	-	CC	0:1	**1285**	41.9	1195	200	41.26	22
5	Sand	CC	1:2	**1079**	32.7	437	243	43.4	29.5
10	Soil	CC	1:2	**1057**	35.2	690	159	30.05	24
4	Sand	CC	2:1	**507**	14.3	133	83.9	23.4	11.2
6	Soil	-	1:0	**476**	5	98	13.1	3.51	5.7
15	Soil	CC	5:1	**461**	16.5	221	78	12.88	21.1
9	Soil	CC	2:1	**437**	24.4	348	111	18.97	24
13	Sand	CC	5:1	**323**	9.58	65	63	20.2	7.85
14	Sand	AD	5:1	**54**	2.1	2	18.2	14.06	1.13
16	Soil	AD	5:1	**47**	4.23	73	16.8	4.53	6.55
1	Sand	-	1:0	**46**	1.43	3	13.4	20.68	0.26
2	Sand	AD	2:1	**41**	1.47	2	13.2	11.36	0.88
7	Soil	AD	2:1	**41**	3.81	36	14	3.85	6.65
11	-	AD	0:1	**18**	3.72	3	3.86	1.22	6.76
8	Soil	AD	1:2	**12**	3.8	3	8.99	2.5	7.53
3	Sand	AD	1:2	**8**	2.41	2	10.1	4.22	3.72
				Correlation	**0.911**	**0.817**	**0.878**	**0.738**	**0.701**

Table 3b. Experimental results (ranked by dry mass yield) and final soil properties: K (potassium, ppm), NaX (exchangeable sodium, %), Ca (calcium, meq/L), P (phosphorus, ppm), Organic Content (organic matter, %) and pH (soil paste pH) where CC is conventional compost, AD anaerobic digestate.

Composition				**Yield**	Soil Properties (ranked by correlation with yield)				
Lot	Base Material	Amend-ment	Ratio	**Dry (mg)**	K	Na X	Ca	P	Organic Content
12	-	CC	0:1	**1285**	7660	37.3	25	645	18.32
5	Sand	CC	1:2	**1079**	2510	38.6	33.2	244	4.63
10	Soil	CC	1:2	**1057**	3430	30.1	32	358	8.54

4	Sand	CC	2:1	**507**	636	25	14.5	84	1.91
6	Soil	-	1:0	**476**	98	3.8	22.1	24	0.76
15	Soil	CC	5:1	**461**	646	15.1	52.3	101	2.19
9	Soil	CC	2:1	**437**	1360	21.1	44.5	268	4.26
13	Sand	CC	5:1	**323**	254	22.2	11.6	54	1.12
14	Sand	AD	5:1	**54**	22	16.3	2.22	13	0.43
16	Soil	AD	5:1	**47**	128	5.1	21	48	1.86
1	Sand	-	1:0	**46**	8	22.6	0.58	1	0.04
2	Sand	AD	2:1	**41**	26	13.4	1.82	15	1.53
7	Soil	AD	2:1	**41**	161	4.2	19.8	50	3.65
11	-	AD	0:1	**18**	1280	0.5	13.1	773	28.55
8	Soil	AD	1:2	**12**	326	2.4	18.3	164	2.46
3	Sand	AD	1:2	**8**	140	4.7	7.71	83	3.45
				Correlation	**0.694**	**0.671**	**0.291**	**0.192**	**0.062**

