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Evaluating Anaerobically Digested Dairy Fiber as a Substitute for Peat in Container Production and Nutrient Availability from Organic Fertilizers and Amendments

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Evaluating Anaerobically Digested Dairy Fiber as a Substitute for Peat in Container Production and Nutrient Availability from Organic Fertilizers and Amendments

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Contents

List of Tables

List of Figures

Abstract

The purpose of this research was to investigate alternative, renewable materials for potted plant production.

Sphagnum peat moss has been a primary component of soilless potting media for decades. Concerns over the sustainability of harvesting peat have fostered a search for renewable media components. Anaerobically digested dairy fiber (ADDF), a byproduct of methane production, shows promise as an alternative to peat. A variety of representative floriculture and nursery crops were grown in a numerous ADDF-containing media to evaluate its suitability as a substrate component. Nutrient leaching was monitored to evaluate the potential for environmental impact of using ADDF. Physical properties were not significantly different between greenhouse and nursery mixes with and without ADDF. Greenhouse mixes that replaced 50% of peat with ADDF mostly produced plants of equal quality and size of those grown in a control mix. There was not difference between nursery crops grown in a mix with all peat replaced with ADDF and a control mix. Plants grown in ADDF-containing mixes had higher tissue P concentrations than those grown in mixes without ADDF. ADDF containing mixes leach a significant amount of phosphorus over several weeks. Anaerobically digested dairy fiber can be used as a media component for a variety of floriculture and nursery crops and supplies a significant amount of plant available P. Nutrient leaching should be considered when using ADDF in media.

Switching to an organic fertilization regiment is one of the greatest obstacles greenhouse growers face in adopting organic practices. Nutrient availability from organic sources is difficult to predict. Greenhouse crops grown using a combination of organic fertilizers generally often have better results than those grown using only one organic fertilizer. Incubation trials with unplanted media were conducted to monitor nutrients leached and changing nutrient forms over time. A

variety of liquid organic fertilizers (LF), organic pre-plant incorporated organic fertilizers (PPIF), vermicompost and combinations of fertilizers were incorporated into a peat-perlite potting mix. Media was stored at 25°C. Leachate and saturated media extracts (SME) samples were taken to evaluate nutrient quantity and transformations, respectively. Mixtures of fertilizers produced many significant interactions over time indicating that organic fertilizers have different nutrient release patterns over time. Most nutrients are leached within the first four leaching events. Cumulative phosphorus leached as a percentage of phosphorus incorporated in the media varied greatly between fertilizers. Combinations of LF and PPIF slowed nitrification in SME samples. Vermicompost acts much like a PPIF in media. Numerous factors affect nutrient availability from organic sources.

Chapter 1: Anaerobically Digested Dairy Fiber as a Substitute for Peat in Soilless Potting Media

1.1. Introduction

Growing plants in containers offers a number of advantages over growing in the ground, most importantly the ability to precisely manipulate various attributes of the root zone to optimize plant growth. One of the most important manipulations of the root zone is the choice of growing media.

The purpose of this project is to evaluate anaerobically digested diary fiber (ADDF) as a sustainable alternative to peat in nursery container mixes. Peat is plant material, usually *Sphagnum* moss that has partially decomposed under low-nutrient, acidic, anaerobic conditions in bogs, leaving only a lignified cell wall structure. The skeletal cellular structure left by this partial decomposition remains intact under pressure and provides a great deal of inter- and intra-cellular pore space. The combination of a strong, lignified cell structure and extensive pore space provide peat with the physical and chemical characteristics that have made it such an important raw material for the horticulture industry for decades (Handreck, 1994).

Recently, concerns about the sustainability of peat have been raised. Peatlands are wetland ecosystems that are both economically and ecologically important. Peatlands play an important role in water purification and are enormous carbon sinks. Mining of peat drastically alters the chemical, physical and biological composition of peatlands. It takes a long time to reestablish their ecological functionality of peatlands. Although peatlands accumulate more peat over time, it is only about 0.5-1.0mm per year. Peat mining harvests from deep in the bogs and can

represent hundreds of years of peat accumulation. Most peat is produced in cold, northern regions and must be shipped long distances to more temperate horticultural areas. These concerns have prompted a search for sustainable, local alternatives to peat (Chalker-Scott, viewed May 5, 2014).

A potential alternatives to peat is anaerobically digested dairy fiber (ADDF); a byproduct of methane extraction from dairy manure. Systems to extract methane and reduce odor from manure have been used since the 1970's and have been vastly improved in the ensuing decades. Selling methane as a biofuel generates additional income or on-site energy for livestock farmers and utilizes this carbon-rich greenhouse gas rather than losing it to the atmosphere and contributing to climate change.

Marketing ADDF as a useful horticultural material rather than simply manure could become yet another source of income for dairy farmers and provide a partial solution to the waste management problems associated with raw manure. Leaching and run off of nutrients from soils with excess nutrients from manure application are a significant source of non-point source water pollution in some areas of The United States. If ADDF were used in a growing media, nutrients that would otherwise be lost as pollutants would be used for plant nutrition.

The potential for use of ADDF in growing media seems especially promising for the Northeast region. Agriculture in the Northeast is characterized by small diversified enterprises occupying a large portion of the industry. The diversity of farms and strong local agricultural networks in the Northeast make it an ideal locale for a product like ADDF potting mixes to be used widely.

Mixes containing ADDF have been used successfully to grow bedding plants (MacConnell and Collins, 2007), but currently there is no information published about growing

woody or herbaceous perennials in ADDF mixes. The robust nature of woody perennials makes them excellent choices for test subjects to grow in ADDF. The longer growing season of nursery crops presents a need to further investigate the physical properties of ADDF over time, particularly shrinkage.

The greenhouse, nursery and dairy industries are important to the New England economy and generate about one third of all agricultural cash receipts in New England (New England Agricultural Statistics, 2012). The environmental horticulture industry of New England represents almost 5 billion dollars, 11,900 firms, and 156,000 jobs and is growing. Nursery production represents a significant portion of this industry with almost half of New England horticultural firms engaged in some kind of production enterprise (New England Nursery Association, 2009). ADDF shows promise as a locally sourced, inexpensive, sustainable alternative to peat for growers in the Northeast

Utilization of ADDF in soilless potting media (SPM) has the potential to greatly benefit the Northeastern dairy industry as well. The dairy industry of New England has historically been, and continues to be a vitally important part of the region's economy. Despite contributing over 3 billion dollars to the region's economy annually, the New England dairy industry has been in long term decline (Department of Economic and Community Development and Department of Agriculture. 2009). Methane extraction from manure shows great promise as a supplementary revenue source for Northeastern Dairy farmers but revenue generated by energy production alone is often not enough to offset the capital costs of constructing anaerobic digesters. If ADDF were proven as a high quality media component, it would be a value-added product to add to dairy profits. The demand for ADDF from growers would be an added incentive for dairy farmers to

adopt the more sustainable anaerobic manure digestion systems (Lynda Brushett, Cooperative Development Institute, Barrington, New Hampshire, personal communication, May 1, 2014).

1.2. Literature Review

Research to find suitable and renewable alternatives to peat has been ongoing for decades. Peat alternatives should be comparable in physical and chemical properties as peat. Many potential alternatives are byproducts from agricultural and food industries. Agricultural and food byproducts are especially appealing because they are renewable resources and change the problem of waste management to an opportunity to generate revenue from a high-value horticultural product (Raviv, 2005).

Composts are often recommended as a natural slow release fertilizer amendment in SPM and compost as direct or partial replacement for peat in SPM has a substantial number of research reports supporting its use. Before the development of peat-based mixes composts often comprised a large proportion of potting mixes (Hankdrick & Black, 1994). Compost is organic material that has been stabilized using thermophilic and aerobic processes. A diversity of composts have been shown to possess physical and chemical properties within the acceptable range for plant growth. The most common limitation to using composts in SPM is a lack of physical and chemical stability, which may lead to compaction and unpredictable nutrient release (Raviv, 2005). Despite these limitations, a wide variety of composts have been successfully used as replacements for peat in nursery SPM (Chong, 2005).

Cowpeat is a composted dairy manure product that has been tested extensively as an alternative to peat. Bedding (Shober et al., 2010), nursery (Shober et al., 2011) and foliage crops (Li et al., 2009) were grown successfully in Cowpeat-based media. However, cowpeat-

containing mixes had much higher phosphate loads in leachate samples for up to 88 days after planting. Concerns over phosphate pollution could limit the use of Cowpeat as a direct replacement for peat. Shober et al. (2011) suggested growers modify fertilization regimes to account for additional P supplied by CowPeat. The additional P in leachate from CowPeat-containing mixes likely came from calcium phosphate minerals used in nutritional supplements for dairy cows. ADDF likely contains similar phosphate compounds.

Another composted dairy manure product, “dairy biofiber”, is produced by separating liquid and solid fractions of dairy waste and composting the solid fraction. Dairy biofibers have been shown to be a suitable replacement for up to 30% of the peat in a SPM but high pH limited its use. While mixes with a combination of dairy biofiber with bark or PBRH had the highest concentrations of P in SME samples, the concentrations were still within an acceptable range for use in greenhouse media. It was suggested that dairy biofiber be blended with peat or amended with iron sulfate or elemental sulfur to maintain a suitable pH for plant growth (Evans et al., 2014).

Spent mushroom compost (SMC) is another proposed alternative to peat that shares many important characteristics with ADDF. Both ADDF and SMC are alkaline in reaction, have a high electrical conductivity and have similar physical properties to peat. Several growing trials with a variety of nursery crops have been done replacing peat with SMC in nursery SPM (Chong, 2005). The successful results from SMC trials and its similarity to ADDF show that ADDF has a strong potential as a replacement for peat in nursery SPM. Compaction (Chong et al., 1994) and chlorosis in potentilla (*Potentilla fruticosa*) and privet (*Ligustrum vulgare*) (Chong et al., 1991) still present some challenges to using SMC as a direct peat replacement.

Tree-based products are another group of potential peat alternatives, which has had quite a bit of research attention recently. A wide variety of hardwood and softwood species processed in a variety of ways have been evaluated as media components with mixed results. Media made with softwood species yielded much better growth results than hardwood-containing media (Murphy et al., 2007). Pine tree substrates (PTS), most frequently from loblolly pine (*Pinus taeda*), are widely studied tree-based greenhouse and nursery media component. PTS can be manufactured to have a designated particle size distribution, which gives it particular physical properties appropriate for specific applications in media blends (Jackson et al., 2010). Manufacturing procedures, however. do need to be consistent to produce a product that will behave reliably (Field et al., 2014). Aged PTS produces higher quality plants than fresh PTS, likely due to pH stabilization and nutrient mineralization in the aging process (Gaches et al., 2012), and the possible presence of phytotoxic substances in fresh PTS (Taylor et al., 2013). The physical properties of PTS are consistent through the aging process (Taylor et al., 2013). PTS has been shown to have similar nitrification potential to conventional media when treated with lime (Taylor et al., 2012). PTS-containing media do however need higher fertilizer levels than conventional media to yield the same growth, likely due to microbial immobilization or greater porosity increasing leaching of nutrients (Wright et al., 2008).

The limitations of conventional composting have led to a search for alternative processes to produce more stable SPM components. Vermicompost can be a significant source of nutrients, however, it is much less biologically active than conventional composts, making it more chemically and physically stable (Ngo et al., 2013). Vermicompost also has a lower electrical conductivity (EC) than conventional compost and is less prone to induce salt stress (Chaoui et al., 2003). Vermicompost made from tomato crop waste has been demonstrated to be

a suitable replacement for up to 75% of the peat in SPM for *Calendula officinalis* and *Viola cornuta* (Belda et al., 2013). Media containing varying proportions up to a 2:1 ratio of vermicompost to coir yielded faster and greater yields of Swiss chard than either coir alone or a commercial potting media (Abbey et al., 2012).

Anaerobic digestion may be another alternative way to process organic waste into a useful and stable SPM component. Bedding plants grown in acidified ADDF-based media were of the same or better quality and size of those grown in peat-based media (MacConnell and Collins, 2007).

ADDF and ADDF products have already been successfully marketed as value-added horticultural products. Cowpots™ (Freund Farms, East Canaan, CT) are biodegradable pots made from ADDF which are sold nationwide. Cenergy USA, Inc. (Little Rock, AR) produces "Magic Dirt™", a potting mix made from ADDF and composted forest products. Eco-Tek® (Rossville, IN) and Organix, Inc (Walla Walla, WA) produce and sell ADDF as a sustainable peat substitute for many years.

Some characteristics of ADDF do present challenges. ADDF has a high pH and interacts with different media components unpredictably (Evans and Salazar, 2014). ADDF-containing media can be adjusted to an appropriate pH with the use of elemental sulfur (MacConnell, 2007). Mixes containing ADDF can be brought into an appropriate pH range for plant growth by blending it with an acidic material, like peat. The varying reactions of ADDF to different media components is likely due to the biological activity of ADDF. A detailed evaluation of the biological activity of ADDF may aid in predicting how ADDF will react in a SPM.

Along with evaluating ADDF as a replacement for peat, it is also important to evaluate how ADDF works with other alternative media components that growers who may be interested in using ADDF as a peat replacement may also be interested in using.

Parboiled rice hulls (PBRH) have been considered as a direct or partial replacement for either peat or perlite in SPM. Whole PBRH provide more pore space and are used as a replacement for perlite. Ground PBRH of various grades are used in place of peat. While the physical properties of whole and ground PBRH are similar to perlite and peat, respectively, some chemical attributes of ground PBRH likely make it unsuitable as a direct substitute for peat. PBRH contain high levels of P, K and silica. Silica acts as a base in PBRH-containing media and can raise the pH outside of the recommended range for plant growth. When PBRH are ground, significant amounts of P and K can be released and raise P and K levels outside the recommended range for SPM (Evans et al., 2011). Despite these obstacles, PBRH have been used successfully as a replacement for up to 30% of the perlite or 40% of the peat in SPM for a variety of bedding plants (Lopez and Currey, 2013) and up to 100% of the perlite in propagation mix for New Guinea impatiens (Lozez et al., 2013)

Coir is a renewable, fibrous byproduct of coconut processing. It can possess many similar physical properties to peat and has been tested widely as a partial or, in many cases, complete replacement for peat. There can be quite a bit of variability in coir based on how it is produced and the source it come from. Different particle sizes can be blended to produce a media that is appropriate for a specific applications. Variability in physical properties due to particle size distribution and age of coir needs to be considered when using coir as a media component. High salinity in coir has been reported but is easily fixed by leaching. Despite the challenges in using coir, it has been shown to be an effective replacement for peat in many cases. (Nichols, 2007)

Research Objectives for This Project

1. To evaluate ADDF as a substitute for peat in a variety of soilless potting media formulations.
2. To evaluate nutrient availability in ADDF over time.
3. To evaluate physical characteristics of ADDF over time.

1.3. Materials and Methods

1.3.1. Media Formulation and Analysis

Five greenhouse mixes and four nursery mixes were evaluated. The greenhouse mixes contained peat-ADDF-perlite, peat-ADDF-parboiled rice hulls (PBRH), coir-ADDF-perlite and coir-ADDF-PBRH each in a 2:2:1 ratio amended with $4g\cdot L^{-1}$ gypsum. A control mix was composed of peat and perlite in a 4:1 ratio amended with $2.5g\cdot L^{-1}$ dolomitic lime. The nursery mixes contained bark-peat-sand, bark-ADDF-sand, bark-peat-perlite and bark-ADDF-perlite each in a 4:2:1 ratio. ADDF-containing mixes were amended with $4g\cdot L^{-1}$ gypsum and peat-containing mixes were amended with $2.5g\cdot L^{-1}$ dolomitic lime.

Preliminary SME samples were taken from each mix to measure initial pH, EC and nutrient concentration. SME samples were analyzed for ammoniacal nitrogen (Chanet and Marlback 1962), nitrate nitrogen (Cataldo et al., 1975), and phosphate phosphorus (Murphy and Riley, 1962) using colorimetric methods (refs). EC and pH were measured using Twin pH/conductivity meters (Horiba Corp., Kyoto, Japan).

The physical properties of several ADDF-containing media were evaluated using the techniques described by Elliott (1992b): Media put in pots with known dimensions (truncated cone with

height (H) of 120mm, bottom radius (R_b) of 30mm and top radius (R_t) of 40cm). Pots were weighed at the start of the trial and were subsequently irrigated, drained and weighed several times a week until the irrigated mass reached equilibrium. Equilibrated irrigated mass was used to derive effective water holding capacity (EWHC) using the equation (net weight after irrigation - initial dry weight). Pots were then saturated with subirrigation for 24 hours, then weighed before and after draining. Saturated and drained masses were used to derive container capacity (CCAP) using the equation (net weight after saturated and drained - initial dry weight). The volume of media in each pot after saturation was derived by measuring the height of the media in the pot and calculating volume as a function of height using the formula for a truncated cone: $V=\pi H(R_b^2+ R_b+ R_t+ R_t^2)$. Dry bulk densities were obtained by weighing a given volume of each media before and after drying and using the formula (initial dry weight)/(volume).
Physical properties and volume shrinkage (Based on the formula of a truncated cone described above) of the bark-peat-sand and bark-ADDF-sand mixes were measured again at the end of the woody shrub growth trial to evaluate long-term use of ADDF for nursery crops.

1.3.2. Bedding Plants and Vegetable Seedlings.

Seedlings of pansy (*Viola* x *wittrockiana* ‘Karma White’), viola (*Viola cornuta* ‘Penny-jump-up’), petunia (*Petunia* x *hybrid* ‘Fuseable Vogue’), rooted cuttings of geranium (*Pelargonium* x *hortorum* ‘Patriot Red’) and seeds of cucumber were planted in pots containing the peat-ADDF-perlite, peat-ADDF-PBRH and control mixes described previously. Pansies and petunias were planted in Nu-Pots™ 4 (423ml capacity, 9.8cm tall) (Summit Platic Co., Tallmadge, OH), geraniums were planted in Nu-Pots™ 3 (321ml capacity, 8.9cm tall), violas

were transplanted and cucumber seeds were sown in #3 CowPots™ (200ml capacity, 73mm tall) (Freund Farm Inc., East Canaan, CT).

