Pretreatment of AD-Treated Fibrous Solids for Value-Added Container Media Market

C. MacConnell, C. Frear, W. Liao

Background

As already noted, where electricity prices are low, reasonable returns on investment from dairy AD often require additional revenue from value added by-products and tipping fees for non-farm substrates (Bishop and Shumway, 2009; Frear et al., 2009). Fiber is the most significant by-product by mass, representing 46% of raw manure prior to digestion (Table 6.1) (Liao et al., 2009). Raw fiber, produced upon mechanical separation, has minimal value of around $3/cubic yard and a small market due to its odor and high pathogen content (King, 2003). Extended composting of the raw fibrous solids and resulting alterations in odor, color and texture can open up additional markets for the product, including topsoil bedding, nursery greenhouse bulk soil, turf top-dressing, peat replacement, bedding replacement, and transportation erosion control, however nearly ½ of the orginial mass is lost in the process (Armstrong et al., 2007; Birt et al., 2007; Caceres et al., 2006; Johnson et al., 2006). Prices for these products range from $9-27/cubic yard, with most options concentrated on the lower end of the range due to variability of product and other concerns. In addition, the composting process costs the farmer about $5/cubic yard (for labor, equipment and space) and reduces the mass of marketable product by as much as 50% (King, 2003).

Table 6.1: Characteristics of dairy manure and AD separated fibrous solids from that manure

	Raw Manure	*Raw Solids*	*AD Solids*
Dry Matter, % dry	13.42 ± 0.10	13.26 ± 0.1	25.13 ± 1.85
Fiber, % dry	45.89 ± 0.35	67.11 ± 0.68	74.33 ± 1.01
Cellulose, % dry	23.13 ± 0.26	35.67 ± 1.43	37.49 ± 0.31
Hemicellulose, % dry	10.64 ± 0.10	14.88 ± 0.94	9.17 ± 1.00
Lignin, % dry	12.11 ± 0.19	16.56 ± 0.65	27.66 ± 0.69
N, % dry	2.90 ± 0.045	2.21 ± 0.01	1.58 ± 0.13
C, % dry	45.35 ± 0.52	41.00 ± 0.88	58.13 ± 0.88
F. Coliform (CFU/g)	339,031 ± 247,461	8,000 ± 860	35.56 ± 16.44

[a] data are the average of triplicates with standard deviations of the means (n=3) at α=0.05

AD is a pretreatment alternative to compost, capable of upgrading the raw fibrous solids through extended time and temperature in the digester. After mechanical separation from the AD effluent, the treated solids are notably reduced in pathogenic contaminants (>99% or 2.4 $\log_{10}$), volatile solids, odor, and viable weed seeds while still being high and even increasing in fibrous content and containing key macro and micro-nutrients (Table 6.1-6.2) (Frear et al., 2009; Liao et al., 2009; US-EPA, 2005).

Table 6.2: Selected values and range for AD separated solids from scrape dairy (Lynden, WA)

Parameter [a]	Scrape, Co-digestion AD Separated Solids
Moisture (%)	74.2 ± 4.5
Bulk Density (lbs/yd^3)	675.2 ± 72.3
Dry Matter (lbs/yd^3)	171.7 ± 12.1
Organic Fraction (lbs/yd^3)	158.2 ± 12.6
Mineral Fraction (lbs/yd^3)	13.8 ± 1.9
EC (dS/m)	3.62 ± 1.11
pH	8.65 ± 0.3
N, P, K (%)	1.42 ± 0.21; 0.28 ± 0.04; 0.68 ± 0.16
Micronutrients (Mn, Fe, Cu) (ppm dry soil)	32.67 ± 23.8; 35.67 ± 37.4; 22.43 ± 8.8

[a] data are the average of seven trials with standard deviations of the means (n=7) at α=0.05

Presently the major use for digested fibrous solids is as an on-farm bedding replacement, generating offset revenue because the farm no longer has to purchase outside bedding material such as straw, sawdust, or wood chips. The typical value for this is around $3-6/cubic yard, hardly above the price for non-digested, separated solids (Andgar, 2008). Typical FAN separators (US Farm, Tulare, CA) are capable of mechanically separating about 7-8 yd^3 fiber/cow yr from the AD effluent. Roughly fifty percent of this is required for on-farm bedding replacement, thus freeing up nearly 4 yd^3 fiber/cow yr for off-farm markets, hopefully at a value-added price well above that received for the bedding replacement (Frear et al., 2009).

Of all the potential markets listed above, the most highly valued option is as a substitute for peat moss in containerized plant growth media (Long and Jackson, 2002). Containers are convenient for growing, shipping, and selling most plants (e.g., trees, shrubs, flowers, and vegetables), and have become the industry standard for greenhouses and nurseries that grow plants under controlled conditions for the residential and office markets. Within this context, soilless media are preferred to those containing soil because of their light weight, defined physical and chemical characteristics, and beneficial growth properties. Typically, soilless media used in the greenhouse and nursery industries contain peat moss as the main substrate.

In view of the economic importance of container plants, much time and research has been expended to optimize container growth conditions and identify new substrates that are suitable for growth of a large number of different plants. Peat moss, softwood bark, or a combination of the two is currently the primary base for most greenhouse and nursery container growth substrates. Peat moss in particular is an excellent substrate for container plant growth and maintenance. However, peat moss has some drawbacks, particularly in regard to sustainability and climate issues. Existing peat lands are a limited, unsustainable resource whose mining (vegetative clearing, bog drainage, peat extraction and transportation) moves peat lands from an overall carbon sink (long-term uptake estimated at 20-30 g C/m^2 yr) to a carbon source. In 2000 alone, the Canadian peat industry mined and sold 1.3 MMT of peat, mostly to the nursery industry, emitting in the process an estimated 0.89 MMT of CO_2e or 0.685 MT CO_2e/harvested ton with 71%, 15% and 14% of relative releases due to end-use peat decomposition, land use changes, and fossil fuel combustion, respectively (Cleary et al., 2005; Waddington et al., 2009).[1]

Importantly, the nursery and greenhouse industry appears to be relatively amenable to obtaining suitable substitutes with 38%, 4% and 58% of nursery operator survey respondents answering yes, no and maybe, respectively, to the question whether or not they would be interested in alternatives to peat moss in container media (MacConnell and Collins, 2007). These investigators determined that composted turkey litter could be used as a plant growth substrate in combination with other substrates but also concluded that the animal waste tested was unsuitable as the sole substrate for growth of container plants. Thus, there is a continuing need for a relatively sustainable, inexpensive and abundant substrate that can be used as the sole substrate, or as the main constituent of a substrate, for growth and maintenance of container plants.