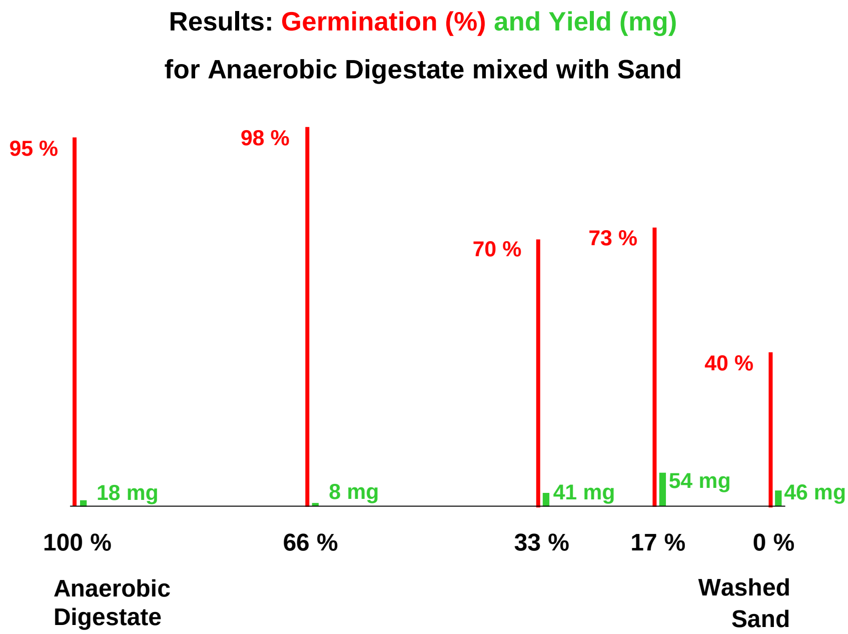

Figure 2. Experimental results showing emergence-based germination (%) and dry mass lettuce yield (mg) for anaerobic digestate mixed at various ratios with washed sand, ordered by percent anaerobic digestate.

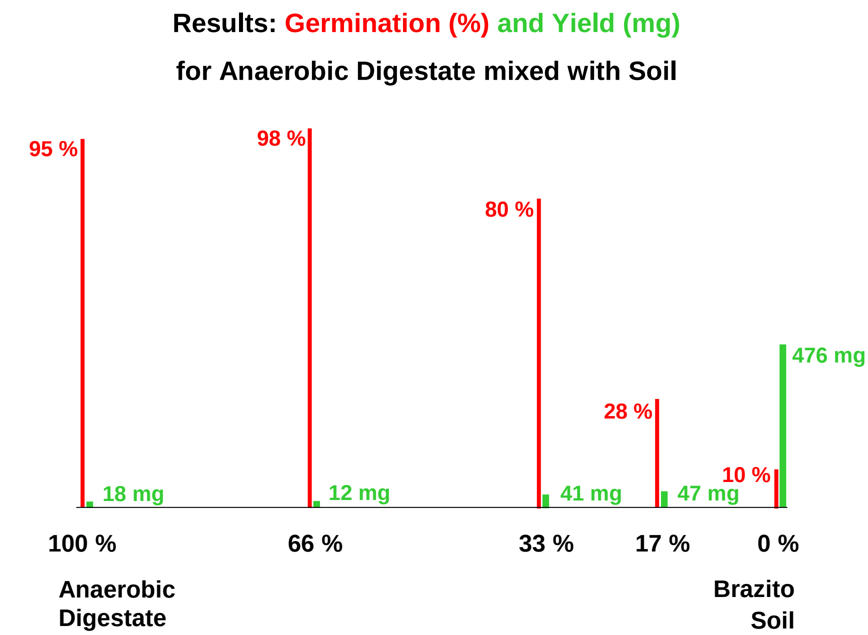

Figure 3. Experimental results showing emergence-based germination (%) and dry mass lettuce yield (mg) for anaerobic digestate mixed at various ratios with native Brazito sandy loam soil, ordered by percent digestate.