All bedding plant trials were completely random design (CRD) experiments. Pansies and violas had 32 plants per treatment; geranium and petunia had 16 plants per treatment and cucumber had 8 plants per treatment.

Plants were overhead irrigated without fertilizer for 12 days and then sub irrigated with constant liquid feed with 100 $mg \cdot L^{-1}$ N delivered from Plantex® 19N-0.9P-15.8K (Master Plant-Prod Inc. Brampton, ON) for the remainder of the experiment. Trials were conducted in a computer-controlled greenhouse covered with corrugated polycarbonate. Pansies and violas were grown with 62°F days and 58°F nights. Geranium, petunias and cucumbers were grown with 75°F days and 63°F nights.

Plants were harvested approximately 8 weeks after planting and fresh weight, dry weight and tissue nutrient concentrations were measured.

1.3.3. Garden Chrysanthemum

Rooted cuttings of chrysanthemum (*Chrysanthemum morifolium* 'Hankie Yellow') were transplanted into 8" pans (Dillen 8x5" Pan, 2.88L capacity) (The HC Companies, Middlefield, OH) containing the peat-ADDF-perlite, peat-ADDF-PBRH, coir-ADDF-perlite, coir-ADDF-PBRH or the control mix described previously. One cutting was planted in each pan and grown, unpinched, outdoors with natural season lighting. Plants were overhead irrigated for one week and then drip irrigated with a constant liquid feed at the rate of 100 $mg \cdot L^{-1}$ N using a Plantex 19N-0.9P-15.8K. The experimental design of this trial was randomized complete block with 3 blocks and 8 plants per treatment per replication for a total of 120 pots.

The shoot fresh weight and volume were measured 12 weeks post-transplant. Canopy volume was estimated using the formula for a semi-ellipsoid ($(\frac{4}{3}\pi(\frac{w_1}{2})(\frac{w_2}{2})(\frac{H}{2})/2)$) where w_1 and w_2 are the maximum and minimum diameters and h is the height from the top of the pot rim. Maturity was rated subjectively on a 3 point scale with a rating of 1 with 30% or fewer flowers open (Syngenta stages 0-1), 2 a plant with 31-69% flowers open (Syngenta stages 2-3) and with 3 representing a plant with 70% or more flowers open (Syngenta stages 4-5) (Syngenta Flowers Inc., 2015). Leaf tissue samples were obtained for nutrient analysis.

1.3.4. Cyclamen

Cyclamen (*Cyclamen persicum*) 'Silver Heart White' and 'Winfall White' seedlings were transplanted into 4" pots (414ml capacity) containing the same media used previously in the garden mum trial, with six plants of each variety in each treatment for a total of 30 plants. The experimental design was a CRD.

Pots were placed in flood and drain trays and irrigated with 100 $mg{\cdot}L^{-1}$ N from Plantex 19N-0.9P-15.8K. At the end of the trial, approximately 9 weeks post-transplant, plants were evaluated qualitatively based on appearance and plant height and width were measured. Canopy volume was calculated as described in the chrysanthemum trial.

1.3.5. Poinsettias

Rooted cuttings of poinsettia (*Euphorbia pulcherrima* 'Classic Red') were transplanted into Dillen 6" jumbo azalea pots (approximately 1.8L volume) containing the peat-ADDF-perlite and control mixes previously described with twelve plants of each variety in each treatment. Pots were placed in flood and drain trays and irrigated with 100 mg.L-1 N from Plantex 19N-0.9P-

15.8K. At commercial maturity 15 weeks post-transplant, plant growth was evaluated qualitatively based on appearance. Shoot height, fresh weight and dry weight were measured and leaf tissue was analyzed. PourThru samples (Wright 1986) were taken approximately biweekly and analyzed for pH, EC and nutrient concentrations as previously described.

1.3.6. Woody Nursery Crops.

Liners of button bush (*Cephalanthus occidentalis*) and silky dogwood (*Cornus amomum*) were transplanted into #2 pots (7.3L volume) containing either the bark-ADDF-sand mix or the bark-peat-sand mix. Plants were fertilized with a top dressing of Osmocote 18-6-12 (Everris NA, Inc.) at a rate of 30g per pot. Plants were grown outdoors with natural season lighting and irrigated with drip irrigation during the first season's growth. Plants were overwintered in an unheated hoop house. Plants were moved from the hoop house and forced out of dormancy in a double polyethylene film greenhouse with overhead irrigation. At the end of the first growing season, plant height, width, thickest stem caliper and number of shoots were measured. After leafing out at the beginning of the second season (approximately 10 weeks after being moved into greenhouse) plant height and shoot fresh weight and dry weight were measured. Leaf tissue samples were taken for nutrient analysis at the end of the first season before plants began to enter dormancy and at the beginning of the second season after plants had leafed out. Shrinkage of media was measured at the end of the first season and upon harvest at the beginning of the second season. Media physical properties including bulk density, porosity and water holding capacity were measured again upon harvest at the beginning of the second season. PourThru samples were taken regularly and analyzed for pH, EC and nutrient concentrations during the first season.

1.3.7. Woody Cuttings

Cuttings from ninebark (*Physocarpus opulifolius*) and cranberry bush viburnum (*Virburnum opulus*) were rooted in sand under intermittent mist with bottom heat. The rooted cuttings were then transplanted into 2.5” establishment pots (approximately 250 ml volume) and grown outdoors with overhead irrigation for one growing season. Plants were overwintered in a cold frame and forced out of dormancy in a greenhouse in early spring. Plants were evaluated after leafing out by measuring dry weight, height, above ground tissue concentrations and with a subjective visual evaluation.

1.3.8. Herbaceous Nursery Crops

A variety of representative herbaceous perennials were used in this trial. Plugs of brunnera (*Brunnera macrophylla* ‘Jack Frost’), Shasta daisy (*Lucanthemum superbum* ‘Whoops-a-Daisy’) and rooted cuttings of phlox (*Phlox paniculata* ‘David’), liatris (*Liatris spicata* ‘Kobold Original) and coreopsis (*Coreopsis verticillata* ‘Moonbeam’) were transplanted in pots (approximately 2.8L volume) containing either the bark-ADDF-perlite or bark-peat-perlite mix. Plants were fertilized with a top dressing of Osmocote 18-6-12 at a rate of 6g per pot. Plants were grown in a glass greenhouse. Plants were overhead irrigated and leachate was collected for nutrient analysis to calculate cumulative quantities of nutrients leached per pot. Growth and quality of each species was evaluated based on quantitative parameters appropriate its growth habits and a subjective visual evaluation. For brunnera, the number of flower spikes, maximum flower spike length and canopy volume (as described in previous trials) were measured. For coreopsis, dry weight was measured. For Shasta daisy dry weight and number of flowers were

measured. For liatris, dry weight, number of flower stems and maximum height were measured. For phlox, dry weight, number of stems and maximum height were measured.

Leachate from each irrigation event was collected, measured gravimetrically and analyzed for NH_4-N, NO_3-N and PO_4-P to calculate the cumulative amount of these nutrients leached.

1.3.9. Unplanted ADDF Leaching

The purpose of this trial was to monitor nutrient release from ADDF. The bark-peat-perlite and bark-ADDF-perlite mixes used for the herbaceous nursery crop trial as well as unammended peat and ADDF were used in this trial. Leachate samples were collected to show nutrient release over time using the methods described by Elliott (1986) using deionized water as an extractant applied 100ml at a time for the first 8 leaching events and 200ml at a time for the remaining leaching events. Leachate samples were collected on days 1, 4, 6, 9, 16, 18, 21, 23, 27, 29, 37 and 40. All media were stored in an incubator set at 25°C. All extracts were analyzed for pH, EC NH_4-N, NO_3-N and P_2O_5-P concentrations using colorimetric techniques described above.

1.3.10. Statistical Analysis

Statistical Analysis System (SAS institute inc., Cary, North Carolina) mixed procedure was be used to analyze data and data graphics were generated using SigmaPlot (Systat Software, Inc., San Jose, California).

1.4. Results

1.4.1. Media Analysis

Effective water holding capacity (EWHC) and bulk density (D_b) of all ADDF-containing greenhouse mixes were not significantly different from the control mix (Table 1.1). The two coir containing greenhouse mixes had greater container capacities (CCAP) than the control. Little differences were observed in bulk density among greenhouse mixes. The addition of PBRH generally increased porosity. The coir-ADDF mixes had a pH range of 6.86-7.09 while the other mixes has pH within the optimum range for plant growth. ADDF-containing media had higher EC measurements in SME samples than the control media (1.14mS/cm^3). The EC of peat-ADDF media ranged from 1.16-1.22mS/cm^3 and the EC of the coir-ADDF media had a range of 1.40-1.96mS/cm^3. The EC of the ADDF-aggregate mixes were much greater than the other mixes with a range of 2.20-2.60mS/cm^3.

Table 2.1. Mean effective water holding capacity (EWHC), container capacity (CCAP) and dry bulk density (D_b)of various greenhouse media. The ratio of mix components is 4:1 for two component mixes and 2:2:1 for three component mixes. Means with different letters are significantly different. Tukey's HSD means separation test was used to find differences in treatments based *p*-value ≤ 0.05.

MIX	EWHC, % volume	CCAP, % volume	D_b, g/cm^3	Air filled porosity at EWHC, % volume	Air filled porosity at CCAP, % volume	Total porosity, % volume
PEAT-PERL	52.7ab	58.7c	0.106ab	32b	26ab	84b
PEAT-ADDF-PERL	52.6ab	61.2bc	0.116a	36ab	27ab	88ab
PEAT-ADDF-PBRH	48.2b	58.0c	0.106ab	45a	35a	93a
COIR-ADDF-PERL	57.1a	66.7a	0.100b	32b	23b	89ab
COIR-ADDF-PBRH	49.2b	63.7ab	0.107ab	48a	34a	97a

There were no significant differences in initial physical properties (Table) or pH (5.53 for bark-peat-sand and 5.66 for bark-ADDF-sand) between the nursery mixes. The ADDF-containing nursery mixes had a higher mean EC (1230µS vs. 156µS). At the beginning of the second growing season of the woody nursery crop trial the bark-ADDF-sand mix had significantly lower EWHC and CCAP than the bark-peat-sand mix. Both mixes did, however, have similar D_b upon final measure (Table 1.2). The bark-peat-sand mix had significantly more shrinkage in the first season under drip irrigation whereas the bark-ADDF media had significantly more shrinkage

upon final measure after approximately 10 weeks of overhead irrigation. Both mixes had the same total amount of shrinkage.

Table 1.2. Mean effective water holding capacity (EWHC), container capacity (CCAP) and dry bulk density (D_b) of two nursery media used for woody nursery crop trial before planting and at the end of the trial. The ratio of mix components is 4:2:1. Means with a * are significantly different based on *p*-value ≤ 0.05.

	EWHC	CCAP	D_b
Initial	% volume	% volume	g/cm
Bark-ADDF-sand	0.476	0.509	0.353
Bark-peat-sand	0.474	0.528	0.335
Significance	ns	ns	ns
End of trial			
Bark-ADDF-sand	0.489	0.698	0.508
Bark-peat-sand	0.591	0.772	0.524
Significance	*	*	ns

Table 1.3. Mean shrinkage of media used in woody nursery crop trials between the beginning of the trial and the end of the first season, between the end of the first season and the end of the trial and total shrinkage. Means with a * are significantly different based on *p*-value ≤ 0.05.

% of initial volume

lost

Mix	Season 1	Season 2	Total
Bark-ADDF-sand	0.63	10.25	10.87
Bark-peat-sand	5.37	7.00	12.34
Significance	*	*	ns

1.4.2. Bedding Plants and Vegetable Seedlings.

Fresh shoot weights of pansy grown in the control mix and ADDF-perlite mix were greater than those grown in the ADDF-PBRH mix. The mean fresh weight of viola was significantly greater in the ADDF mixes than the control. Fresh weights of petunias grown in the control mix were significantly less than those grown in either of the ADDF mixes and plants grown in the ADDF-perlite mix had greater fresh weights than those grown in the ADDF-PBRH mix. Fresh weights of geranium were not significantly different among treatments. Fresh weights of geranium grown in the control mix were significantly greater than those grown in either ADDF mix and plants grown in the ADDF-perlite mix had greater fresh weight than those grown in the ADDF-PBRH mix. Fresh weights of cucumber were neither significantly different between the two ADDF mixes nor between the ADDF-perlite mix and the control mix but plants grown in the ADDF-PBRH mix had a greater fresh weight than the control (Fig. 1.1).

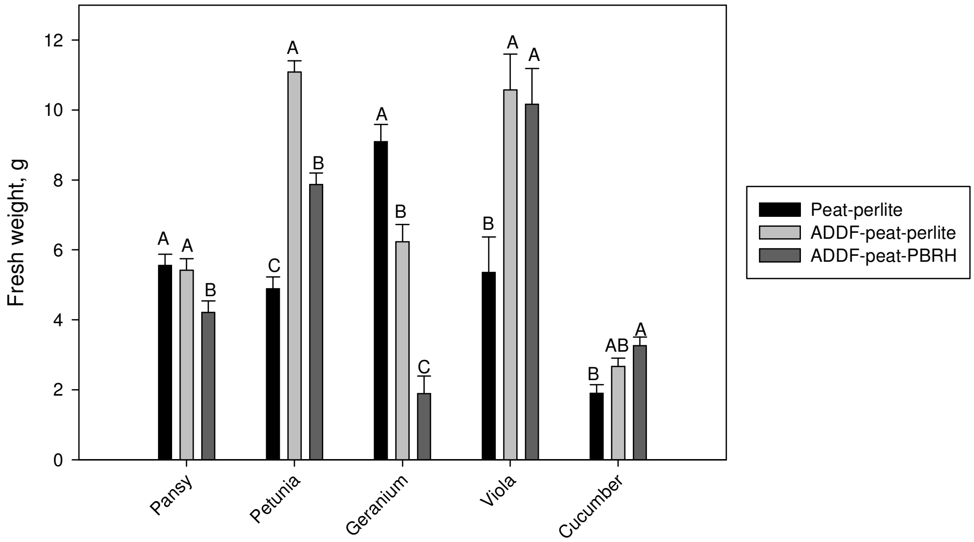

Figure 1.1. Mean fresh weight for bedding plant species grown in media containing either peat and perlite, ADDF and perlite or ADDF and PBRH. Means with different letters are significantly different within species. Tukey's HSD test was used for means separation at $\alpha = 0.05$.

The phosphorus concentrations of plant samples were significantly greater in both ADDF mixes than in the control for all species (Fig. 1.2). Geranium and cucumber grown in the peat-ADDF-PBRH mix had the greater tissue phosphate than either of the other mixes.

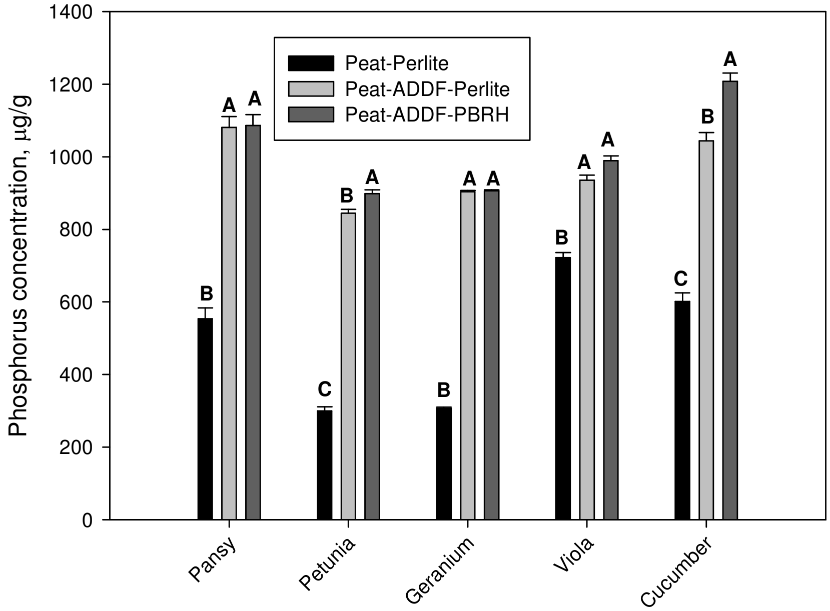

Figure 1.2. Mean leaf tissue phosphorus concentration for bedding plant species grown inmedia containing either peat and perlite, ADDF and perlite or ADDF and PBRH. Means with different letters are significantly different within species. Tukey's HSD test was used for means separation at α=0.05.

Plants grown in ADDF-containing media had significantly greater tissue concentrations of Ca and Mn and significantly lower concentrations of Mg than those grown in the peat-perlite mix for all species. There were no significant differences in tissue K concentrations. There were differences between other nutrient concentrations, which varied between species (Table 1.4).

Table 1.4. Mean nutrient concentrations of above ground tissue of four bedding plant species grown in three greenhouse media. Means within species with different letters are significantly different. Tukey's HSD test was used for means separation at α=0.05.