Although earlier work has shown that AD treated dairy slurry, either subsequently composted, sieved or leached, could be beneficial as a growth medium substrate, providing peat-like properties with added levels of nutrients (Marchaim et al., 1991; Raviv et al., 1986), little progress has been made in developing a market within the nursery industry. One reason centers upon the requirement that plant growth media have physical, chemical, and other properties that are well established (Boertje, 1983; Goh and Haynes, 1977; Raviv et al., 1986) a requirement that is currently best met by a more consistent peat product as opposed to a more variable AD treated, fibrous solid. Tables 6.2-6.3 demonstrate the variability that exists in AD treated fibrous solids both within a single farm and resulting from various farm sources and AD technologies utilized.

---

[1] MT = metric tons (1 MT = 1 Mg); MMT = million metric tons (1 MMT = 1 Tg)

Table 6.3: AD separated fiber properties from various sources [a]

Parameter	Unit	Lowest	Highest	Mean	Std. Dev.
pH		7.6	8.9	8.4	0.38
EC_a	dS/m	2.0	6.3	3.5	1.18
Na	% EC_a	3.9	19.1	9.4	5.00
Cl	% EC_a	2.1	14.8	8.3	3.66
N	%	1.10	2.06	1.59	0.33
P	%	0.22	0.73	0.43	0.17
K	%	0.46	1.26	0.73	0.20
Ca	%	0.94	4.5	1.92	0.78
Mg	%	0.23	0.96	0.50	0.22
Na	%	0.12	0.42	0.24	0.09
S	%	0.24	0.80	0.47	0.16
Cu	ppm	56	408	163	98
Zn	ppm	76	218	131	46
Mn	ppm	70	350	156	76
Fe	ppm	342	2310	972	615
B	ppm	21	64	39	11

[a] data are the average of twenty trials from ten different farms incorporating two different AD technologies (complete mix and plug flow) with standard deviations of the means (n=20) at α=0.05

An additional concern centers upon the pH of the fiber, given that micro-nutrient availability to plants is influenced by pH. Some plant micronutrients, such as Mn, may become unavailable as the pH rises over neutral (Hausenbuiller, 1972) and AD separated solids normally have pH in this range. A potential solution to this problem is to add elemental sulfur (S^0) which once within the media will partially oxidize to SO_4 and H^+, thereby decreasing the pH and making micro-nutrients available to plant growth (Slaton et al., 2001). The appropriate rate for S^0 addition was suggested based on the equation, 144.5 g S^0 x 0.7 pH unit^{-1} reduction x m^{-3} (0.25 lbs yd^{-3}), used for pre-treatment of composted yard waste before use as a container substrate (Beeson, 1996). One potential issue with this approach is that the S^0 oxidation will also elevate media electroconductivity (EC), but prior studies with pea plants (highly sensitive to changes in salinity) have shown that they can fully acclimate to changes in external osmotic potential after treatment with sulfate-salinized media (Hasson-Porath et al., 1972).

Given the need for a more climate-friendly peat replacement and the potential benefits of this byproduct, in terms of improved AD project economics and enhanced adoption rates, a fibrous solid pretreatment study was initiated. Overarching goals of the research were to: (1) record baseline capabilities of AD separated solids as a nursery media, particularly in regard to pH, micro-nutrient availability, salinity and product variability; (2) evaluate an elemental sulfur (S^0) addition as well as other protocols for overcoming above said concerns, and (3) finalizing, patenting (MacConnell, 2006) and commercializing the developed protocol to enable marketing of a value-added peat replacement in the container industry.

Methods

Growth experiments were performed with fiber from the plug flow digester located in Lynden, Washington State except as specified. All fiber, growth media, and plant tissue samples were analyzed by the Soil and Plant Laboratory, Santa Clara, California, USA for chemical, nutrient, and physical properties. During plant growth trials, some pH and EC data were collected using a Hanna Instruments pH meter and Spectrum Industries PET 2000 EC Meter.

Physical and Chemical Analysis of Digested Fibers

Instrumental methods for the routine determination of the physical properties, dry bulk density, water volume, air volume, shrinkage value and total pore space followed the CEN Standards for Chemical and Physical Analysis of Growing Media ((Baumgarten, 2004) .

Experiments with Unmodified AD Separated Solids using Petunia grandiflora

Single *Petunia* Ultra Violet plugs size 512 were randomized and transplanted into 10.16 cm pots in five media treatments (r=4, n=25). These five media treatments were:

1. 60% peat moss, 25% compost (sterilized greenhouse cull plant waste), 15% pumice (P);
2. 85% peat moss and 15% P;
3. 85% digested fiber (DF) and 15% P;
4. 60% DF, 25% compost, 15% P;
5. 40% DF, 40% peat moss and 20% P

All media had dolomite lime ($CaMg(CO_3)_2$) incorporated pre-plant at a rate of 0.59 kg/m^3. Plants were grown at a large commercial greenhouse in Washington State and fertigated daily with a mixture of 20-10-20 and 15-0-15 at 150 ppm N. Plants were harvested 28 days after planting. Measured attributes at harvest included plant height (from soil surface to the base of the sepals on the longest flower stalk), number of visible buds and open flowers, greenness of the leaves measured with a Minolta SPAD-502 leaf chlorophyll meter (Markwell et al., 1995) (average of three readings taken from the 2nd leaf set from the top of the tallest branch), and fresh and dry weight of the entire plant (cut at soil surface) were measured.

Experiments in pH Adjustment

Dried DF samples (50 ml or 5.5 g) were mixed with 45.0, 89.1, or 133.6 mg of 90% sulfur (S^0) and pH measured weekly over 20 weeks. Initially, before measuring pH, DF and deionized water was mixed 1:1 on volume basis, shaken for one hour and then allowed to settle. After each pH measurement, the fiber sample was air dried to field capacity (45%), placed in a beaker, stirred, covered with parafilm with 5 pin holes in the center and incubated at 25°C. Starting week 2, DF was mixed with 0.01 M $CaCl_2$ instead of deionized water.

Experiments with Mn and Fe Supplements using Petunia grandiflora

Dreams plugs of *Petunia grandiflora*, size 512, were transplanted into 10.16 cm pots in six media treatments and grown in a commercial greenhouse. Treatments (r=4, n=18) included:

1. 80% DF, 20% P, with $MnSO_4$;
2. 80% DF, 20% P with $FeSO_4$;
3. 40% DF, 40% peat moss and 20% P with $MnSO_4$;
4. 40% DF, 40% peat moss and 20% P, with $FeSO_4$;
5. 80% peat moss and 20% P, $MnSO_4$;
6. 80% peat moss and 20% P, with $FeSO_4$

At planting, pots were treated with 100 ml of 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$. Plants were watered as needed and fertilized every third day with 200 ppm N solution using a mixture of soluble 20-10-20. Plants were harvested after 33 days and plant growth was evaluated as described above.