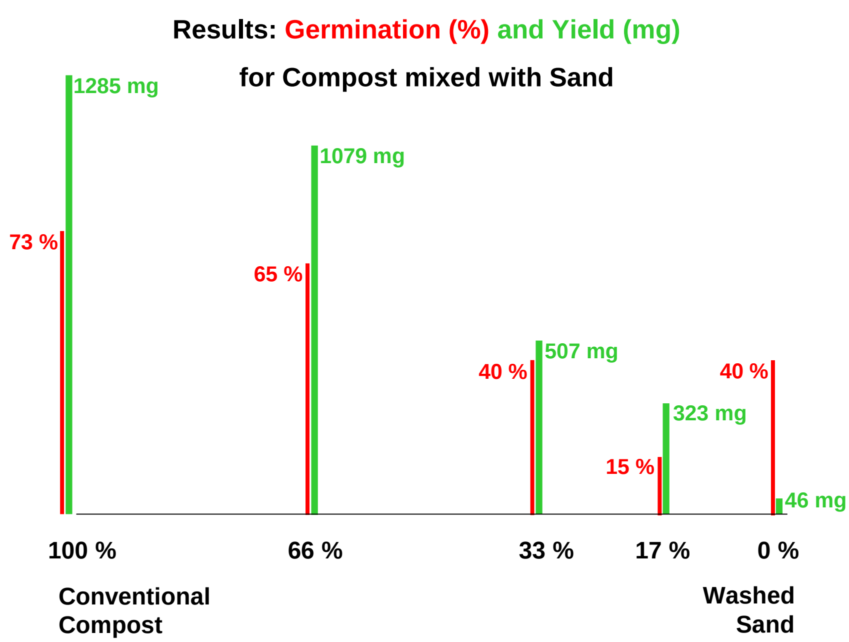

Figure 4. Experimental results showing emergence-based germination (%) and dry mass lettuce yield (mg) for conventional compost mixed at various ratios with washed sand, ordered by percent conventional compost.

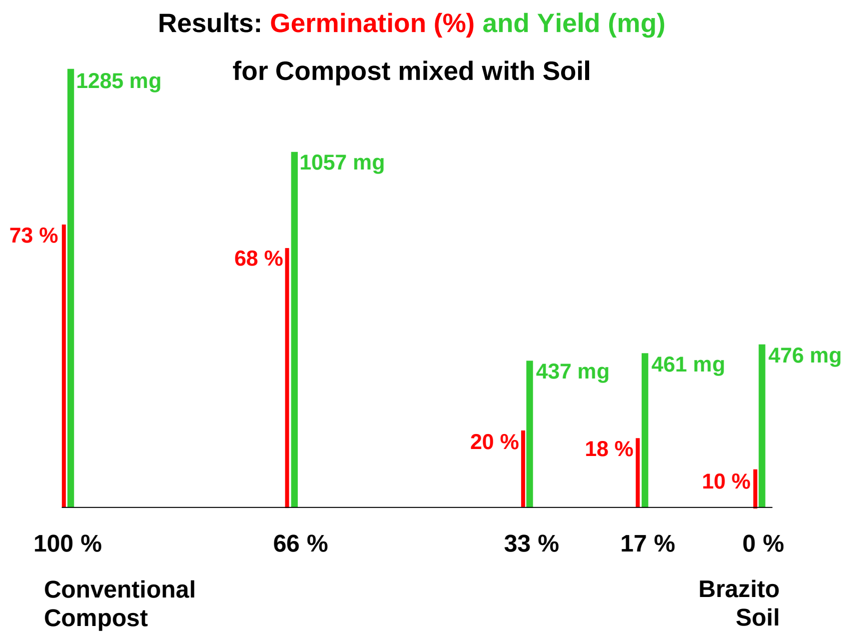

Figure 5. Experimental results showing emergence-based germination (%) and dry mass lettuce yield (mg) for conventional compost mixed at various ratios with native Brazito sandy loam soil, ordered by percent compost.

Yield results were opposite from emergence results. Even though anaerobic digestate mixes resulted in near total emergence-based germination, the material was not able to support plant growth. Conventional compost resulted in lower seedling counts. But when all pots were thinned (or transplanted) to two plants, it was the pots containing conventional compost that produced the largest lettuce plants (Figures 2 through 5).

Replacing solid phase leachate with fresh water instead of returning it from an upflow anaerobic filter is not representative of the two phase system as it will be operated. It is likely that this caused the absence of nutrients in the anaerobic digestate. Beyond nutrient deficiency, anaerobic digestate appeared to inhibit plant growth in soil (Figure 3) for reasons that are unclear. A possible explanation is that soil nitrate was immobilized by microbes in the anaerobic digestate. Future trials need to be conducted that look at nutrient availability and that use anaerobic digestate from an operating two-phase system.

Conclusions

Seed germination and emergence were not hindered by adding anaerobic digestate made with cotton ginning waste and dairy manure to sand or soil. Plant growth and yield was. While germination was improved with this particular hyperleached anaerobic digestate, lettuce yields were negligible due to its low nitrate content. Anaerobic digestate may be needed where carbon is preferred over nutrients. Trials need to be repeated using anaerobic digestate from a true two-phase fermentation system.

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