	K	Ca	Mg	Al	B	Cu	Fe	Mn	Mo	Na	Zn
Pansy	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Peat-perlite	2.97	0.63b	0.67a	12.5a	186.5	17a	76a	108b	6.9a	352	135.5
ADDF-peat-perlite	3.18	0.97a	0.44b	18.5a	178	14.5ab	58.5b	303a	4.75b	355	134
ADDF-peat-PBRH	3.15	0.98a	0.45b	0b	260.5	13b	51.5b	293.5a	1.9c	561	126
Petunia											
Peat-perlite	3.07	0.094c	0.82a	65	398.5	19.5	77	46.5b	4.05a	932.5	51b
ADDF-peat-perlite	3.16	1.23b	0.31b	72.5	598	14.5	62.5	92a	0.05b	1083	82.5a
ADDF-peat-PBRH	3.58	1.39a	0.34b	40	667	16.5	62.5	101.5a	0b	1315	91.5a
Geranium											
Peat-perlite	2.54	0.94b	0.63a	5.5	117b	10.5a	62a	57.5c	3.5a	334.5b	40
ADDF-peat-perlite	2.33	1.16a	0.21b	3	104b	7b	39b	133.5b	0.45b	275b	48.5
ADDF-peat-PBRH	2.37	1.22a	0.25b	5.5	211.5a	8b	47b	177.5a	0.3b	542.5a	48
Viola											
Peat-perlite	3.17	0.57b	0.57	34.5a	346.5	18	84.5	147.5b	2.1	534.5	119.5
ADDF-peat-perlite	3.63	0.94a	0.51	13.5b	374.5	16.5	81	216a	1.55	706	145
ADDF-peat-PBRH	3.77	0.93a	0.51	7b	400.5	17	80.5	235.5a	0.9	665	137.5

Overall performance varied. In some crops, such as viola, plants performed much better in the ADDF mixes than in the control mix but in some other crops the control plants were larger and were a healthier dark green than plants grown in the ADDF mixes (Fig. 1.3).

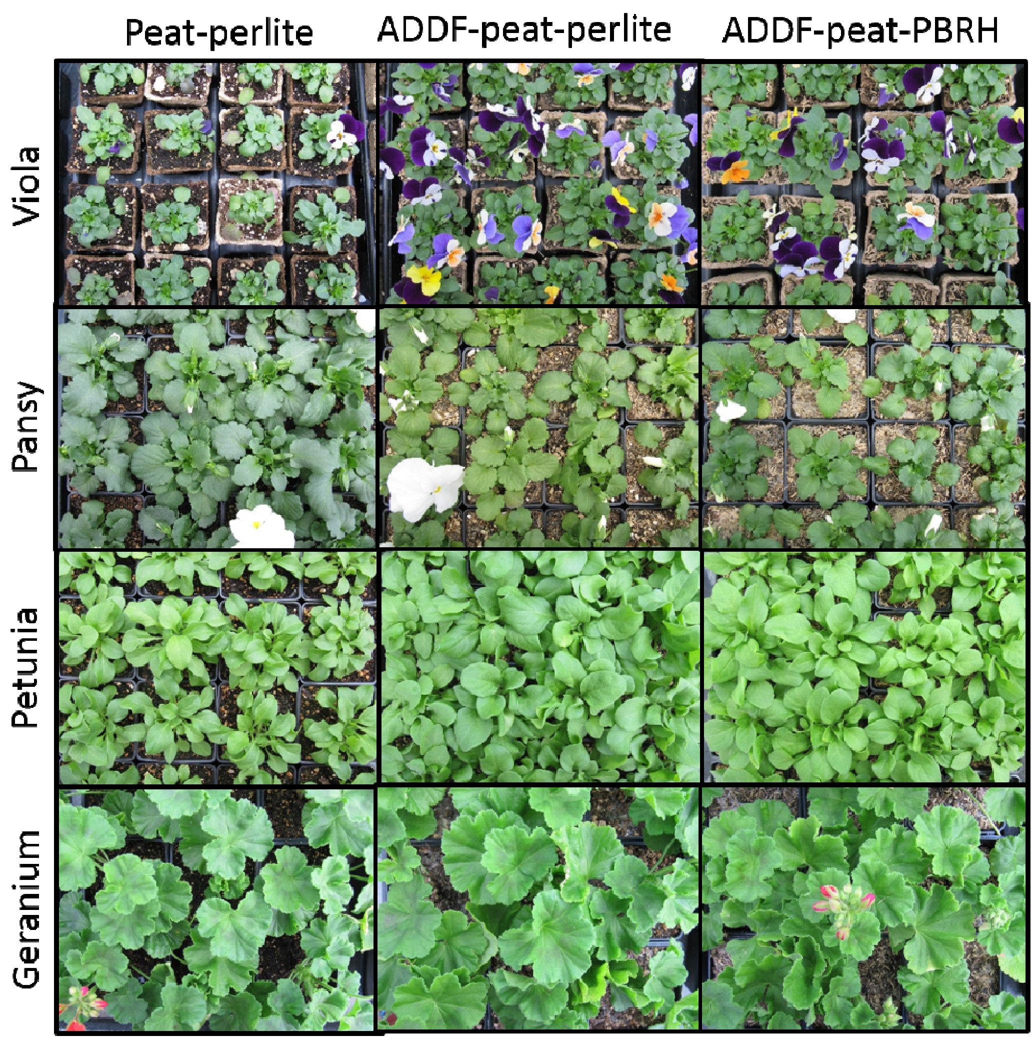

Figure 1.3. Bedding plants grown in media containing peat-perlite, ADDF-peat-perlite or ADDF-peat-PBRH

1.4.3. Garden Chrysanthemum

Final plant fresh weights volumes and maturity were greatest for plants in the control mix. Fresh weights were greater in plants grown in perlite-containing mixes than in PBRH-containing mixes

(Table 1.5). Plants grown in mixes with PBRH were the only that did not reach marketable size and quality (Fig. 1.4).

Figure 1.4. Chrysanthemum ‘Hankie Yellow’ grown in mixes with a 2:2:1 ratio of the following; peat:ADDF:perlite (PP), peat:ADDF:PBRH (PR), coir:ADDF:perlite (CP), coir:ADDF:PBRH (CR) and fafard 1-P, a peat-lite control mix (C).

1.4.4. Cyclamen

All peat-containing mixes produced saleable plants of a similar quality (Fig. 1.5) and size (Table 1.5). Both coir-containing mixes produced smaller plants of inferior quality.

Figure 1.5. Cyclamen ‘Silver Heart’ (left) and ‘Winfall’ (right) grown in mixes with a 2:2:1 ratio of the following; peat:ADDF:perlite (PP), peat:ADDF:PBRH (PR), coir:ADDF:perlite (CP), coir:ADDF:PBRH (CR) and fafard 1-P, a peat-lite control mix (C).

Table 1.5. Mean canopy volumes, fresh shoot weight and maturity of garden mums and mean canopy volumes cyclamen grown in five SPM with a 2:2:1 ratio of the following; peat:ADDF:perlite (PP), peat:ADDF:PBRH (PR), coir:ADDF:perlite (CP), coir:ADDF:PBRH (CR) and fafard 1-P, a peat-lite control mix. Means with different letters are significantly different. Tukey's HSD means separation test was used to find differences in treatments based *p*-value ≤ 0.05.

	Garden Chrysanthemum			Cyclamen
Mix	Volume, dm^3	Fresh weight, g	Maturity rating	Volume, cm3
Peat-perlite	15.46a	611a	2.5a	1103a
Peat-ADDF-perlite	13.34b	537.44b	2.56a	925a
Peat-ADDF-PBRH	9.91d	460.44c	1.89b	837a
Coir-ADDF-perlite	11.6c	511.67b	2.56a	467b
Coir-ADDF-PBRH	9.20d	402.22d	2.06b	226b

1.4.5. Poinsettia.

Plants grown in the ADDF mix were significantly larger (Table 1.6) than those grown in the peat-based mix. Poinsettias grown in the ADDF mix also had higher leaf tissue concentrations of N, P, K and Ca. The plants grown in the peat based mix, however, had higher leaf tissue concentrations of Mn, Na and Zn (Table 1.7)

Table 1.6. Mean fresh weight, height and phosphorus concentration of poinsettias grown in ADDF or peat-containing media. Parameters with a * are significantly different based on *p*-value ≤ 0.05.

Mix	Fresh weight, g	Dry weight, g	Height, mm
Peat-perlite	117	15.5	177
ADDF-peat--perlite	133	18.0	192
Significance	*	*	*

PourThru samples from pots containing ADDF mixes had significantly higher P_2O_5-P concentrations for approximately five weeks and P_2O_5-P concentrations began to rise again toward the end of the trial (Fig. 1.6).

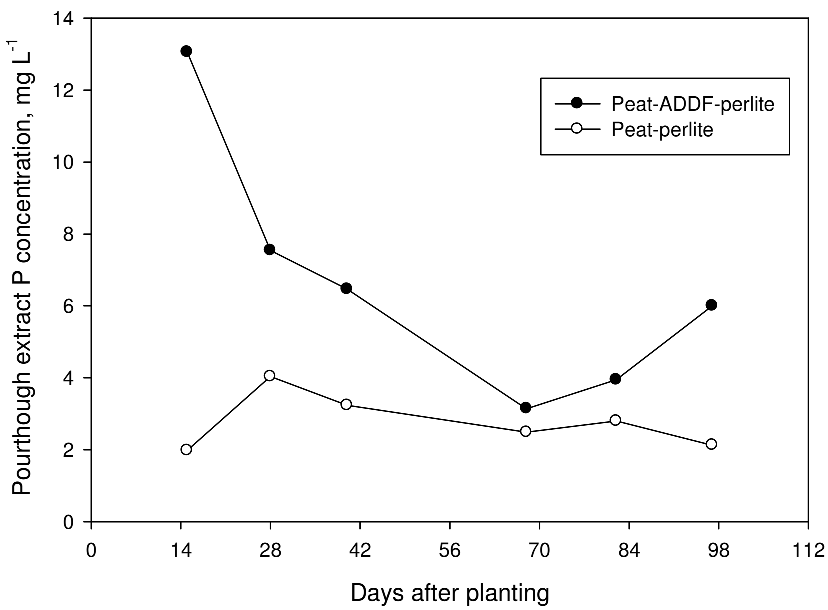

Figure 1.6. Mean phosphorus concentration in PourThru extracts from poinsettia crop grown in peat-perlite and ADDF-peat-perlite media.

Poinsettia plants grown in the ADDF mix were also visually larger and denser (Fig. 1.7).

Table 1.7. Mean leaf tissue nutrient concentrations of poinsettia grown in two greenhouse media. Nutrients with * have significantly concentrations different means between plants grown in the two mixes at *p*-value ≤ 0.05.

	N	P	K	Ca	Mg	Al	B	Cu	Fe	Mn	Mo	Na	Zn
Mix	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	mg/kg
Peat-perlite	3.5	0.27	2.5	0.6	0.5	4.4	26.7	10.6	217.9	81.9	0.1	0.2	50.8
ADDF-peat-perlite	3.9	0.34	2.3	0.5	0.5	1.1	26.7	12.2	140.8	108.1	0.0	0.3	86.2
Significance	*	*	*	*	ns	ns	ns	ns	ns	*	ns	*	*

Figure 1.7. Poinsettias grown in peat-perlite (left) and peat-ADDF-perlite (right) media.

1.4.6. Woody Nursery Crops

Measurements taken at the end of the first season of growth after transplanting show no differences in size, stem caliper or number of stems between button bush and silky dogwood grown in the peat mix and ADDF mix (Fig. 1.8). Analysis of PourThru samples show elevated levels of orthophosphate in the ADDF mix for approximately 8 weeks after planting (Fig. 1.9). At the end of the first growing season there was 0-13% media shrinkage with no significant difference between the two nursery mixes (Table 1.3). Upon harvest after leafing out in the second season there were no differences in height, maximum caliper, dry weight, new shoots (Fig. 1.10) or visual appearance (Fig 1.11) between plants grown in the two mixes.

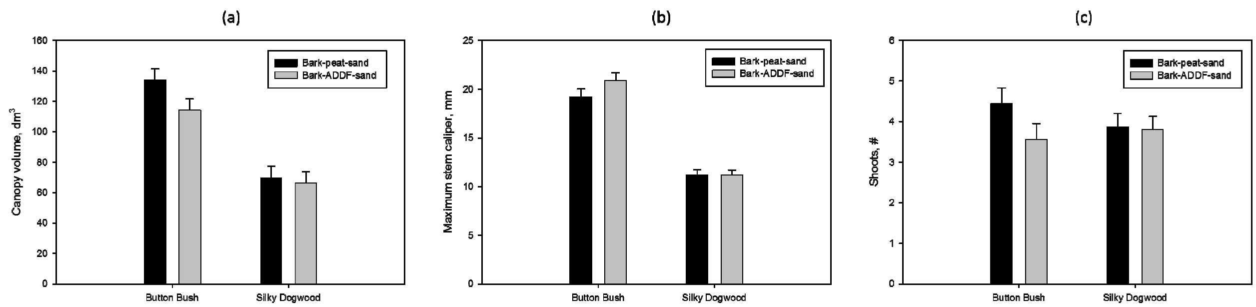

Figure 1.8. Mean volume, number of shoots and largest shoot caliper of button bush and silky dogwood after one season of growth in either peat- or ADDF-containing media in a ratio of 4 bark: 2 peat:1 sand or 4:bark:2 ADDF: 1 sand. No significant differences were found based on p-value ≤ 0.05.

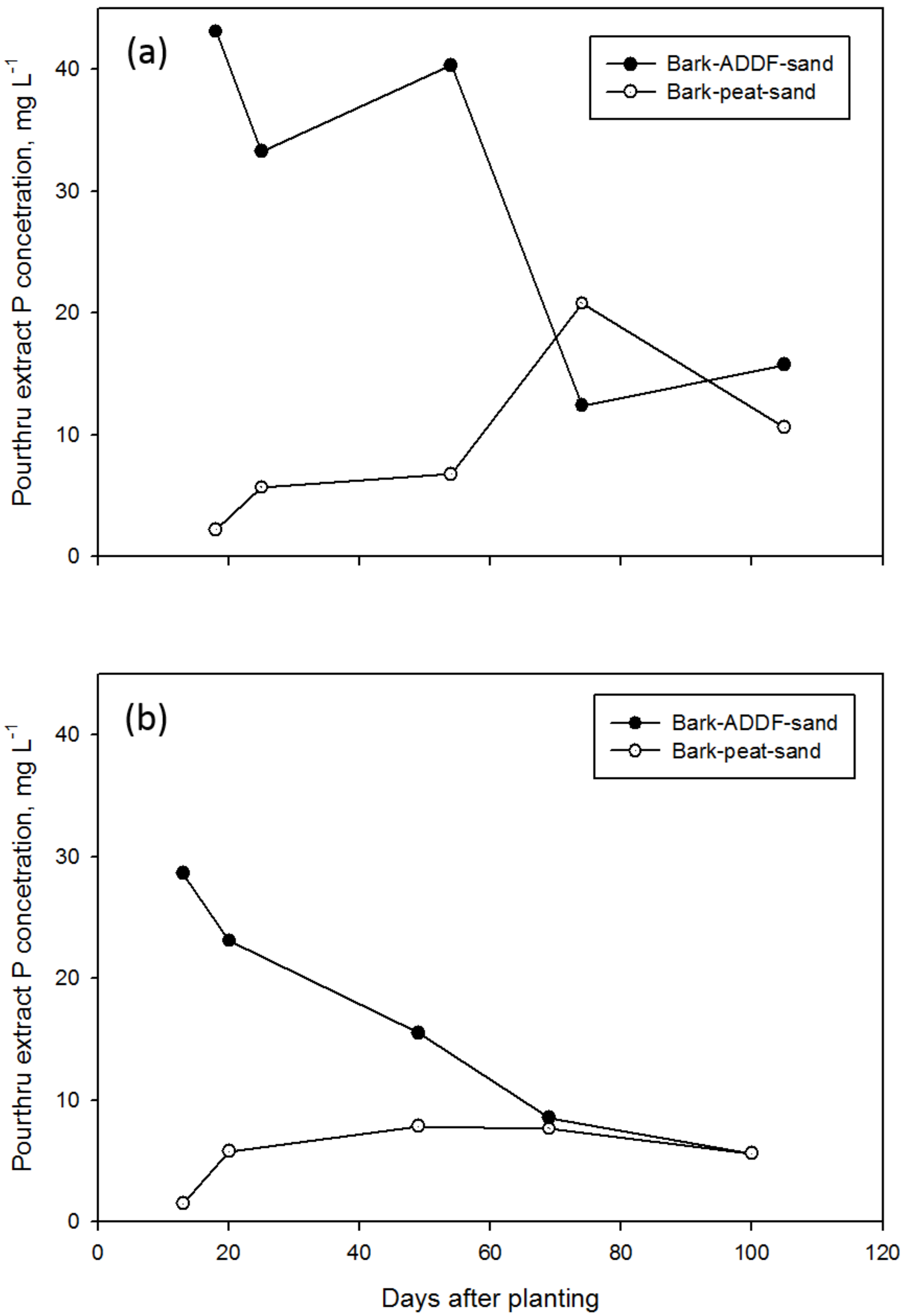

Figure 1.9. Mean phosphorus concentrations in PourThru samples from button bush (a) and silky dogwood (b) through one growing season.