Experiments with S^0 Treated DF using Petunia grandiflora

Petunia Ultra Red and *Petunia* Ultra Blue (flower color split equally among treatments) plugs size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 72 cell inserts for standard 1020 flats. Treatments (r=4, n=18) included: 70% peat moss, 30% P with 1.78 kg/m^3 dolomite lime (DL) ($CaMg(CO_3)_2$) and 0.89 kg/m^3 limestone flour (LF) ($CaCO_3$); and for treatments 2-5, 70% DF, 30% P, with no S^0, 0.89 kg/m^3, 1.78 kg/m^3, or 2.67 kg/m^3 S^0. All supplements were incorporated one day pre-plant. Plants were fertigated daily with 125 ppm nitrogen using a 20-20-20 fertilizer. Plants were harvested after 33 days. Chemical analyses of media were conducted at planting and harvest for all treatments. Plant growth was evaluated as described above.

Experiments with S^0 and $CaSO_4$ Supplemented DF

Unrecorded observations suggested that S^0 treated DF did not support adequate root development. Plug *Petunia* Midnight Madness, size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 500 ml inserts for standard 1020 flats, with five media treatments (r=4, n=18):

1 80% peat moss, 20% P with 1.78 kg/m^3 DL and 0.89 kg/m^3 LF;
2. 70% DF, 30% P;
3. 70% DF, 30% P with 0.89 kg/m^3 S^0;
4. 70% DF, 30% P with 0.89 kg/m^3 S^0 and 4.15 kg/m^3 gypsum (G) ($CaSO_4{\cdot}2H_2O$);
5. 70% DF, 30% P with 0.89 kg/m3 S^0, 4.15 kg/m^3 G, and 0.89 kg/m^3 LF

All supplements were incorporated one day pre-plant. Plants were fertigated daily with 125 ppm nitrogen using a 20-20-20 fertilizer. High pressure sodium supplemental lighting began the day after transplanting from 08:00 to 17:00 for the duration of the experiment. Plants were harvested at 34 days. Media and plant tissue were analyzed at harvest. Aerial plant growth was evaluated as described above. Root growth (r=4, n=3) was evaluated using scanned and digitized washed roots using WinRhizo PRO 2005 root analysis software (Arsenault, 1995) total root length (cm) and total root surface area (cm^2).

Experiments with Rinsed Media

Petunia Midnight Madness, plug size 512, were randomized and grown at the Washington State University research station in Mount Vernon, Washington in 72 cell inserts for standard 1020 flats, with twenty media treatments (t=20, r=5, n=1).

(1) 70% peat moss, 30% P with 1.78 kg/m^3 DL and 0.89 kg/m^3 LF;
(2) 70% DF, 30% P with 0.89 kg/m^3 S^0;
(3-7) 70% DF, 30% P with 0.89 kg/m^3 S^0, and 1.77, 2.36, 2.95, 3.54, or 4.13 kg/m^3 G;
(8) 70% DF and 30% P with 0.89 kg/m^3 S^0 and 0.89 kg/m^3 LF;
(9-12) 70% DF and 30% P with 0.89 kg/m^3 S^0, 0.89 kg/m^3 LF and 1.77, 2.95 or 4.13 kg/m^3 G.

Most of these treatments were duplicated using fiber rinsed in perforated buckets with 3X fiber volume of greenhouse tap water five days before mixing, except the 70% DF and 30% P with 0.89 kg/m^3 S^0, 0.89 kg/m^3 LF and 4.13 kg/m^3 gypsum (G) treatment. 500 ml pots were filled (5 reps/treatment) and watered in using greenhouse fertigation (125 ppm N) as needed, pots were left to equilibrate for 96 hours before planting. Substrate pH and EC_e were measured using distilled H_2O percolated through the medium on the day of planting and 2, 7, and 16 days afterward. Plants were harvested after 17 days. Aerial and root growth were evaluated as described above.

Results and Discussion

Physical and Chemical Analysis of Digested Fibers

Tables 6.1 and 6.2 (above) summarize the physical and chemical nutrient analyses completed on fiber samples collected. Analysis showed that DF samples contain significant amounts of plant nutrients, with the most variability in Fe content. Notably, both mean pH (8.4) and mean EC_e (3.5 dS/m) were very different from peat moss. A correlation between EC_e and Na concentration (r=0.80) was noted (data not shown) with Na ion, as a percentage of EC_e ions, ranging from a low of 3.9% to a high of 19.1%, with a mean of 9.4%. Differences in values from farm to farm probably were due to differences in inputs, technologies and modes of separation of the fiber as well as exposure to rainfall and sampling point from the stored fiber. Between different AD technologies, complete mix digester fiber exhibited significantly lower air-filled porosity at container capacity than plug flow (7.9 for complete mis vs. 6.1% for plug flow).

Analysis of 70/30 peat/pumice and 70/30 DF/pumice for porosity indicated significant similarities with some differences. The peat composite had 25.9% (vol.) readily available water (CC to 50cb) and the fiber composite, 23.4%. The peat composite had 10.5% (vol.) air space at container capacity (CC), while the fiber composite had 26.1%. The peat composite had a density at CC of 1.06 g/cm^3 and 0.76 g/cm^3 at 50 cb suction, while the fiber composite had a density of 0.99 g/cm^3 and 0.72 g/cm^3 (Figure 6.1).

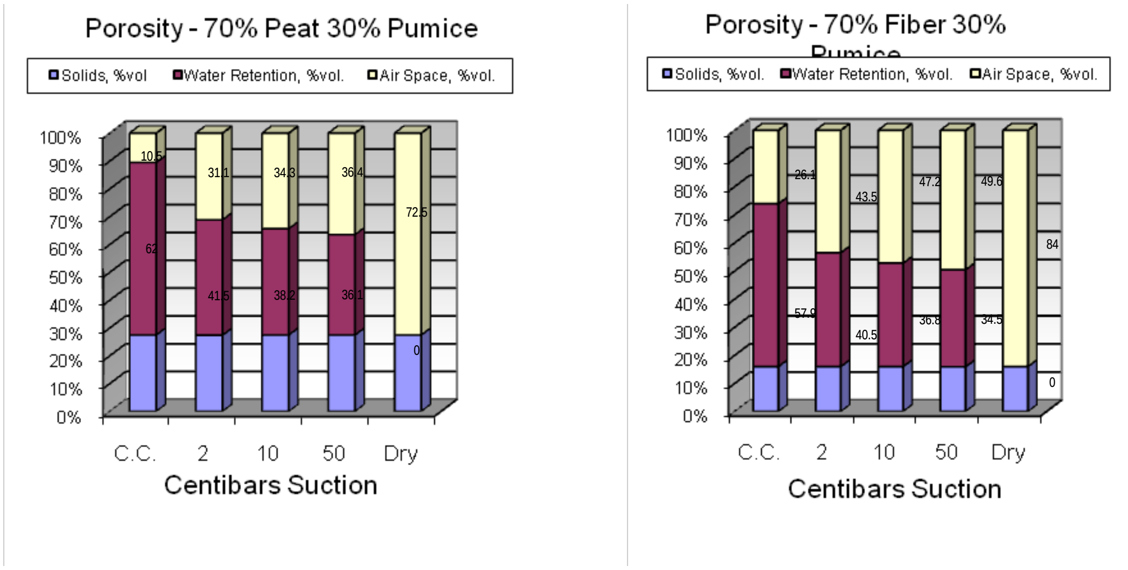

Figure 6.1: Air and water filled porosity of horticultural peat moss/pumice mix and dairy anaerobically digested fiber/pumice mix.