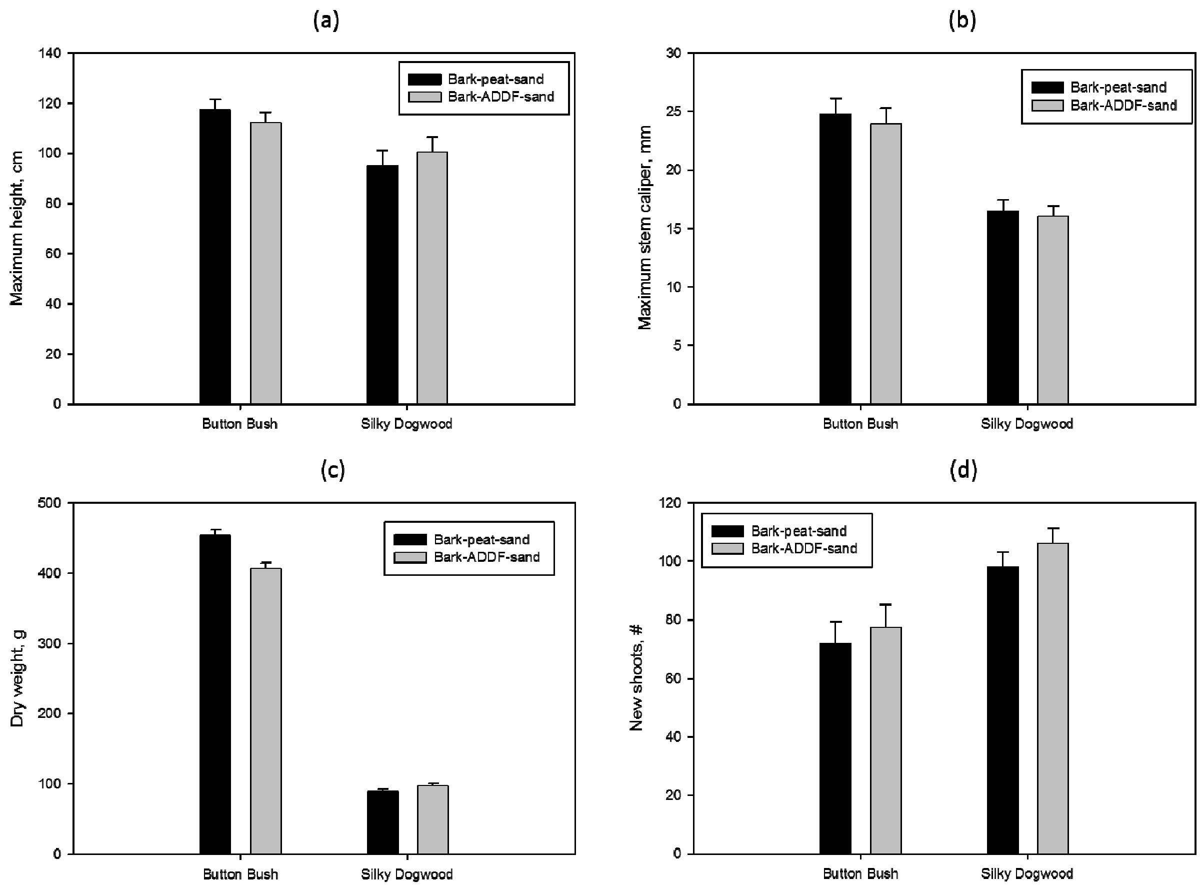

Figure 1.10. Mean maximum height (a), maximum stem caliper (b), dry weight (c) and number of new shoots (d) of button bush and silky dogwood after leafing out in spring of second season growing in bark-peat-sand or bark-ADDF-sand nursery media. No significant differences were found based on p-value ≤ 0.05.

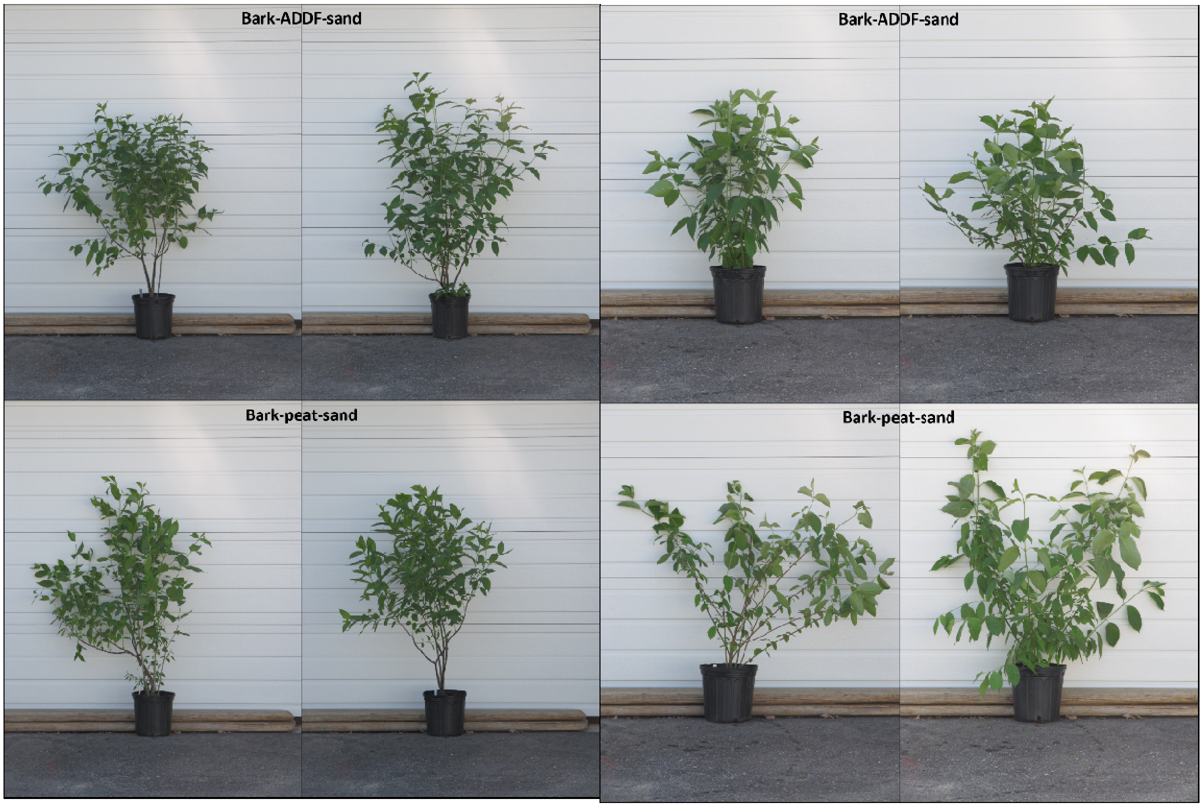

Figure 1.11. Randomly selected representatives of button bush (left) and silky dogwood (right) after leafing out in second season growing in bark-ADDF-sand (top) or bark-peat-sand (bottom) nursery mixes

1.4.7. Woody Cuttings

At the end of the first growing season there were no noticeable differences between plants in the two mixes. At the beginning of the second season both ninebark and viburnum grown in the bark-ADDF-sand mix appeared to break from dormancy more quickly, vigorously and with darker foliage (Figs. 1.13 & 1.14). The plants grown in the bark-ADDF-sand mix were also significantly taller than the plants grown in bark-peat-sand mix. Ninebark grown in the bark-ADDF-mix had a greater dry weight but there was no difference in dry weight between viburnum grown in either mix (Fig. 1.12).

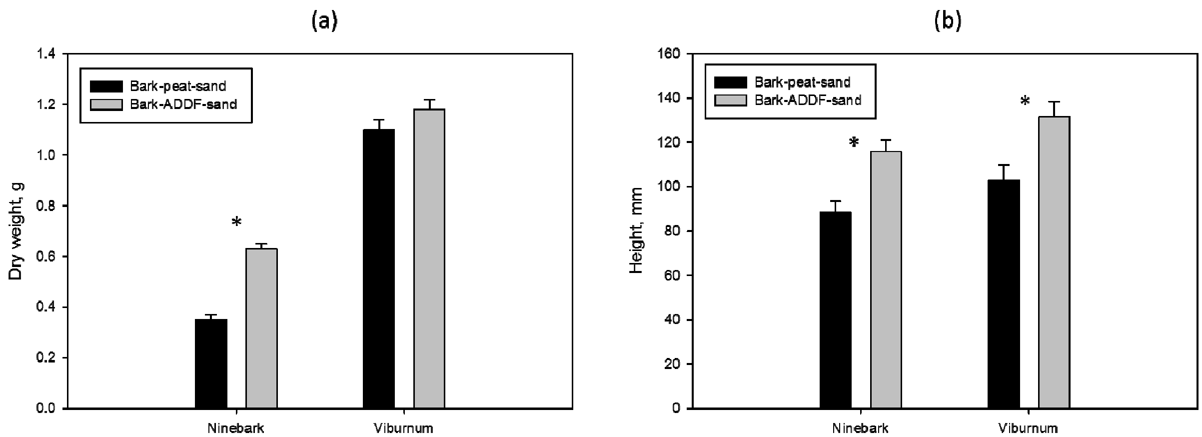

Figure 1.12. Mean above ground dry weight (a) and height (b) of rooted cutting of ninebark and cranberry bush viburnum after leafing out in second season growing in bark-ADDF-sand (top) or bark-peat-sand (bottom) nursery mixes. Bars with a * have significant differences between media at p-value ≤ 0.05.

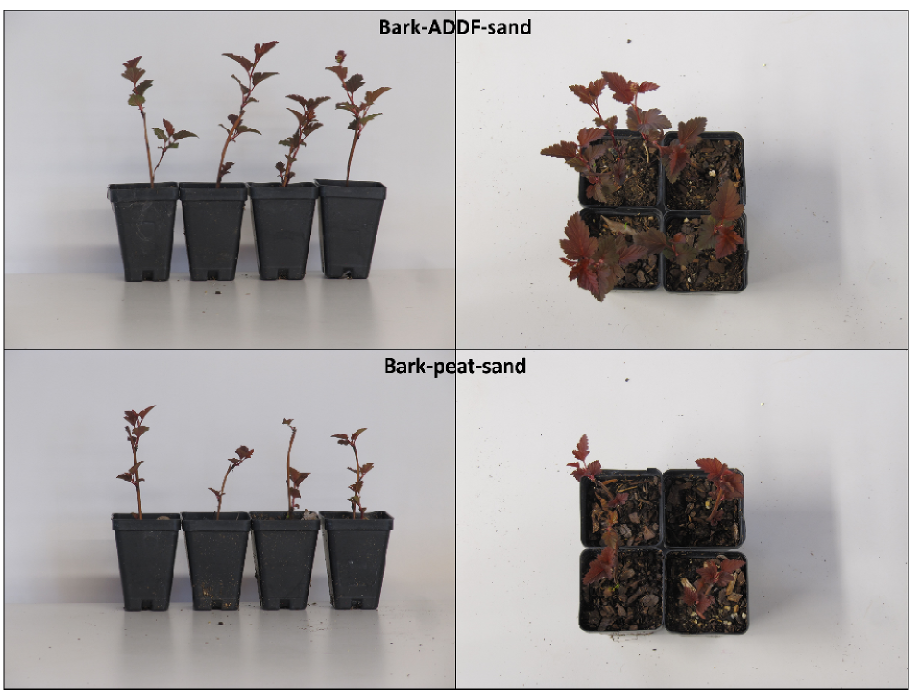

Figure 1.13. Randomly selected representatives of ninebark after leafing out in second season growing in bark-ADDF-sand (top) or bark-peat-sand (bottom) nursery mixes

Figure 1.14. Randomly selected representatives of cranberry bush viburnum after leafing out in second season growing in bark-ADDF-sand (top) or bark-peat-sand (bottom) nursery mixes

1.4.8. Herbaceous Nursery Crops

Of all plant growth parameters measured, the only significant differences between plants grown in bark-peat-perlite and bark-ADDF-perlite were greater fresh and dry weights in Shasta daisy grown in the bark-ADDf-perlite mix (Tables 1.8-1.12). While no differences were found in measured parameters there were some visible differences in plant growth and development between the two treatments in some species (Fig 1.15). Coreopsis (Fig 1.15.b) grown in the bark-ADDF-perlite mix were slightly chlorotic and less dense. Brunnera (Fig. 1.15.a) grown in the bark-ADDF-perlite mix had slightly chlorotic leaf margins and a deeper blue flower color than those grown in the bark-peat-perlite mix. Overall, plant growth in the bark-ADDF-perlite

mix was more variable than in the control mix with many plants in the bark-ADDF-perlite mix growing to an acceptable size and quality but others being severely stunted.

A much greater amount of phosphate was leached from pots containing the bark-ADDF-perlite mix and continued to be released through the growing season of all crops tested (Figs. 1.16-1.20)

Table 1.8. Mean number of flower spikes, maximum flower spike length and canopy volume of brunnera grown in two nursery mixes. No significant differences were found based on p-value ≤ 0.05.

Mix	Flower spikes	Maximum flower spike length, mm	Volume, ml
Bark-ADDF-sand	2.4	171.96	1016.86
Bark-peat-sand	1.8	170.72	791.37

Table 1.9. Mean dry weight of coreopsis grown in two nursery mixes. No significant differences were found based on p-value ≤ 0.05.

Mix	Dry weight, g
Bark-ADDF-sand	8.81
Bark-peat-sand	9.24

Table 1.10. Mean dry weight and flower count of Shasta daisy grown in two nursery mixes. Parameters with a * are significant at p-value ≤0.05.

Mix	Dry weight, g*	Flowers
Bark-ADDF-sand	4.29	1.75
Bark-peat-sand	2.74	1.33

Table 1.11. Mean dry weight, flower stem count and maximum height of liatris grown in two nursery mixes. No significant differences were found based on p-value ≤ 0.05.

Mix	Dry weight, g	Flower stems	Height, cm
Bark-ADDF-sand	20.81	5.08	28
Bark-peat-sand	18.6	6.42	29.5

Table 1.12. Mean dry weight, stem count and maximum height of phlox grown in two nursery mixes. No significant differences were found based on p-value ≤ 0.05.

Mix	Dry weight, g	Stems	Height, cm
Bark-ADDF-sand	7.74	2.67	29.17
Bark-peat-sand	6.9	3.25	29

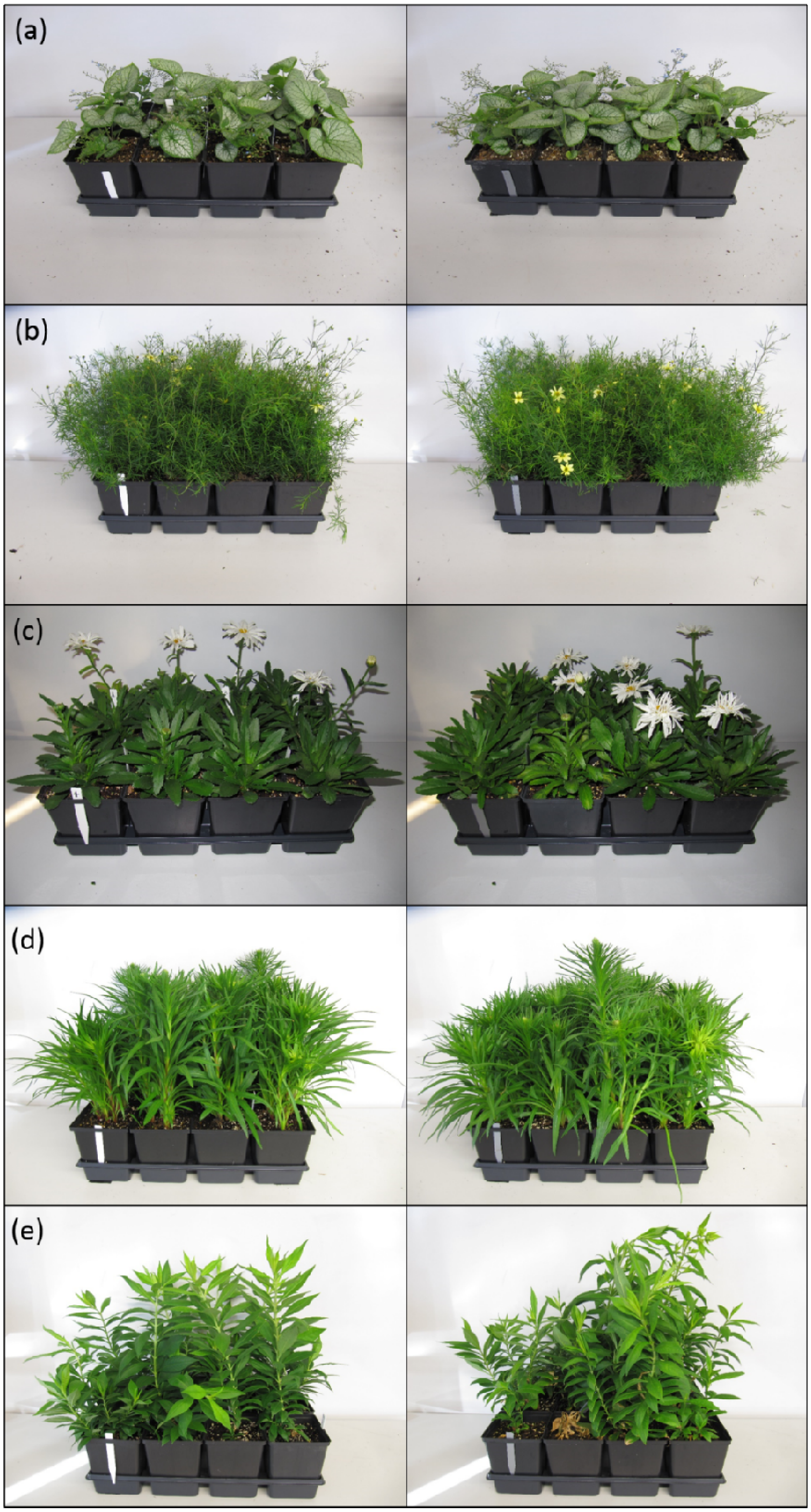

Figure 1.15. Brunnera (a), coreopsis (b), Shasta daisy (c), liatris (d) and phlox (e) grown in bark-peat-perlite (left) or bark-ADDF-perlite (right) nursery mixes.

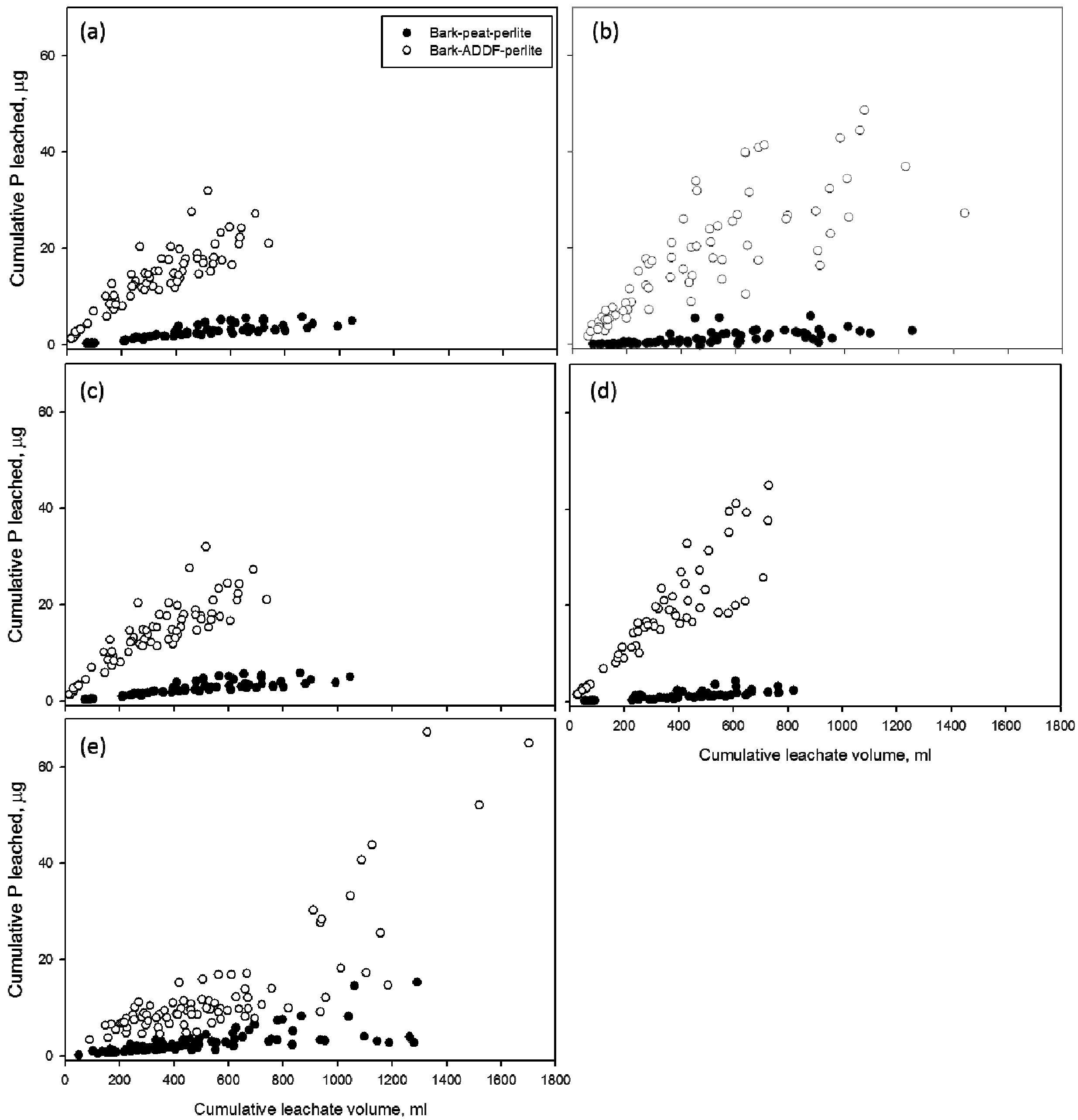

Figure 1.16. Cumulative phosphorus leached from brunnera (a), coreopsis (b), Shasta daisy (c), liatris (d) and phlox (e) pots containing two nursery mixes

1.4.9. Unplanted ADDF Leaching

Phosphate was continually released from the raw ADDF and the bark-ADDF-perlite mix throughout the trial and only began to plateau at the end. Peat and the bark-peat-perlite mix released negligible amounts of phosphate (Fig 1.21).

Virtually all nitrate was released after the fourth leaching event. The raw ADDF released far more nitrate than the bark-ADDF-perlite. The bark-ADDF-perlite mix is slightly less than 30% ADDF but only releases approximately 17% of the nitrate released from the raw ADDF. This suggests that mixing ADDF with bark immobilizes nitrogen and reduces nitrate leaching. Peat and the bark-peat-perlite mix released negligible amounts of nitrate (Fig 1.22).

Ammonium was slowly released by all mixes with the ADDF mixes releasing the greatest quantities (Fig 1.23).

There was an initial dip in pH followed by a rise and a leveling off (Fig 1.24). Most soluble salts were leached in the first few leaching events (Fig 1.25). The rapid release of nitrate and soluble salts in ADDF paired with the steady release of phosphate suggest ADDF has a large store of adsorbed labile phosphate.

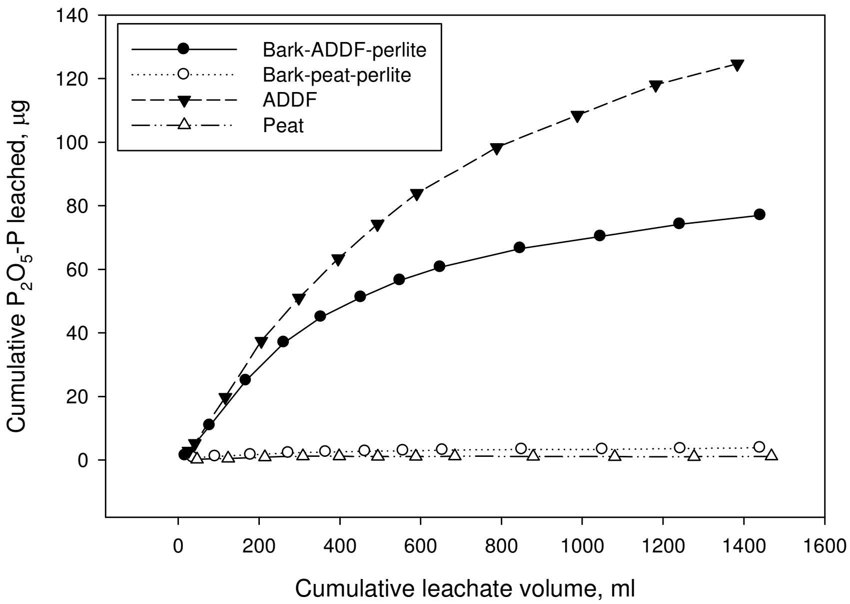

Figure 1.17. Mean cumulative phosphate phosphorus leached from unplanted pots containing two nursery mixes, raw ADDF and peat.

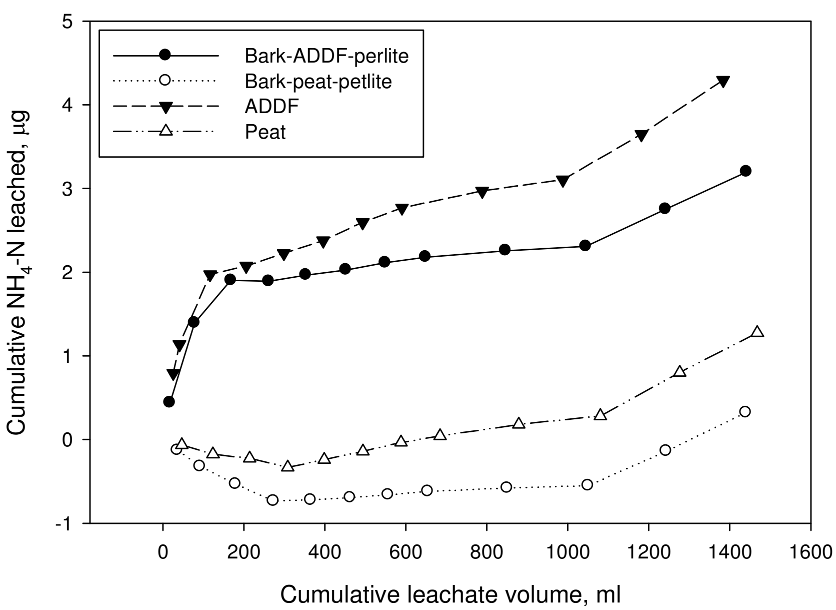

Figure 1.18. Mean cumulative ammonium nitrogen leached from unplanted pots containing two nursery mixes, raw ADDF and peat.

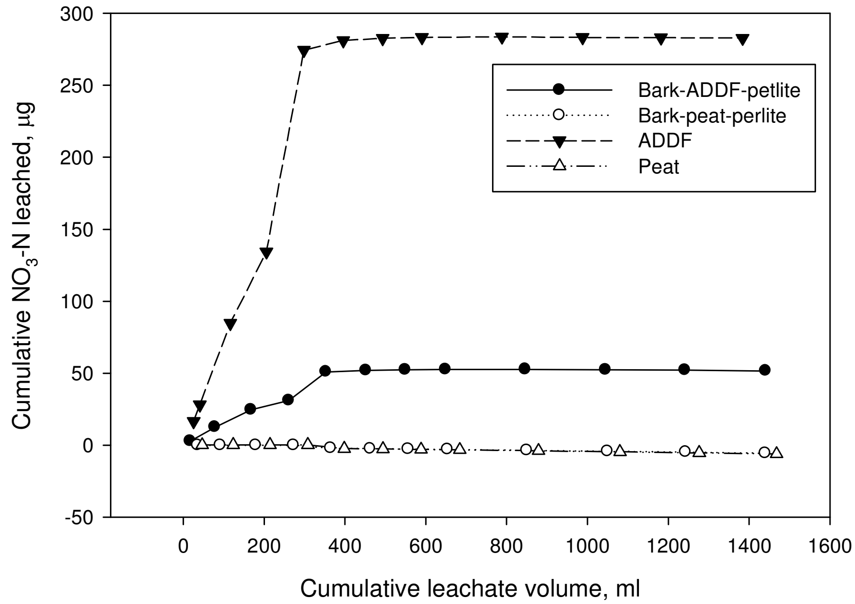

Figure 1.19. Mean cumulative nitrate nitrogen leached from unplanted pots containing two nursery mixes, raw ADDF and peat.

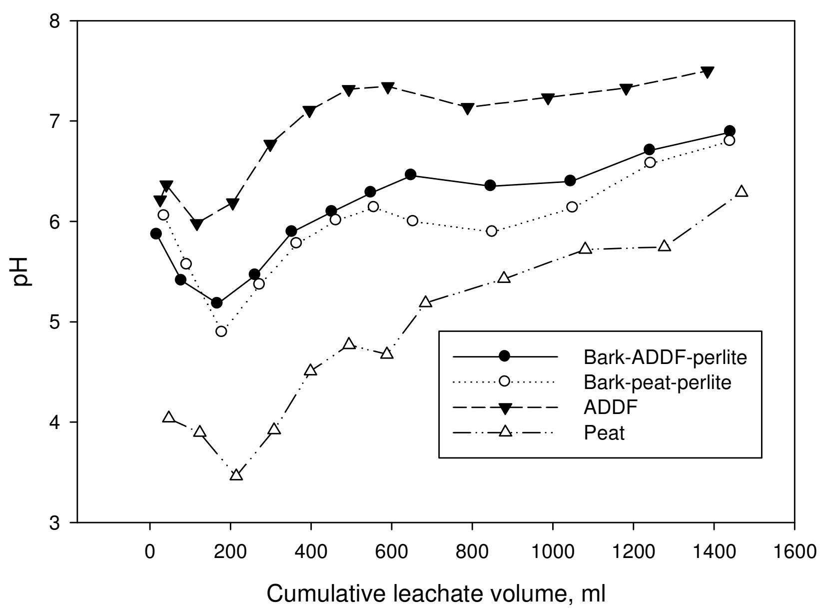

Figure 1.20. Mean leachate pH from unplanted pots containing two nursery mixes, raw ADDF and peat over time.

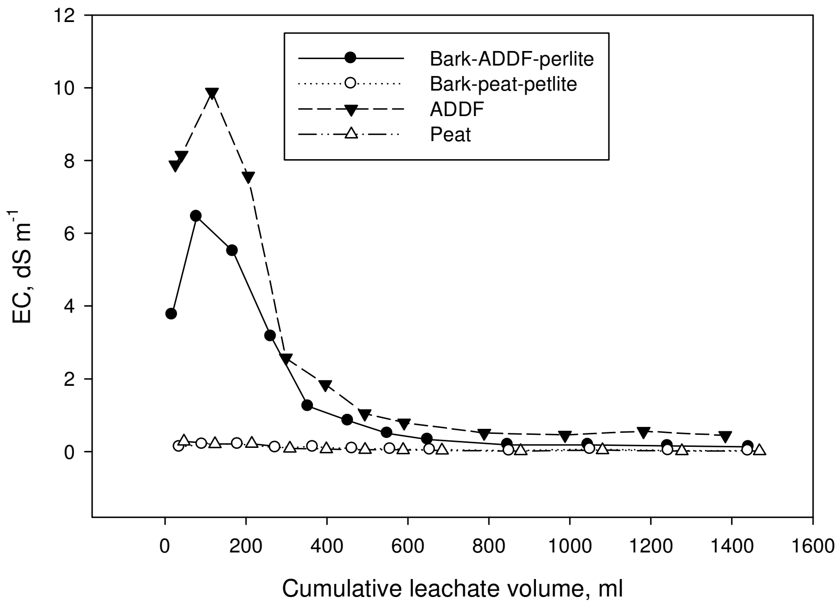

Figure 1.21. Mean leachate EC from unplanted pots containing two nursery mixes, raw ADDF and peat over time.

1.5. Discussion

ADDF can be used as a partial replacement for peat in SPM for a variety of floriculture crops and as a complete replacement for peat in nursery mixes. Irrigation, fertilization and pH management must be considered carefully when using an ADDF as a media component. When other alternative media components, like coir and PBRH were used in concert with ADDF results were less favorable. Generally, the more a mix deviated from a standard peat-based, the more likely it was to have unfavorable results. For example, the coir-ADDF-PBRH mix that was used in the chrysanthemum and cyclamen trials contained none of the same media components as the control and did not yield any favorable results.

Much of the variability in growth response appeared to be related to nutrient availability which, in turn, was likely related to pH. For example, plants grown in peat mixes generally had greater tissue concentrations of Fe, which is more available at lower pH. Nutrient availability is usually more dramatically affected by pH in SPM than in mineral soils (Peterson, 1982) so pH management is especially important in soilless culture. In the greenhouse mixes ADDF only replaced half the peat in the mix and the alkaline ADDF and acidic peat reacted to make a media with an appropriate pH for plant growth (5.4-6.0) (Dole and Wilkins, 1999).

Amending ADDF-containing greenhouse mixes with gypsum was effective in supplying plants with Ca while not affecting the pH but did not supply plants with the Mg normally supplied by dolomitic lime. Leaf tissue analysis revealed that both petunia and geranium grown in ADDF-containing mixes were on the cusp of Mg deficiencies (Dole and Wilkins, 1999). A magnesium source should be added to the fertilization regime of ADDF-containing mixes in an appropriate ratio with gypsum to supply the required amount and ratio of Ca and Mg without greatly altering the pH.

Results from all these trials show that ADDF is a significant source of plant available phosphorus. All plants grown in ADDF-containing mixes had elevated tissue P concentrations and all aqueous extracts (SME and PourThru) from ADDF mixes had higher concentrations of phosphate than peat-based mixes. There were higher concentrations of P in leachate and PourThru samples throughout the growing cycles of all trials. The continued release of P may be from the dissolution of calcium phosphate minerals, which are often found in dairy manure and dissolve at pH below 7 (Shober et al., 2010). Measures should be taken to limit P leaching from ADDF containing mixes, such as using irrigation systems with little or no leaching, adjusting to low P fertilization regimes or formulating media with pH closer to neutral to slow dissolution of

calcium phosphate minerals. Certain media amendments, such as dried alum sludge have been shown to greatly reduce P leaching from media containing organic P sources without adversely effecting plant growth (Bugbee & Elliott, 1999).

Shober et al. (2011) reported that leachate from CowPeat contained only negligible amounts of reactive nitrogen, often even less than peat based mixes. The leaching trials conducted for this research showed much greater quantities of reactive nitrogen being leached from ADDF-containing mixes than from mixes without ADDF. The differences in the nitrogen leaching between Shober et al. (2011) and this research could be due to regional differences in dairy manure (Florida vs Connecticut) or in differences between how aerobic (CowPeat) and anaerobic (ADDF) processing of dairy manure affects the nitrogen forms in the processed material. Nitrogen leaching was not a concern in the use of CowPeat but may be for the use of ADDF. When using ADDF, growers should adopt practices to minimize nutrient leaching, such as adjusting fertilizer rates, minimizing leachate volume or using a recirculating irrigation systems. Nutrients leached from a mix do not necessarily equal the sum of nutrients that leach from the individual components that are in the mix. There are complex interactions between media components which can make nutrients more or less susceptible to leaching. This can be seen in the unplanted leaching trial of nursery mixes, peat and raw ADDF. Mixing ADDF with bark in the nursery mix appeared to reduce the amount of nitrate leached. Bugbee and Elliott (1998) showed that bark and other media components could reduce the amount of P leached from a compost-based mix when compared with peat. In the same study, a compost-based mix with zeolite or vermiculite leached greater quantities of P when compared to the bark mix. A better understanding how ADDF interacts with other media components will allow mixes to be

formulated which minimize leached while providing a sufficient supply of plant available nutrition.

In the nursery mixes peat made up a much smaller proportion of the mix than in greenhouse mixes (slightly less than 30% vs. 80%) so ADDF was an acceptable replacement for all the peat in the mix rather than only replacing 50% of the peat. All nursery crops grown in ADDF-containing mixes grew to a similar or better size and quality than those grown in the peat-based nursery mixes. This may have been due to the smaller proportion of peat being replaced or that nursery crops are generally more robust than greenhouse and floriculture crops and may have been better able to tolerate suboptimal root zone conditions. Despite the smaller proportion of peat in nursery mixes, nursery crops are grown in containers with much larger volumes, which require greater volumes of media than greenhouse crops so using ADDF as a replacement for peat in nursery mixes could still significantly reduce demand for peat.

While the growth and quality of nursery crops grown in ADDF containing mixes were statistically similar to those grown in the peat-based control mix, growth responses of plants in the ADDF mix were generally more variable. It is important for a growing mix to produce consistent results so, while the ADDF mixes yielded acceptable means, the variable growth in some species may be unacceptable in commercial applications. This variability may have been due to management decisions or the ADDF itself.