Experiments with unmodified AD separated solids using Petunia grandiflora

Plant growth trials with unmodified DF as a major substrate of the growth medium produced chlorotic and unmarketable plants while plants grown in peat moss medium had higher fresh weight, height, greenness, and number of flower buds (Figure 6.2). Plant tissue and medium analysis indicated that the most probable cause for the chlorosis was pH driven Mn deficiency (peat plant tissue with Mn=242 ppm and DF plant tissue with Mn=70 ppm).

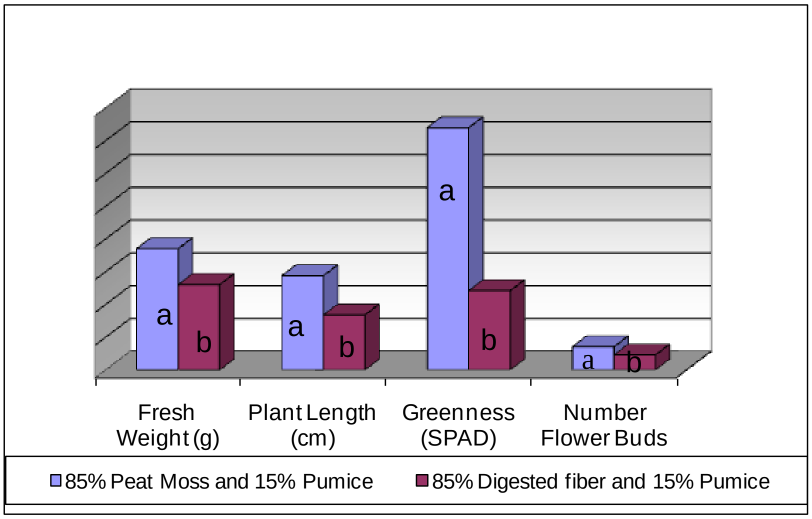

Figure 6.2: *Petunia* grown in peat moss and pumice or anaerobically digested dairy fiber fresh weight, leaf length, greenness (SPAD) and flower bud numbers grown. Different letters indicate statistical difference at $p \leq 0.01$

Experiments in pH Adjustment

Treatment of DF with S^0 was tested as a means of lowering the pH of the substrate and making Mn and Fe available to the plants. Supplementation at 0.89, 1.78 kg/m^3, and 2.78 kg/m^3 after 3 weeks incubation, lowered the pH to a range generally suited to plant growth (Figure 6.3).

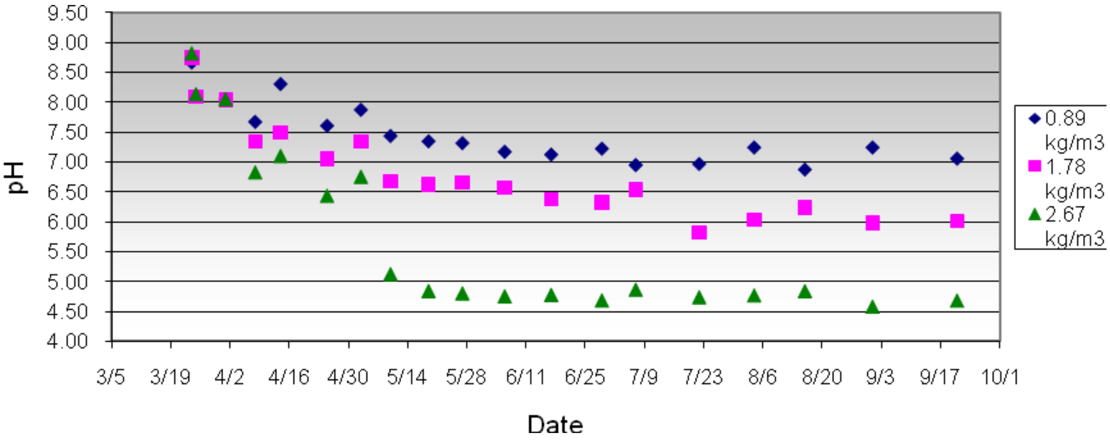

Figure 6.3: Changes in anaerobically digested dairy fiber pH over time with varying rates of S^0

Experiments with Mn and Fe Supplements using Petunia grandiflora

In subsequent trials Mn and Fe was added to DF in various forms, including nutrient drenches and supplementation of the substrate. None produced non-chlorotic plants. Plants grown in DF with either 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$ were statistically less green than plants grown in peat moss with either 204 ppm of $FeSO_4$ or 95 ppm of $MnSO_4$, and the plants grown in peat had statistically higher fresh weight than those in DF (Figure 6.4).

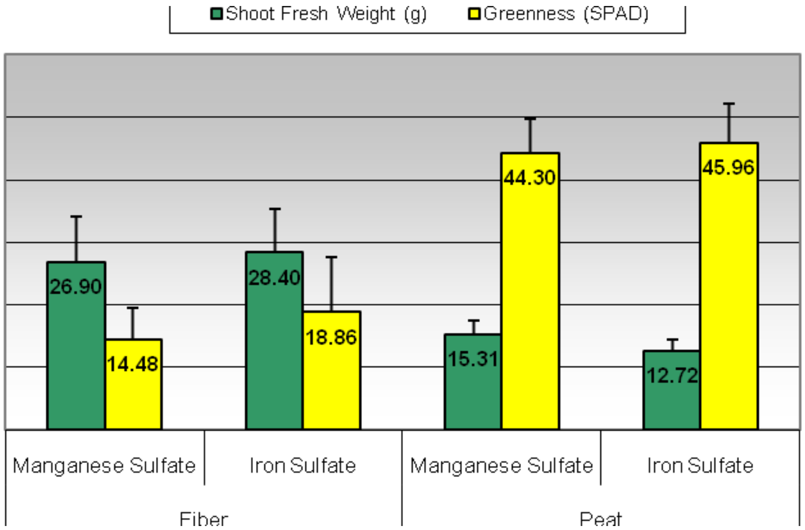

Figure 6.4: *Petunia* grown in peat moss and pumice or anaerobically digested dairy fiber amended with either $MnSO_4$ or $FeSO_4$, fresh weight and greenness (SPAD). $p \leq 0.01$

Experiments with S^0 Treated DF using Petunia grandiflora

Plants grown with S^0 added as an amendment to DF at a rate of 1.78 kg/m^3 S^0 had statistically better fresh weight, plant height, and greenness than lower, or no rate, of sulfur^0, or the standard limed peat moss media (Figure 6.5).