In these trials, management decisions were based on established cultural recommendations for peat-based control mixes. In many cases, irrigation management that was optimal for the control mix was less than optimal for other treatments. This was illustrated by the media analyses at before, during and after the woody nursery crop trial. The ADDF mix had less shrinkage than the control during the first season when pots were under drip irrigation but experienced much

more shrinkage during the second season under overhead irrigation. Many of the crops that were exclusively overhead irrigated, like phlox, coreopsis and cranberry bush viburnum had dead or severely stunted individuals. All of this suggests overhead irrigation may lead to accelerated compaction of ADDF mixes. Through observations during trials and from results for the bedding plant, chrysanthemum and cyclamen trials it appears that mixes containing PBRH do not conduct water as well as perlite and do not work as well with irrigation systems that require good hydraulic conductivity such as subirrigation and, especially drip irrigation. The poor hydraulic conductivity of PBRH-containing media is likely due to high porosity (93-97% of volume) that is well above the recommended porosity range of 60-80% by volume for most media (Handreck and Black, 1994). Better results may be produced with individualized management decisions based on differences in mixes. Additionally, ADDF is a significant source of phosphate and nitrate and fertilization regimes should be adjusted accordingly.

Some of the variability in growth response of plants grown in ADDF-containing mixes may have been due to heterogeny of the ADDF itself. The ADDF used in this project was processed to be used in the production of biodegradable "Cowpots™" rather than for use in potting media. An ADDF product that produces more consistent results may be obtainable from processing with a media component as a goal as is done with other anaerobically digested organic media components such as Magic Dirt™ or EcoTek®.

There may also be variability in ADDF on a larger scale. Dairy feed can vary from region to region and seasonally so the feedstock used to produce ADDF likely varies equally. Regional variability in dairy manure may have contributed to discrepancies between the results of this research and the results of research using a dairy manure product in Florida (Shober et al., 2011). However, similarities in results of chemical and physical analysis of ADDF and ADDF-

containing mixes between MacConnell and Collins (2009) in Washington and these trials in Connecticut demonstrate that ADDF can be consistent from region to region.

Differences in climate have been show to influence the nutrient availability in manure. Growing degree days have been shown to be useful in predicting nitrogen availability from manure (Griffin and Honeycutt, 2000). Special consideration must be given to any potential variability in ADDF.

As with other alternative media components more research is needed to establish the best ways to manage ADDF in media and to process ADDF into a consistent horticultural material. Apart from establishing best practices for ADDF, it is an acceptable replacement for peat in a wide variety of media and for a diversity of horticultural crops.

Chapter 2: Nutrient Availability from Organic Sources in Soilless Potting Media

2.1. Introduction

The purpose of this project is to evaluate the nutrient availability of a variety of organic fertilizers and amendments individually and in combinations. Concerns about the environmental effects of greenhouse production coupled with consumer demand have prompted many greenhouse growers to consider implementing organic programs. One of the greatest obstacles to converting a greenhouse operation to organic is a reliable nutrition program. Organic fertilizers are usually less stable and less predictable in reaction than chemical fertilizers and it can be difficult to coordinate mineralization cycles in organic materials with the nutritional needs of crops.

The use of organic fertilizers in place of chemical fertilizers contributes to a more sustainable society in two ways; by turning waste, which would otherwise end up in landfills, into valuable horticultural products, and by abating the reliance on energy-intensive chemical fertilizers for plant nutritional needs. Certified organic labels can be used as marketing tools and make a grower's product stand out and command a higher price.

Containerized plant culture is usually a much more intensive and precise production system than field crop culture. A high initial cost for containerized plant operations, especially greenhouse operations, requires growers to maximize production efficiency by controlling every factor affecting plant growth. Precision horticulture of this sort is only possible with reliable and predictable equipment and material.

Chemical fertilizers are popular in containerized plant production because they are stable, easy to use and nutrients are delivered in known quantities of known, generally plant available, forms. With chemical fertilizers, growers are able to precisely match plant nutrition with all other factors affecting plant growth.

Presently, the use organic fertilizers in containerized plant production can be somewhat more challenging than chemical fertilizers. Nutrients in organic fertilizers may be in a number of different forms including complex organic compounds. Organic fertilizers are far less stable than chemical fertilizers and usually undergoes unpredictable chemical changes. Organic fertilizers innately contain some carbon, which can stimulate microbial activity that causes nutrient cycling. The reactions of organic fertilizers can also be affected by the composition of the SPM to which it is being applied. Organic fertilizers can be made from a wide variety of materials, all of which have different chemical compositions and will react in different ways when mixed with other materials in SPM or in fertilizer mixtures.

Despite these obstacles, organic fertilizers have repeatedly been shown to produce containerized plants of equal or greater quality than those produced using chemical fertilizers. Some of the best results have been shown when organic fertilizers are used in combinations.

Other organic media amendments like composts and vermicompost have also been used to produce quality plants. A variety of composts have also been shown to possess other desirable qualities like disease suppression and good water holding capacity. Little research has been done to evaluate nutrient availability from organic fertilizers when used in combination with other organic media amendments. As demand for alternative media and fertilizer material increases it will be important to gain a better understanding of the performance of different fertilizer-media-

amendment combinations so nutrient availability can be better predicted and matched to plant needs.

A better understanding of nutrient availability, nutrient cycling and interactions with media components is essential to wider adoption organic nutrition programs for containerized plant production.

2.2. Literature Review

Greenhouse plant production operations face many unique challenges in converting to organic nutrition programs. Organic and conventional greenhouse growers in Maine identified fertility, media and pH as the second biggest challenge in organic production and almost 30% considered it to be the greatest challenge. Among conventional growers, challenges associated with fertilization were identified as the greatest barrier in transitioning to organic production (Burnett and Stack, 2009).

Chemical nitrogen fertilizers are almost entirely produced using the Haber-Bosch process which combines atmospheric dinitrogen gas with hydrogen at high temperature and pressure to produce biologically available ammonium. The ammonium can subsequently be processed further into a variety of chemical fertilizers. Increases in nitrogen use in the 20th and 21st century have led to global anthropogenic changes in the nitrogen cycle. Excess reactive nitrogen in the environment can cause eutrophication of waterways, harm human health and alter a host of environmental balances. One proposed strategy to mitigate the harmful effects of excessive reactive nitrogen is to reduce the production of reactive nitrogen (Erisman et al., 2008). The use of organic fertilizers serves both to recycle reactive nitrogen and to reduce the need to produce more reactive nitrogen through the Haber-Bosch process. Reducing the use of the Haber-Bosch

process would also reduce the amount of natural gas needed to produce the required heat and pressure.

The production of phosphate fertilizers also presents major concerns. The use of highly concentrated and soluble phosphorus fertilizers saturates soil reservoirs of phosphorus, leading to excessive phosphate leaching and eutrophication. Phosphorus for chemical fertilizers is a mined, non-renewable resource. The global supply of rock phosphate is expected to be entirely depleted in 100-400 years. Recycling P is one of the ways these problems may be mitigated (Cordell et al., 2009). The use of organic fertilizers may be an effective way to recycle P and to lessen demand for mined P.

The major concerns surrounding chemical fertilizers are often overlooked due their practical convenience. Chemical fertilizers are inexpensive, well researched, predictable and effective. Organic fertilizers are much less predictable than chemical fertilizers for a variety of reasons. Labeling of organic fertilizers is often less useful than chemical fertilizers because organic fertilizers contain complex organic compounds that may degrade and release nutrients at vastly different rates. Temperature (Hartz and Johnstone, 2006), media components (Treadwell et al., 2011), fertilizer composition (Hartz et al., 2010) and moisture (Gaskell and Smith, 2007) can greatly impact the availability of nutrients from organic sources. Animal-based liquid fertilizers have been shown to have a higher N mineralization potential than plant-based counterparts (Hartz et al., 2010). Knowing the ingredients of a composite organic fertilizer is not very useful in predicting how the fertilizer will perform unless the quantities of the ingredients are known. Ingredients may interact with each other, further complicating the prediction of nutrient availability. Nutrient release from organic fertilizers is also highly influenced by the composition of the media to which it is applied (Treadwell et al., 2007, Elliott and Hulshart,

unpublished). Foul odor and clogging irrigation lines have been identified as limitations for organic liquid fertilizer (LF) (Eaton et al., 2013)

Research is required to better understand nutrient availability from organic fertilizers so they can be used more predictably and effectively. Immediately available nutrients in organic fertilizers do not necessarily equate to better plant growth or quality (Treadwell et al., 2011). Nitrogen cycling plays a critical role in N availability from organic fertilizers so these cycles must be better understood so N availability can be synchronized with N uptake during different plant growth stages (Gaskell and Smith, 2007).

Organic fertilizers generally contain a much higher proportion of ammoniacal nitrogen (Williams et al., 2013). Plants usually grow best when supplied with ammonium and nitrate with ammonium constituting 50% or less of total nitrogen. Ammonium generally promotes taller, lusher growth while nitrate promotes darker, more compact growth. Excess ammonium cannot be stored in plant tissue so it can accumulate in the root zone and become toxic (Dole and Wilkins, 1999). Ammonium uptake by plants lowers media pH, especially close to the roots, and can lead to problems related to low pH. Ammonium can also be directly antagonistic to the uptake of Ca, Mg and K. An overabundance of ammonium can result in stunted growth, curling leaves and chlorotic leaf margins. Some plants grow better with higher proportions of either ammonium or nitrate. Seedling are particularly susceptible to ammonium toxicity. Ammonium toxicity is more common in soilless culture because peat-based media usually has slower nitrification rates than mineral soils and a lower initial pH (Bunt, 1988).

In many cases, combinations of organic fertilizer often yield better results than organic fertilizers used alone. Calibrichoa and marigold grown with only an oilseed-based liquid fertilizer or an alfalfa-based solid fertilizer had poor quality and overall growth, however, when the fertilizers

were combined they produced plants of acceptable quality. Calibrachoa and marigold grown with fish-based fertilizer were of acceptable size and quality. However, large amounts of nitrogen were leached from pots with only fish-based or oilseed-based fertilizers. Significantly less nitrogen was leached from pots with combinations of organic fertilizers, showing that some fertilizer combinations are more environmentally sound than individual organic fertilizers (Eaton et al., 2013).

While some combinations of organic fertilizers have yielded favorable results some fertilizer combinations did not. Composite organic pre-plant incorporated fertilizer (PPIF) used alone have produced better quality basil than PPIF+ organic LF treatments. Composite organic PPIF may provide the benefits combining different fertilizers while better synchronizing nutrient release with plant growth needs (Treadwell et al., 2011)

Organic LFs have been used successfully in nutrient-film-technique hydroponic systems for lettuce but pH management was more challenging than with chemical fertilizers. Basil grown in a recirculating system with PPIF and a low liquid feed (100 mg L^{-1}) produced a better quality plant than those grown a stronger liquid feed (200 mg L^{-1}) alone (Williams et al., 2013).

In containerized plant production it is important to carefully monitor the pH, EC and nutrient status of the growing media solution to make appropriate adjustments to optimize plant growth. Two aqueous extraction techniques are commonly used to monitor the SPM solution. The Saturated Media Extract (SME) technique is a popular way of monitoring media pH, EC and nutrients in media. The SME procedure involves making a saturated paste of deionized water and media that is left to equilibrate for 30-60 minutes before the solution is extracted (Dole and Wilkins, 1999). The solution displacement, also known as “pour-thru” (PourThru), technique is a non-destructive way to monitor the pH, EC and nutrition of media solution *in situ*. The

PourThru technique was originally developed for nursery crops grown in large containers (Wright, 1986) and has since been adapted for use with greenhouse crops (Cavins et al., 2008) and even for *Phalaenopsis* orchids grown in sphagnum moss (Yao et al., 2008). The relationships between EC, pH and nutrient values in PourThru and SME are well established for chemical fertilizers in standard potting mixes (Cavins et al., 2004, 2008). While PourThru extracts are frequently used to monitor and evaluate nutrient availability, it has not been established that it is an accurate measurement for organic nutrient sources.

PourThru and SME may not be accurate for crops grown using organic fertilizers. For chemical fertilizers, the quantity of phosphorus applied to media correlates to the concentration measured in aqueous extracts across fertilizers. For organic fertilizers, there is usually a correlation between phosphorus applied and concentration measured within a fertilizer but not across fertilizers (Elliott and Hulshart, unpublished data).

Vermicomposting is a controlled, mesophilic process that uses earthworms to decompose a variety of organic material. Vermicompost has a number of qualities that may make it a beneficial media component. Vermicompost can be a significant source of nutrients. It is much less biologically active than conventional composts (Chaoui et al., 2003), therefore it is more chemically and physically stable (Ngo et al., 2013). Vermicompost has also been shown to contain much less salt and be less likely to produce salt damage in plants than conventional composts (Chaoui et al., 2003). Vermicompost from manure has a higher phosphorus mineralization potential than conventional compost (Ngo et al., 2013).

Vermicompost made from tomato crop waste has been demonstrated to be a suitable replacement for up to 75% of the peat in SPM for *Calendula officinalis* and *Viola cornuta* (Belda et al., 2013). Media containing varying proportions up to a 2:1 ratio of vermicompost to coir yielded

faster and greater yields of Swiss chard than either coir alone or a commercial potting media (Abbey et al., 2012). Many feedstocks, such as manure, food waste, crop waste and paper waste can be used for vermicompost and each type of vermicompost will react differently in different appluications (Arancon et al., 2008)

Research Objectives for This Project

1. To evaluate nutrient availability from organic fertilizers alone and in combinations
2. To determine the relationship between nutrients applied, nutrients measured and nutrients availability
3. To evaluate SME and PourThru methods efficacy in measuring nutrient availability from organic sources

2.3. Materials and Methods

2.3.1. Incubation I

The purpose of this trial was to monitor nutrient release and transformations of organic LF over time in SPM. Five certified organic commercial LF were used in this trial; Nature's Source Organic Plant Food (formerly Danniel's Pinnacle) (PINN) (Ball DPF, LLC, Sherman, TX), Drammatic 'K' (DRAM) (Dramm Corp., Manitowoc, WI), Biolink All-Purpose (BIOL) (Westbridge, Vista, CA), Converted Organic LC (ORGA) (Converted Organics of California LLC, Gonzales, CA) and Verdanta PL2 (VERA) (BioWorks Inc., Victor, NY) (Table 2.1). Each fertilizer was mixed with Sunshine #2 Mix (about 80% SPM, 20% perlite) at a N rate of 150g L^{-1} based on the labeled guaranteed analysis. A control mix had no fertilizer added. Leachate

samples were collected to show nutrient release over time using the methods described in Elliott, 1986 using deionized water as an extractant. SME samples were collected to show nutrient transformations over time. SME samples were collected on the day the various mixes were prepared and on days 5, 7, 12, 14, 19 and 22. Leachate samples were collected on days 1, 6, 8, 13, 15, 19 and 21. All media were stored in an incubator set at 25°C. All extracts were analyzed for ammonium-N (NH_4-N), nitrate-N (NO_3-N) and phosphate-P (P_2O_5-P) concentrations using colorimetric techniques described previously

Table 2.1. OMRI listed commercial fertilizer product information for fertilizers used in organic fertilizer trials.

Fertilizer	Guaranteed Analysis	Label Ingredients
NatureSafe (NATU)	5-6-6	Meat, bone, blood, fish, & hydrolyzed feather meals; langbeinite, yeast, sugars, carbohydrates, and humus
Microstart 60 (MICR)	3-2-3	Dehydrated poultry waste
Nature’s Source (formerly Daniel’s Pinnacle) (PINN)	3-1-1	Oilseed extract
Drammatic ‘K’ (DRAM)	2-5-0.2	Liquid fish hydrolysate stabilized with phosphoric acid, kelp
Organic BioLink All-Purpose Fertilizer (BIOL)	3-3-3	Hydrolyzed soy, rock phosphate, potassium sulfate
Converted Organics LC (ORGA)	1-1-1	Composted food waste
Verdanta PL2 (VERA)	2-0-6	Fermented sugar beet and sugar cane molasses
Bombardier (BOMB	8-0-0	Vegetable concentrate
WormPower (VERM)	1.5-0.7-1.5	Worm castings from dairy manure

2.3.2. Incubation II

The purpose of this trial was to monitor nutrient release and transformations of organic LF and PPIF over time in SPM with and without vermicompost. Three certified organic commercial LF were used in this trial; Danniel's Pinnacle (PINN), Drammatic 'K' (DRAM) and Bombardier (8-0-0) (BOMB) and two certified organic PPIF; NatureSafe (NATU) (Griffin Industries, Cold Spring, KY) and MicroStart (MICR) (Converted Organics of California LLC, Gonzales, CA) (Table 2.1). The media used contained 80% peat, 20% perlite and 1.5g/L $CaCO_3$, 2.7g/L dolomitic lime and 1.2g/L ground gypsum, with and without 5% vermicompost (VERM) by volume. The control mix and the mix with VERM were allowed to sit for one week to let the lime react (Elliott, 1996) and microbes in VERM to proliferate. Each fertilizer was mixed with the media at a N rate of 150 g L^{-1} for LF and 200 g L^{-1} for PPIF based on the labeled guaranteed analysis, plus two control mixes; one with no fertilizer added and one with only vermicompost added (Table 3). Leachate samples were collected to show nutrient release over time using the methods previously described. SME samples were collected to show nutrient transformations over time. SME samples were collected on the day the various mixes were prepared and on days 5, 7, 12, 14, 19 and 22. Leachate samples were collected on days 1, 6, 8, 13, 15, 19 and 21. All samples were stored in an incubator set at 25°C. All samples were analyzed for ammonium-N (NH_4-N), nitrate-N (NO_3-N) and phosphate-P (PO_4-P) concentrations using colorimetric techniques described above. Each fertilizer combination was compared to the sum of its individual components to test for additively or enhanced nutrient availability in combinations. All fertilizers and vermicompost were individually analyzed for NH_4-N, NO_3-N, P_2O_5-P and total C and N. The three LF were diluted to 150mg L^{-1} N and their pH and EC were measured.

2.3.3. Plant Growth Trial

The purpose of this trial was to determine if there is a correlation between nutrients applied and nutrients measured in plant tissue. Seeds of sunflower (*Helianthus annuus* 'Sunbright Supreme') were direct sown in pots containing a base mix of 80% peat, 20% perlite and 1.5g/L $CaCO_3$, 2.7g/L dolomitic lime and 1.2g/L ground gypsum with MicroStart or NatureSafe at rates of 50, 100 and 300 mg L^{-1} N.