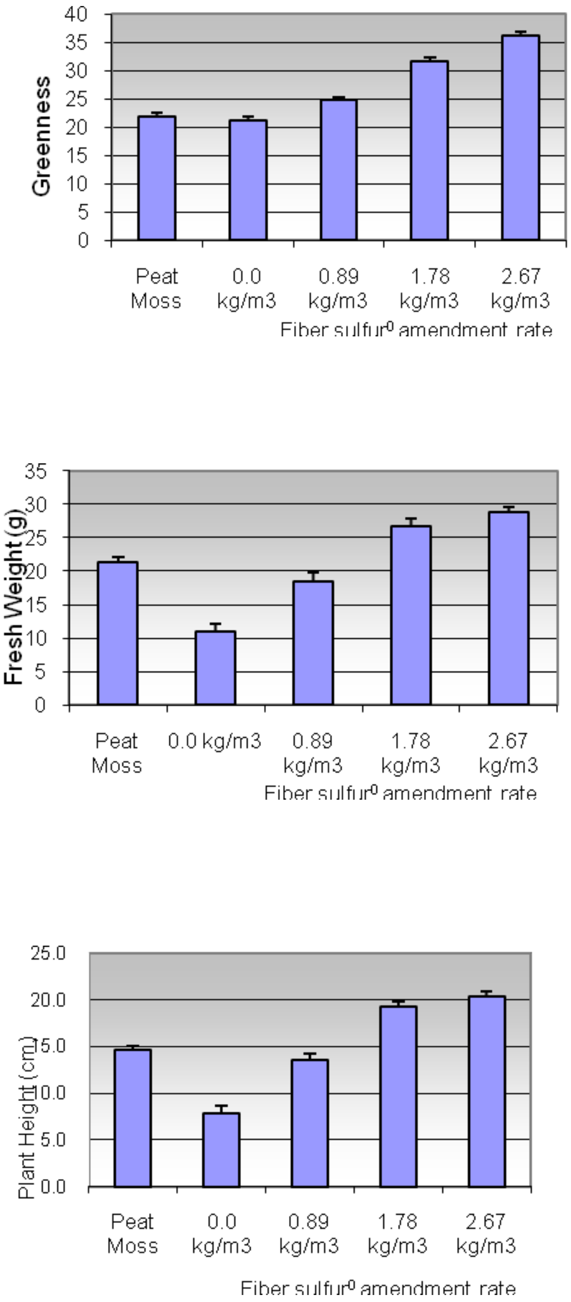

Figure 6.5: Greenness, fresh weight, and plant height for *Petunia* grown in peat moss or anaerobically digested dairy fiber (70/30 Fiber and Pumice) with S^0, 28 days after planting (DAP).

Experiments with S^0 and $CaSO_4$ (G) Supplemented DF

Subsequent investigation using digitalized root images indicated that while the aerial portions of the plants grown using S^0-only treated DF were indistinguishable from plants grown on peat moss, the root systems with that treatment was inadequate. Plants grown with 0.89 kg/m^3 S^0 and 4.15 kg/m^3 G; or with 0.89 kg/m^3 S^0, 4.15 kg/m^3 G, and 0.89 kg/m^3 LF had statistically longer roots and greater surface area than plants grown with just S^0 or plants grown with standard limed peat moss medium (Figure 6.6 and 6.7). Plants grown with both S^0 and G had statistically higher fresh weight at harvest than DF alone, DF with S^0, DF with S^0, G and LF, or plants grown on standard limed peat moss medium (Figure 6.8). Plants grown in standard limed peat moss were the greenest of all treatments, followed by plants grown with just S^0 (Figure 6.9).

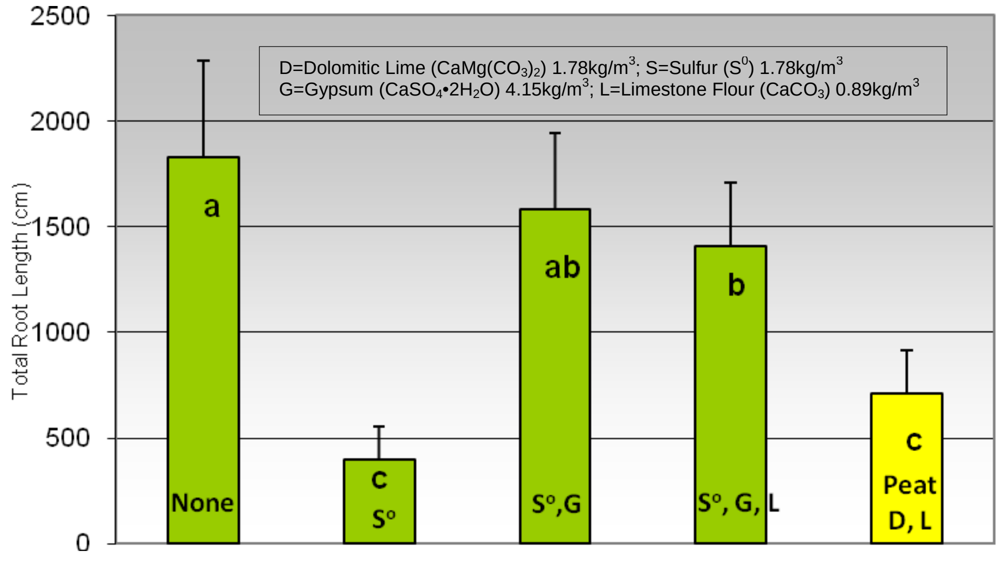

Figure 6.6: Total root length of *Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$). Letters indicate statistical significance at $p \leq 0.01$.

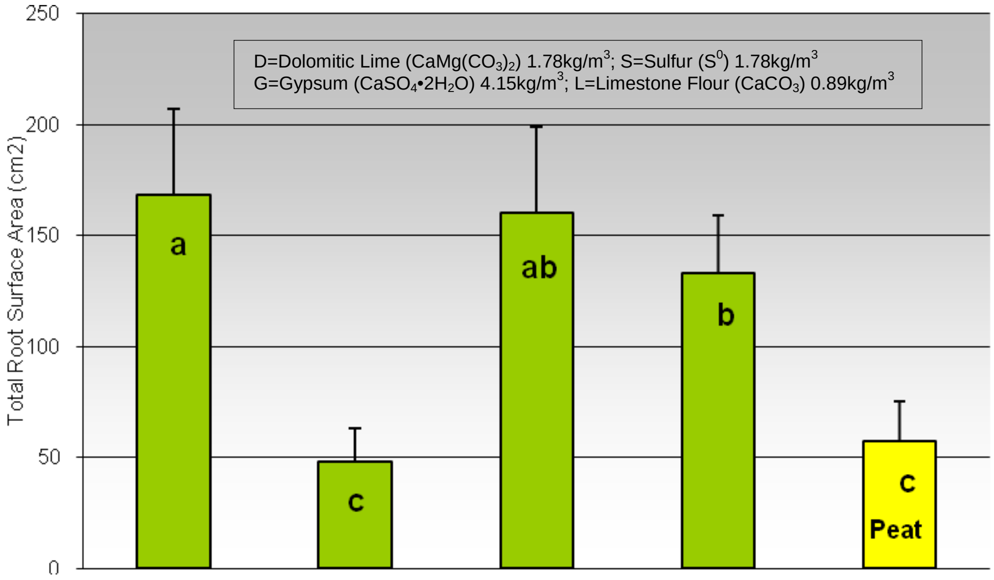

Figure 6.7: Total root surface area-- *Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$). Letters indicate statistical significance at $p \leq 0.01$.