Seeds were germinated under mist with bottom heat. Plants were moved into a greenhouse after emergence and subirrigated in flood and drain trays. Plants were harvested approximately 8 weeks after planting. Plant growth was evaluated by measuring fresh and dry weight of above ground plant tissue and plant height. Dried ground tissue was analyzed for nutrient concentrations.

2.4. Results and Discussion

2.4.1. Incubation I

NH_4-N (Figure 2.1.a) continued to leach from all pots for two weeks. These data along with the increasing NH_4-N concentrations in SME samples for the first two weeks of the trial (Figure 2.1.a) further show mineralization of organic forms of NH_4-N or the gradual release of NH_4^+ from CEC sites.

There was a slow but consistent increase in NO_3-N leached (Figure 2.1.b) from all fertilizer treatments for the first two weeks of the trial. Pots with DRAM continued to leach some NO_3-N throughout the entire trial. The leveling off of NH_4-N and NO_3-N measured in leachate is likely caused by a faster rate of NH_4-N leaching than mineralization, which in turn would leave little NH_4-N to reduce to NO_3-N.

PO_4-P leached (Fig. 2.1.c) from all fertilizers leveled off toward the end of the second week of the trial, much like the N-forms monitored. Nominal N and PO_4-P applied were compared to total N and P recovered in the leachate from each fertilizer. Percent N recovered varied among fertilizers from 27% for ORGA to 77% for DRAM. The percent PO_4-P recovered also varied from 11% for BIOL to 97% for ORGA (Table 2.2). The PO_4-P in many of these fertilizers is likely in forms that are not immediately soluble but may become plant available over time. This shows that nutrient availability during three weeks cannot be accurately predicted for all organic fertilizers based on the guaranteed analysis and that nutrient availability varies greatly between organic fertilizers.

SME NH_4-N concentrations (Figure 2.1.d) for all fertilizer treatment started low and increased over time, plateauing by day 7 or 12, and stayed close to zero for the control throughout the trial. ORGA experienced a dramatic spike in NH_4-N concentration on day 14 followed by a decrease to a lower concentration on day 19 and 22. BIOL showed a slight decline in NH_4-N concentration on days 19 and 21. NH_4-N concentration measures from SME samples shows mineralization of organic forms of N to NH_4-N for most of these fertilizer treatments for one to two weeks after being incorporated into SPM.

NO_3-N concentrations (Figure 2.1.e) for SME samples from PINN and DRAM fluctuated throughout the trial. NO_3-N concentrations stayed close to zero for ORGA, VERA and the control. BIOL accumulated little NO_3-N until the beginning of the third week when NO_3-N concentration began to steadily increase. Fluctuating NO_3-N levels demonstrate that there is rapid N cycling after PINN and DRAM are incorporated in SPM. The increase in NO_3-N concentration coupled with the decline in NH_4-N for ORGA at the end of the trial stands as further evidence for some nitrification approximately two weeks after incorporation intro SPM.

SME PO_4-P concentrations (Figure 2.1.f) for all fertilizer treatment except for DRAM remained consistent throughout the trial with VERA, BIOL and the control remaining close to zero. DRAM experienced a decline in PO_4-P concentration between days 5 and 12 followed by relatively consistent concentrations. These results show that there is little, if any, transformations of P taking place with most of these fertilizers. The decline in PO_4-P for DRAM could be due to microbial immobilization or the formation of sparingly soluble phosphorus minerals.

Table 2.2. Cumulative PO_4-P and reactive N leached from fertilizer treatments in incubation I. Nominal PO_4-P and total N applied based on labeled guaranteed analysis.

Fertilizer	Nominal N applied mg	Reactive N leached, % of N applied	Nominal P_2O_5-P applied mg	PO_4-P leached, % of P_20_5-P applied
Control	0	N/A	0.00	N/A
PINN (3-1-1)	150	64%	21.82	62%
DRAM (2-5-0.2)	150	77%	163.65	43%
BIOL (3-3-3)	150	54%	65.46	11%
ORGA (1-1-1)	150	28%	35.35	97%
VERA (2-0-6)	150	37%	0.00	N/A

Overall, the results of the leaching portion of this study show that, with the exception of DRAM, all other fertilizers tested continue to release plant available N and P for approximately 2 weeks (or 4-5 irrigation events). All fertilizers had increasing concentrations or cumulative amounts of NH_4-N in SME and leachate samples, respectively. This shows that different fertilizers have different mineralization patterns resulting in different amounts of available nutrients over time. The fluctuations in both N forms in SME samples show that N likely cycles rapidly after being applied to media.

2.4.2. Incubation II

The percentage of N measured generally exceeded the N reported on the guaranteed analysis. DRAM contained 32% more N than was reported on the guaranteed analysis. Guaranteed analysis is the minimum concentration required so manufacturers likely underestimate guaranteed analysis to account for variability in feedstock. C:N ratios varied greatly, with VERM having the highest ratio and BOMB lowest. PPIF had lower C:N ratios than the LFs but there was still a wide range of C:N ratios among PPIF (4.92-10.65) and LF (2.91-4.39) (Table 2.3). There was also a wide range in pH (3.46-6.04) and EC (0.64-1.27) for diluted LFs (Table 2.4).

Table 2.3. Labeled guaranteed analysis nitrogen concentration, measured nitrogen concentration, measured carbon concentration and C:N ratio of three liquid organic fertilizers, two preplant incorporated fertilizers and vermicompost.

Fertilizer	Guaranteed analysis nitrogen % dry weight	Nitrogen % dry weight	Carbon % dry weight	C:N
PINN (3-1-1)	3	3.16	12.35	3.91
DRAM (2-5-0.2)	2	2.64	11.58	4.39
BOMB (2-0-6)	8	8.14	23.68	2.91
NATU (5-6-6)	5	6.02	29.64	4.92
MICR (3-2-3)	3	3.67	35.40	9.64
VERM (1.5-0.7-1.5)	1.5	1.62	17.30	10.65

Table 2.4. pH and EC of three organic fertilizers diluted to 150 mg L^{-1} nitrogen.

Fertilizer	Diluted to 150 mg L^{-1} N pH	EC, mS
PINN (3-1-1)	4.11	0.64
DRAM (2-5-0.2)	3.46	1.27
BOMB (2-0-6)	6.04	0.71

Fluctuations in SME NH_4-N concentration for almost every treatment suggested dynamic nitrogen cycling including nitrification, mineralization and biological fixation processes. SME NH_4-N concentrations for combinations are mostly additive. VERM does not contribute a significant amount of NH_4-N in SME samples (Fig. 2.2).

NO_3-N concentrations in SME samples revealed that LFs vary greatly in NO_3-N accumulation, and, that net NO_3-N accumulation is strongly influenced by combining organic fertilizers. Lower NO_3-N was observed in treatments with LF+PPIF, LF+VERM and LF+PPIF+VERM than other combinations. DRAM was shown to be a poor NO_3-N source for the first three weeks, but, when combined with VERM, appears to begin NO_3-N accumulation after the third week. DRAM seemed to strongly inhibit or delay nitrification when combined with other fertilizers. In both DRAM+PPIF combinations, NO_3-N concentrations remained close to zero throughout the trial. Both PPIF yielded higher NO_3-N concentrations than any LF alone except BOMB, which reached the highest NO_3-N concentrations of any fertilizer. BOMB reached higher NO_3-N concentrations when applied alone than in combination with any other fertilizers. BOMB NO_3-N concentrations were more than double those of BOMB+PPIF and

BOMB+PPIF+VERM treatments. Increases in NO_3-N concentration along with declining NH_4-N concentrations in SME samples from BOMB prove a high nitrification potential for BOMB. Conversely, both PPIFs and DRAM appear to inhibit or slow nitrification (Fig. 2.3).

The lower levels of nitrate observed when PPIF was applied suggest nitrification inhibition which may be due to the greater C:N ratios of PPIF as compared to many LFs. MicroStart appeared to have the greatest effect on nitrification and has the greatest C:N ratio (9.64) of any fertilizer in this trial. DRAM also seemed to dampen nitrification. Most treatments containing DRAM had NO_3-N concentrations close to zero throughout the trial. This may also be due, in part, to a higher C:N ratio (4.39) than the other LF. The high EC (1.27) and especially, the low pH (3.46), of DRAM likely contributed to its inhibition of nitrification. The nitrification in LF treatments look to be directly related to C:N ratio and pH with DRAM having the lowest nitrification potential and BOMB, with the highest pH (6.04) and lowest C:N ratio (2.91), having the greatest nitrification potential

PO_4-P concentrations for all LF were somewhat related to the guaranteed analysis but PO_4-P concentrations in all SME samples from DRAM-containing treatments were many times higher than any other treatment, showing differences in PO_4-P availability among fertilizers. PO_4-P concentrations were mostly consistent throughout the trial for all treatments except for those containing DRAM, which fluctuated some. Neither of the PPIF had changes in PO_4-P concentration over time and contributed about the same amount of PO_4-P as VERM. Despite its guaranteed analysis of 5-6-6, NATU did not appear to contain much soluble and reactive PO_4-P based on SME results. Combination treatments with NATU had lower PO_4-P concentrations than the corresponding treatments without NATU (Fig. 2.4).

The high concentrations of PO_4-P in DRAM treatments likely came from the phosphoric acid used to stabilize the liquid fish hydrolysate in DRAM. The low pH of DRAM may further dissolve P immobilized in organic or mineral compounds. Much of the P in the other fertilizers is bound in organic and mineral compounds that may slowly become labile under the right conditions.

The cumulative NH_4-N leached was related to guarantee analysis for all LF and seemed to reach its peak in the second week. PPIFs yielded less NH_4-N and also peaked in the second week. VERM contributed 7.3mg of NH_4-N throughout the trial. NH_4-N leached from combination treatments were mostly additive (Fig 2.5). While the SME data from this trial shows rapid nitrogen cycling, that cycling cannot occur if nitrogen is quickly leached from the media as is shown here with this rapid NH_4-N leaching. Although SPM has a high CEC, ions generally adsorb weakly. This makes nutrients in SPM highly available to plants but also makes the potential for leaching high, even for ions like NH_4-N which are more stable in most mineral soils.

DRAM treatments yielded the greatest quantities of NO_3-N. PINN alone yielded more NO_3-N than when combined with either PPIF. NATU, MICR and BOMB-containing treatments, yielded almost no NO_3-N. Rapid leaching of NH_4-N may have limited the nitrification potential for some treatments that showed greater nitrification potential in SME samples. NO_3-N leached from all combination treatments was additive. VERM alone contributed more NO_3-N than any treatment without VERM. DRAM treatments had the greatest quantity of NO_3-N leached (Fig. 2.6).

Cumulative PO_4-P leached was related to the guaranteed analysis for all LF (Fig. 10) and reached its peak, rapidly, by the end of the first week. The peak in PO_4-P leached was pushed to

the second week when LF was combined with PPIF or VERM. VERM alone contributed the same amount of PO_4-P as MICR with the same rate of release and more PO_4-P than NATU. PO_4-P leached from combination treatments was mostly additive (Fig. 2.7).

Overall, SME and PourThru results show that different organic fertilizers vary greatly and unpredictably in nutrient availability, composition and reaction. Guaranteed analyses do not necessarily relate to nutrient availability in all cases, particularly with PPIF. Complex nutrient cycling, interactions between fertilizers and leaching all play important roles in nutrient availability from organic sources in SPM. A better understanding of how specific fertilizers interact with each other and with SPM components will aid in formulating combinations of fertilizers and media that complement each other. VERM behaved much like a PPIF and both PPIFs (NATU and MICR) has similar results to each other.

Leachate samples yielded more consistent and intelligible results. There was also a better correlation between P measured and P applied in leachate samples. This may be due to the qualitative nature of SMEs. Leaching uses a measured quantity of extractant and a quantity of nutrient is determined whereas SMEs measured a relative concentration. In this leaching procedure, individual units were measured repeatedly. Samples for SMEs were taken from heterogeneous media. Repeated leaching also accounts for removal of nutrients. Leaching measurements had a much better relationship to estimated nutrients applied. (Figs. 2.8 & 2.9). Methods used in these trials could not be used to determine, specifically what nutrient cycling is taking place but may be useful in estimating nutrient availability. Plant growth trials will reveal if nutrients measured in SME or leaching samples are related to plant nutrient availability from organic sources.

2.4.3. Plant Growth Trial

There were clear differences in sunflower growth response between the two PPIFs used in this trial. There were no significant differences in plant dry weight across fertilizers, however, there was a significant fertilizer - nitrogen rate interaction. The 50mg N L^{-1} rates of both fertilizers yielded the least dry weight and the 100 mg N L^{-1} rate of MicroStart produced plants with the greatest mean dry weight (Fig. 2.10).

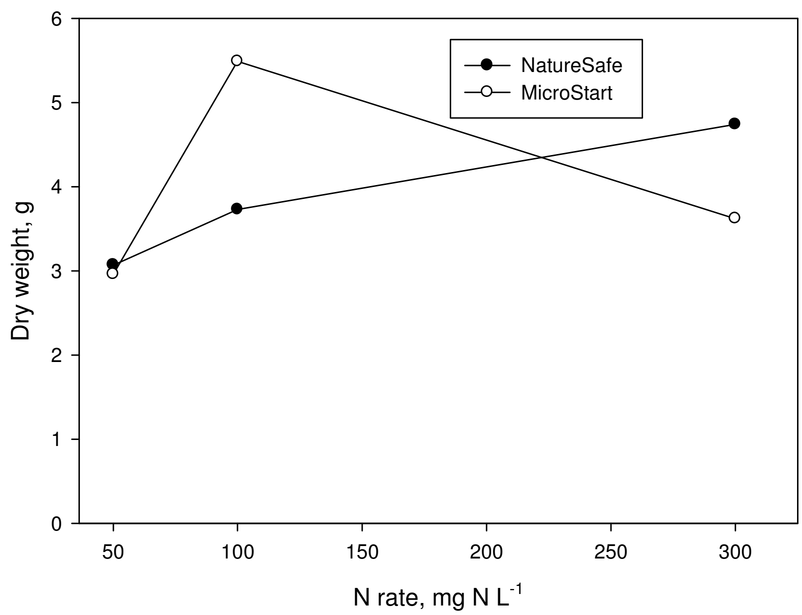

Figure 2.10. Mean dry weights of sunflower grown in media containing two PPIF organic fertilizers at three nitrogen rates.

Despite the absence of significant differences in dry weight between plants grown in either fertilizer there were clear differences in growth response, tissue nutrient concentration and final quality (Fig 2.10). Plants in all NatureSafe treatments had some leaf chlorosis and malformation (Fig 2.11). This may have been caused by sodium toxicity damage and high soluble salts.

Nutrient concentrations for plants grown with NatureSafe were generally greater than or equal to their MicroStart counterparts and sodium concentrations in plants grown with NatureSafe were orders of magnitude greater (Table 2.6). Using flood and drain irrigation may have exacerbated problems with high soluble salts. Results from the Incubation II leaching trials show that most of the immediately available nutrients in both PPIF are leached within the first two weeks (or first 800ml leached). Sodium likely would have leached quickly as well under overhead irrigation.

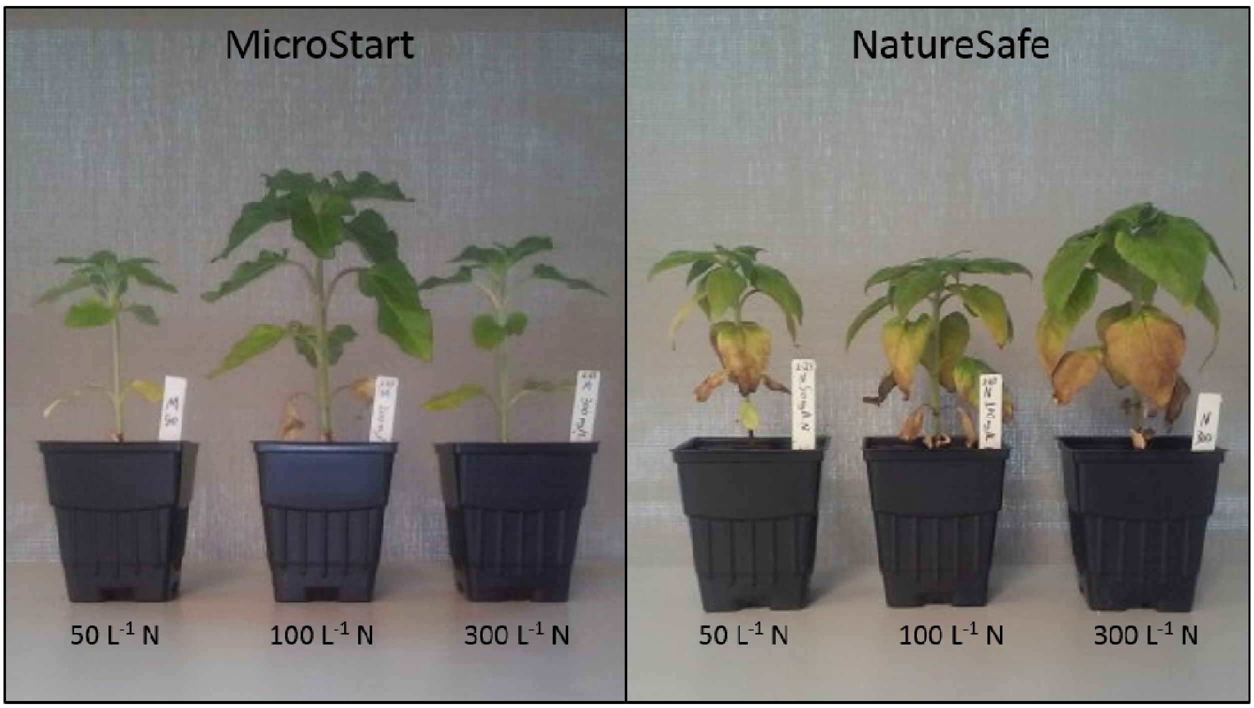

Figure 2.11. Sunflowers grown in media containing two pre-plant incorporated fertilizers at three rates