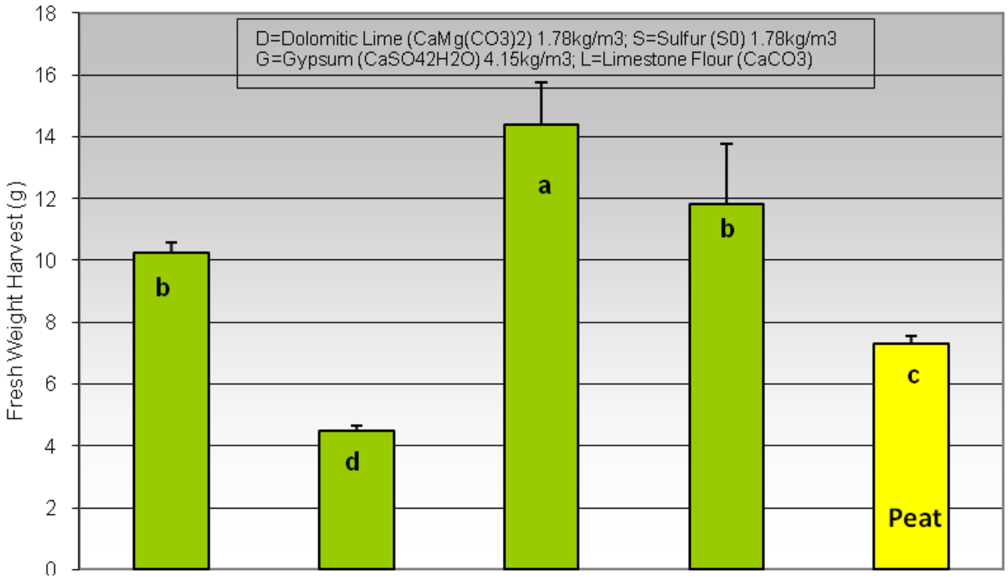

Figure 6.8: Fresh weight at harvest--*Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$). Letters indicate statistical significance at $p \leq 0.01$.

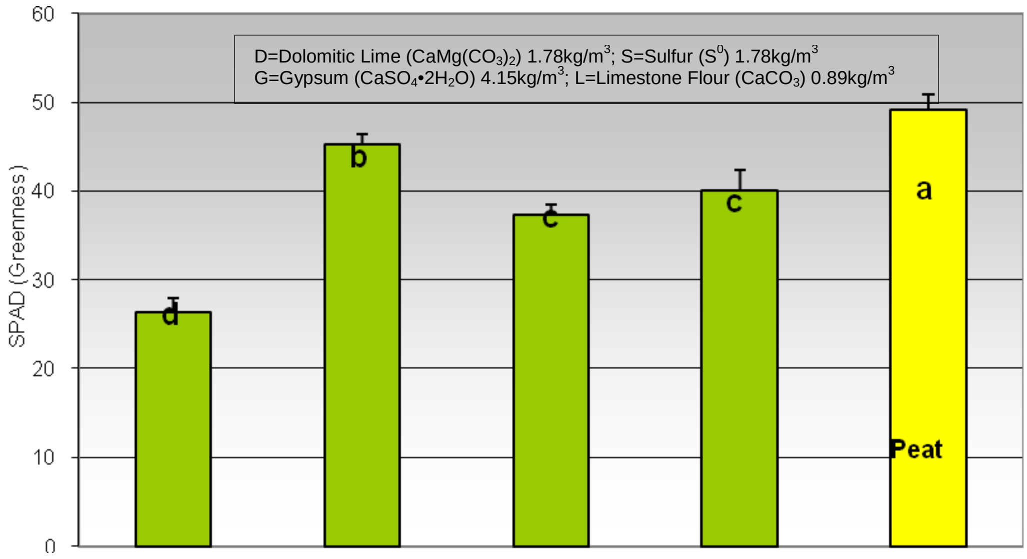

Figure 6.9: Shoot greenness (SPAD)--*Petunia* grown in peat moss or anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$). Letters indicate statistical significance at $p \leq 0.01$.

Experiments with Rinsed Media

Experiments with media rinsed with tap water starting on the day of planting indicated that substrate pH values were reduced in the rinsed treatments when compared to un-rinsed during all times (Figure 6.10).

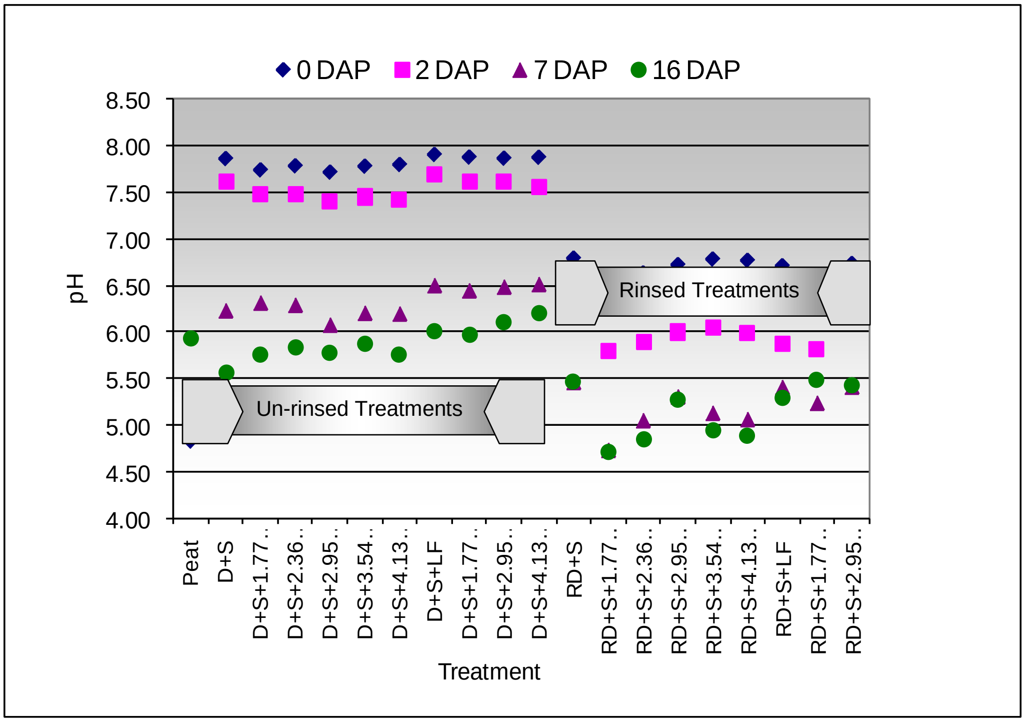

Figure 6.10: Dairy AD fiber, un-rinsed & rinsed, substrate pH, n=5, r=5, t=20

Substrate EC_e values were lower upon planting (DAP) in the rinsed treatments when compared to un-rinsed, but were greater on average, in all DAP>0 (Figure 6.11). There was no statistical difference in fresh weights among un-rinsed treatments. There were significant differences in fresh weights between rinsed treatments, with 0.89 kg/m^3 S^0, 2.95 kg/m^3 G and 0.89 kg/m^3 LF treatment having the highest value. Fresh weight was higher for each un-rinsed DF treatment when compared to the similar rinsed treatment (Figure 6.12).

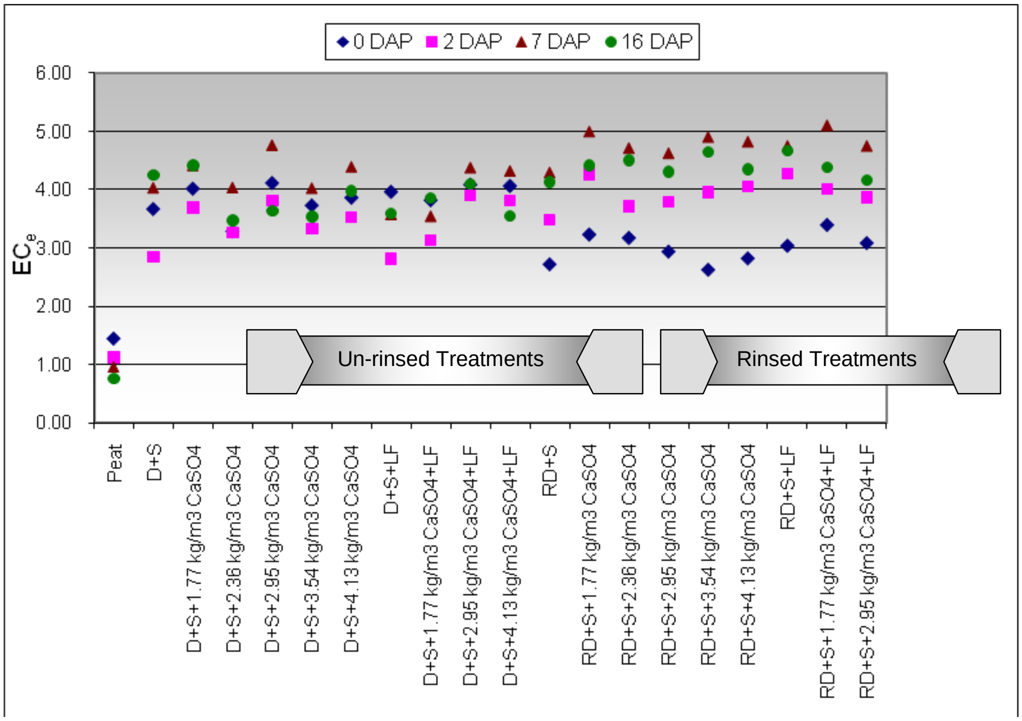

Figure 6.11: Dairy AD fiber, un-rinsed & rinsed, substrate EC_e, n=5, r=5, t=20

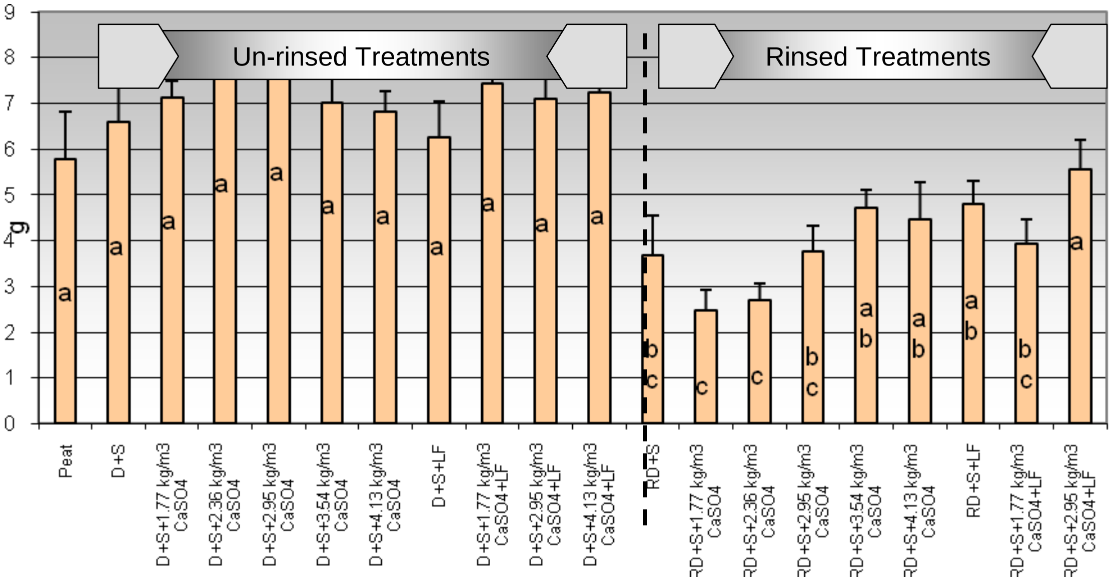

Figure 6.12: Fresh weight at harvest for *Petunia* grown in peat moss or rinsed or un-rinsed anaerobically digested dairy fiber with S^0, gypsum ($CaSO_4$) and limestone flour ($CaCO_3$). Letters indicate that treatments are statistically significant, within rinsed or un-rinsed treatments, at p ≤ 0.01.

Commercialization Efforts

The use of treated AD fiber as a peat moss replacement for container media will rely on significant investment in industry education and training as the fiber will use different production practices. While this will require an investment of resources, it is expected that there will be interest from early adopters, given the many greenhouse operators who said they might be interested in a peat substitute for container media substrate. The process of licensing the fiber treatment technology has proceeded with fits and starts. Discussions with a major multinational horticultural company were initiated based on information that the company was considering a green line of products. Treated fiber samples were submitted for trial substituting 1 for 1 for peat moss as a substrate and performed well. Based on the company's experience and interest, treated fiber samples were provided again. Reliance on a third party to prepare these samples was shown to be problematic as the fiber was not prepared to specifications, but shipped to the interested party. This delayed advancement of an agreement to a point where both global and company financial problems have currently halted further work. There currently is another party who has shown interest but is waiting for successful receipt of grant funds to pursue development.

Conclusions

The solid fraction (fiber) of the dairy manure AD effluent via plug flow technology yields material that has appropriate physical properties; total porosity, air filled porosity at saturation, and water holding capacity to perform satisfactorily as a plant growth medium substrate. Un-amended fiber, however, does not produce marketable plants. The use of S^0 to acidify the fiber produces plants with fresh weight and greenness equal to peat moss when used as a 1:1 replacement, but with inadequate root development. Adding gypsum along with S^0 as amendments to AD fiber produces aerial and root systems that are equal to peat moss when used as a 1:1 replacement as a substrate. The digester fiber (DF) does have a high EC, but most of that EC is due to nutrients that can be utilized by the plant. Plant growth trials indicate that amended DF can produce a substrate equal to peat moss for container plant media (Figure 6.13).

Figure 6.13: Comparison between optimized digested fiber pre-treated media to peat moss control at 1:1 replacement

The substitution of an AD-fiber product for peat could also reduce GHG emissions via reductions in climate emissions from peat mining. If these technologies were used by 40 dairies in Washington State, representing 192,000 wet cow equivalents, under co-digestion scenarios (as presented in chapter two), an *additional* mitigation potential of 0.019 MMT CO_2e/yr could be realized from the sale of the available fiber in replacement of peat (Table 6.4).

Table 6.4: Greenhouse credits from 40 dairy AD assumption—Peat replacement

	Fiber Product MT/yr [a, b]	GWP MT CO_2e/MT Peat [c]	Total Offset MMT CO_2e/yr
Peat Replacement	28,280	0.685	0.019

[a] Assume 40% marketing availability for non-farm uses and production rate of 9.7 m^3/cow yr (Frear et al, 2009)
[b] MT = metric tons (1 MT = 1 Mg); MMT = million metric tons (1 MMT = 1 Tg)
[c] (Cleary et al., 2005; Waddington et al., 2009)

Key project references related to chapter

The majority of the work presented in this chapter has been previously published as:

- MacConnell, C., 2006. Anaerobically digested fiber for use as a container media substrate. in: U.S.P.a.T. Office (Ed.) 20060150495. Washington State University Research Foundation, US.
- MacConnell, C.B., Collins, H.P., 2007. Utilization of re-processed anaerobically digested fiber from dairy manure as a container media substrate. in: W.R. Carlile, A. Coules, V. Surrage (Eds.), Proceedings of the International Symposium on Growing Media. ACTA Horticulturae, Nottingham, UK.

- Liao, W., Frear, C., Oakley, K., Chen, S., 2009. Production of a Pretreated Fibrous Manure Solid as a Soil Amendment Bedding Replacement using A Leaching-Bed Reactor. *Bioresource Technology*, Submission

References

Andgar, 2008. Average digester capital cost per cow, Ferndale, WA.

Armstrong, R.D., Eagle, C., Jarwal, S.D., 2007. Application of composted pig bedding litter on a vertosol and sodosol soil: effect on soil chemical and physical fertility. *Australian Journal of Experimental Agriculture*, 47, 1341-1350.

Baumgarten, A., 2004. CEN-Standards for chemical and physical analysis of growing media. in: P. Alsanius, H. Jensen (Eds.), Acta Horticulture. Acta Horticulturae, Alnarp, Sweden.

Beeson, R.C., 1996. Composted yard waste as a component of container substrates. *Environmental Horticulture*, 14, 115-121.

Birt, L.N., P.A., P., P.K., S., 2007. Evaluation of Texas compost specficiations for stormwater erosion control. *Transactions of the ASABE*, 50, 955-960.

Bishop, C., Shumway, C.R., 2009. Economics of dairy anaerobic digestion with co-product marketing. *Review of Agricultural Economics*, 31, 394-410.

Boertje, G.A., 1983. Physical laboratory analysis of potting composts. *Acta Horticulture*, 150, 47-49.

Caceres, R., Flotats, X., Marfa, O., 2006. Changes in the chemical and physicochemical properties of the solid fraction of cattle slurry during composting using different aeration strategies. *Waste Management*, 26, 1081-1091.

Cleary, J., Roulet, N.T., Moore, T.R., 2005. Greenhouse has emissions from Canadian peat extraction 1990-2000: A lifecycle analysis. *Ambio*, 34, 456-461.

Frear, C., Liao, W., Ewing, T., Chen, S., 2009. Evaluation of co-digestion at a commercial dairy anaerobic digester *Bioresource Technology*, Submitted.

Goh, K.M., Haynes, R.J., 1977. Evaluation of potting media for commercial nursery production of container-grown plants. *New Zealand Journal of Agricultural Research*, 20, 363-370.

Hasson-Porath, E., Kahana, I., Poljakoff-Mayber, A., 1972. The effect of chloride and sulfate types of salinity on growth and on osmotic adaptation of pea seedlings. *Plant and Soil*, 36, 449-459.

Hausenbuiller, R.L., 1972. Soil science: principles and practices. W.C. Brown Company, Dubuque, IA.

Johnson, G.A., Davis, J.G., Qian, Y.L., Doesken, K.C., 2006. Topdressing turf with composted manure improves soil quality and protects water quality. *Soil Science Society of America Journal*, 70, 2114-2121.

King, 2003. Study to Evaluate the Price and Markets for Residual Solids from a Dairy Cow Manure Anaerobic Digester—Final Report. King Country Solid Waste, Seattle, WA.

Liao, W., Frear, C., Oakley, K., Chen, S., 2009. Production of a Pretreated Fibrous Manure Solid as a Soil Amendment Bedding Replacement using A Leaching-Bed Reactor. *Bioresource Technology*, Submission.

Long, D., Jackson, A., 2002. Compost materials market assessment. in: T. Center (Ed.), Seattle, WA.

MacConnell, C., 2006. Anaerobically digested fiber for use as a container media substrate. in: U.S.P.a.T. Office (Ed.) 20060150495. Washington State University Research Foundation, US.

MacConnell, C.B., Collins, H.P., 2007. Utilization of re-processed anaerobically digested fiber from dairy manure as a container media substrate. in: W.R. Carlile, A. Coules, V. Surrage (Eds.), Proceedings of the International Symposium on Growing Media. ACTA Horticulturae, Nottingham, UK.

Marchaim, U., Levanon, D., Danai, O., Musaphy, S., Chen, Y., Inbar, Y., Klinger, I., 1991. A suggested solution for slaughterhouse wastes: uses of the residual materials after anaerobic digestion. *Bioresource Technology*, 37, 127-34.

Markwell, J., Osterman, J.C., Mitchell, J., 1995. Calibration of the Minolta SPAD 502 leaf chlorophyll meter. *Photosynthesis Research*, 46, 467-472.

Raviv, M., Chen, Y., Inbar, Y., 1986. Peat and peat substitutes as growth media for container-grown plants. in: Y. Chen, Y. Avnimelech (Eds.), Role of organic matter in modern agriculture. Kluwer Academic Publishers, Hingham, MA.

Slaton, N.A., Norman, R.J., Gilmour, J.T., 2001. Oxidation rates of commercial elemental sulfur products applied to an alkaline silt loam from Arkansas. *Soil Science Society of America Journal*, 65, 239-243.

US-EPA, 2005. An evaluation of a mesophilic, modified plug-flow anarobic digester for dairy cattle manure. United States Environmental Protection Agency.

Waddington, J.M., Plach, J., Cagampan, J.P., Lucchese, M., Strack, M., 2009. Reducing the carbon footprint of Canadian peat extraction adn restoration. *Ambio*, 38, 194-200.