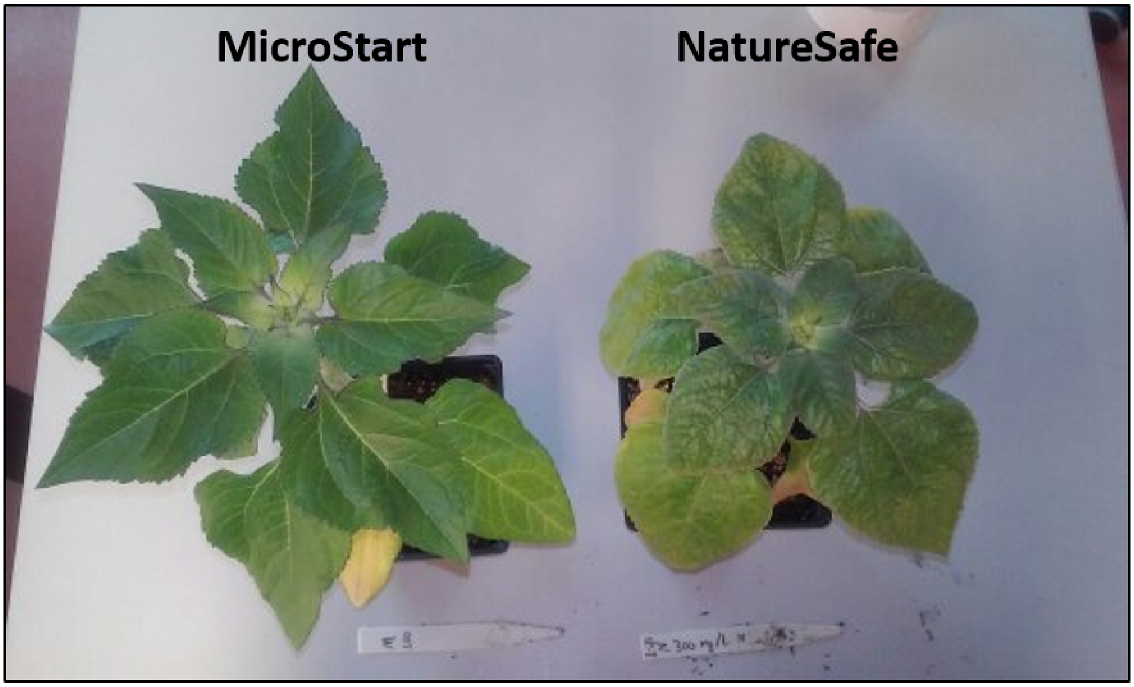

Figure 2.12. Sunflowers grown in media containing two pre-plant incorporated fertilizers at a rate of 300 mg L^{-1} nitrogen

There was a correlation between N and P applied to the media and N and P concentration measured in plant tissue for the NatureSafe treatments. Plants grown with MicroStart had similar tissue N and P concentrations across rates (Figs 2.12 & 2.13). Phosphate leaching and SME results from Incubation II for both PPIFs were almost identical (Fig 2.4.b & 2.4.c) so neither SME nor PourThru sampling are effective methods of predicting plant available P from organic sources in SPM.

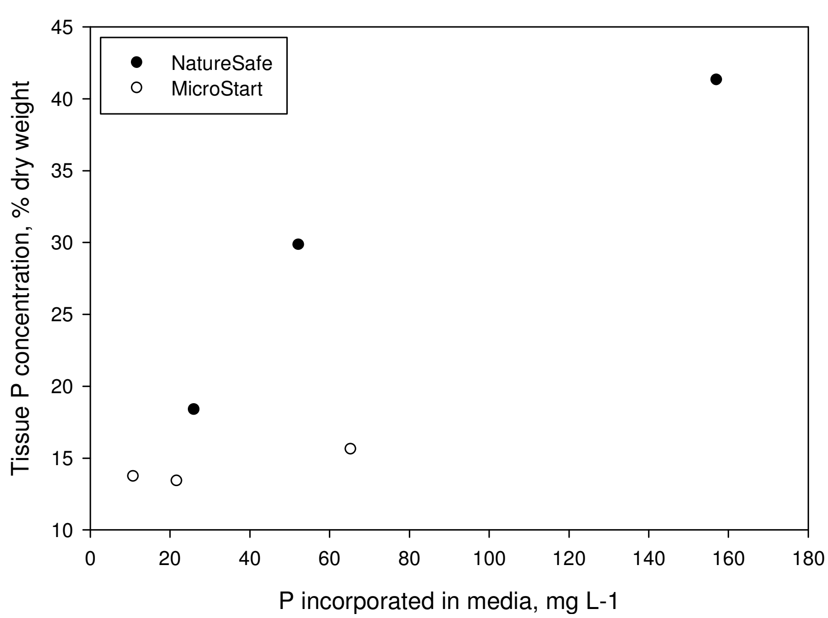

Figure 2.13. Phosphorus concentration measured in sunflower tissue grown in media containing two pre-plant incorporated fertilizers at three rates over phosphorus incorporated in media based on measured phosphorus concentration of the fertilizers.

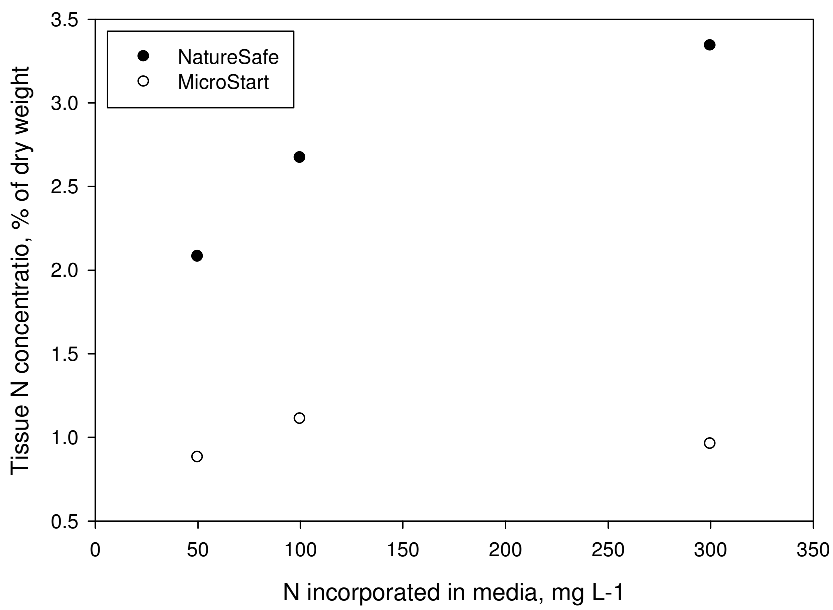

Figure 2.14. Nitrogen concentration measured in sunflower tissue grown in media containing two pre-plant incorporated fertilizers at three rates over nitrogen incorporated in media based on measured nitrogen concentration of the fertilizers.

Nutrients from NatureSafe were readily available whereas the nutrients in MicroStart seem to be released gradually over time. This is further supported by the results of Incubation II, particularly the NH_4-N leaching. The rapid release of nutrients from NatureSafe may have

produced a high concentration of soluble salts in the media solution, leading the salt damage. The high concentrations of Na measured in the tissue of plants grown with NatureSafe indicate that great caution should be exercised when growing salt sensitive plants with NatureSafe. The 100 mg N L^{-1} rate of MicroStart clearly produced the most favorable results. It would be useful to do further investigations with different rates of MicroStarts to develop a growth response curve and critical fertilizer rate.

MicroStart has almost double the C:N ratio of NatureSafe. This may indicate that the nutrients in MicroStart are bound in organic compounds that slowly mineralize over time. The higher C:N ratio in MicroStart may also stimulate microbial immobilization, further slowing the release of nutrients. The Incubation II SME data also suggested that both PPIFs slowed nitrification with MicroStart appearing to slow nitrification more than NatureSafe

Table 2.5. Tissue nutrient concentration of sunflower grown with MicroStart or NatureSafe at three rates.

	Nitrogen rate	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Mo	Na	Zn
	mg N L media	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	mg/kg
MICR	50	0.88	13.7	1.19	1.58	1.04	12.7	5.3	7.2	130.7	0	0.02	44.2
NATU	50	2.08	18.34	1.64	1.45	1.2	6.1	5.7	18.3	124.6	0	1.05	43.2
MICR	100	1.11	13.37	0.98	1.23	0.9	15.9	6.7	9.5	79.8	0	0.04	51.9
NATU	100	2.67	29.81	2.29	1.53	1.32	5.8	6.9	33.8	128.1	0	0.55	47.1
MICR	300	0.96	15.59	1.19	1.53	0.98	14.3	6.7	10.3	136.7	0	0.11	59.5
NATU	300	3.34	41.28	2.33	1.35	1.23	4.1	5.8	31	51.1	0	1.25	43

2.4.4. General Discussion.

There are numerous factors that affect nutrient cycles in SPM and the inclusion of nutrients in the form of organic compounds adds another complicating factor to the prediction of nutrient availability. Organic fertilizers have a wide variety of nutrient release characteristics and could be formulated for an equally wide variety of applications once the interactions between organic fertilizers are better understood. For example, if leaching of nutrients is a concern, an organic fertilizer with a high concentration of soluble nutrients could be used in conjunction with DRAM to slow nitrate leaching or NATU to slow phosphate leaching. Both pH and C:N ratio seem to be important in predicting nutrient availability from organic sources.

Nominal nutrients applied and traditional aqueous extracts are not good predictors of plant response to organic fertilizers in SPM. Organic fertilizers have different time courses for nutrient release that are not necessarily reflected in traditional monitoring techniques. Also, the nutrient transformations observed in SME results may not have much bearing in real world applications as most of the nutrients are leached quickly, even for the PPIFs. The rapid release of nutrients from PPIFs may limit their use in commercial container culture because they will not supply nutrients throughout the duration of a crop and reapplying PPIF throughout the crop cycle is not practical. In these trials treatments received only one application of LF. In practice, LFs are usually used in multiple applications to continuously supply plants with nutrition.

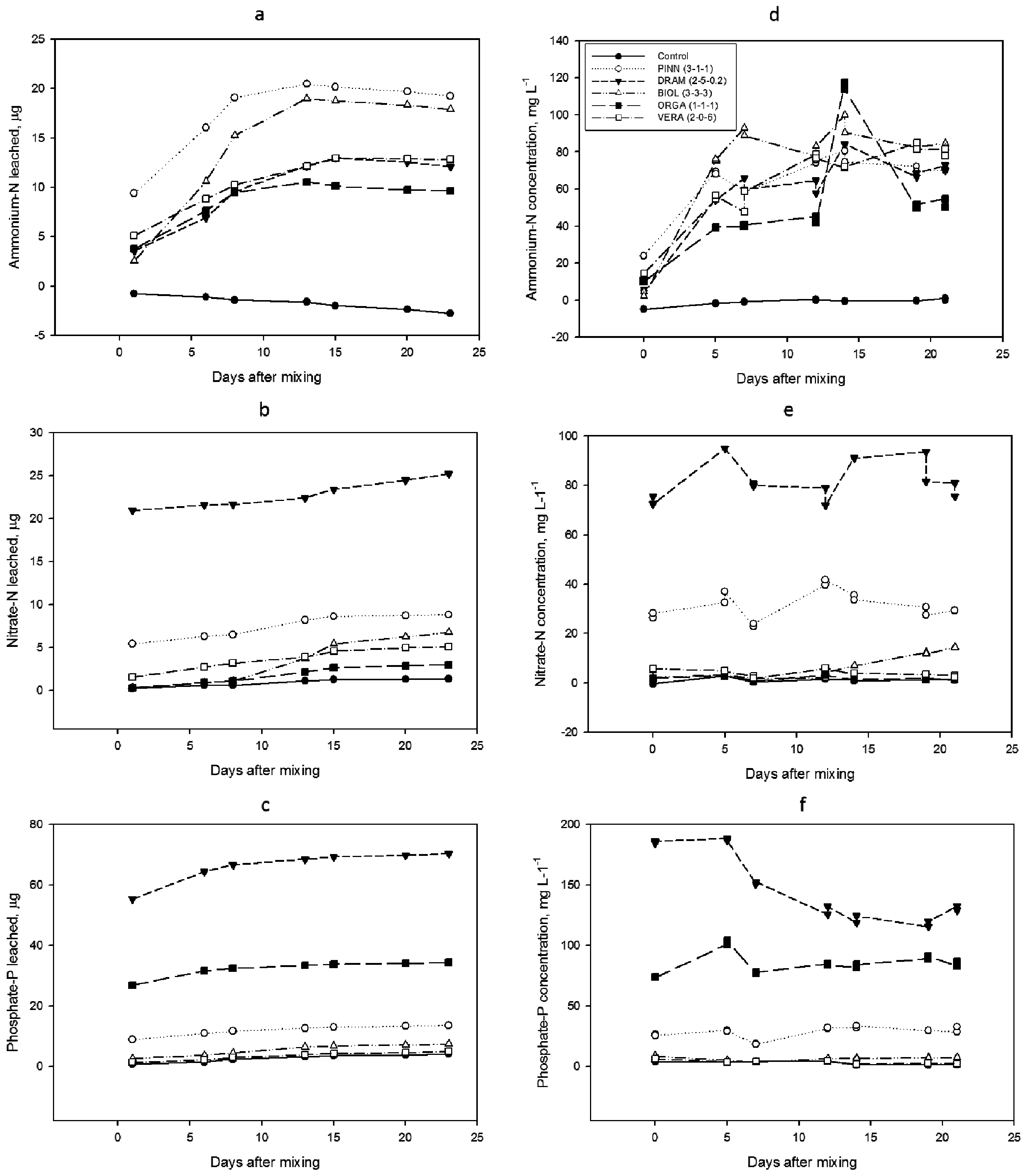

Figure 2.1. Cumulative ammonium-N (a), nitrate-N (b) and ammonium- and nitrate-N (c) leached and mean ammonium-N (d), nitrate-N (e) and phosphate-P (f) concentrations from SMEs from incubation I.

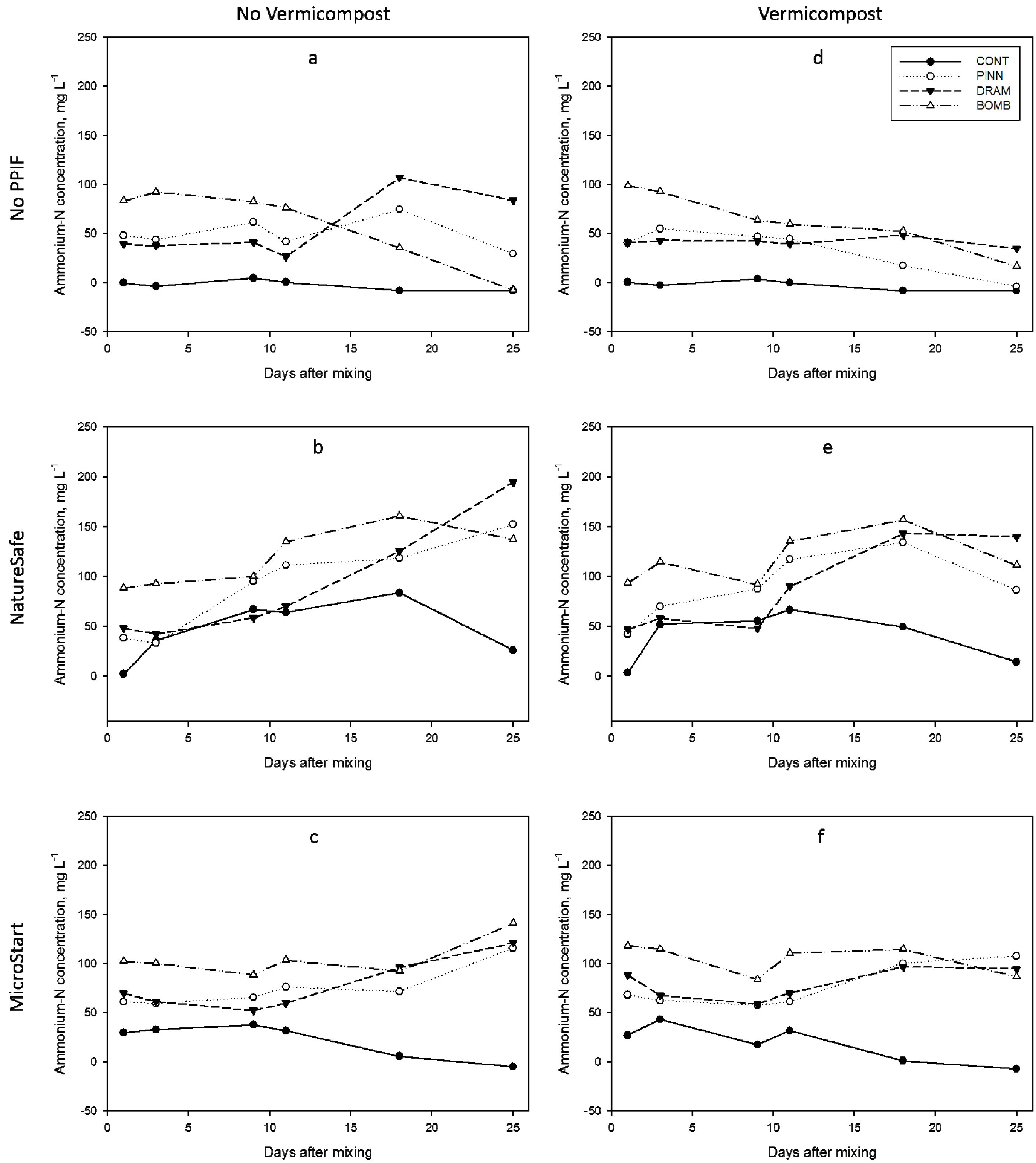

Figure 2.2. Mean SME ammonium-N concentration from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

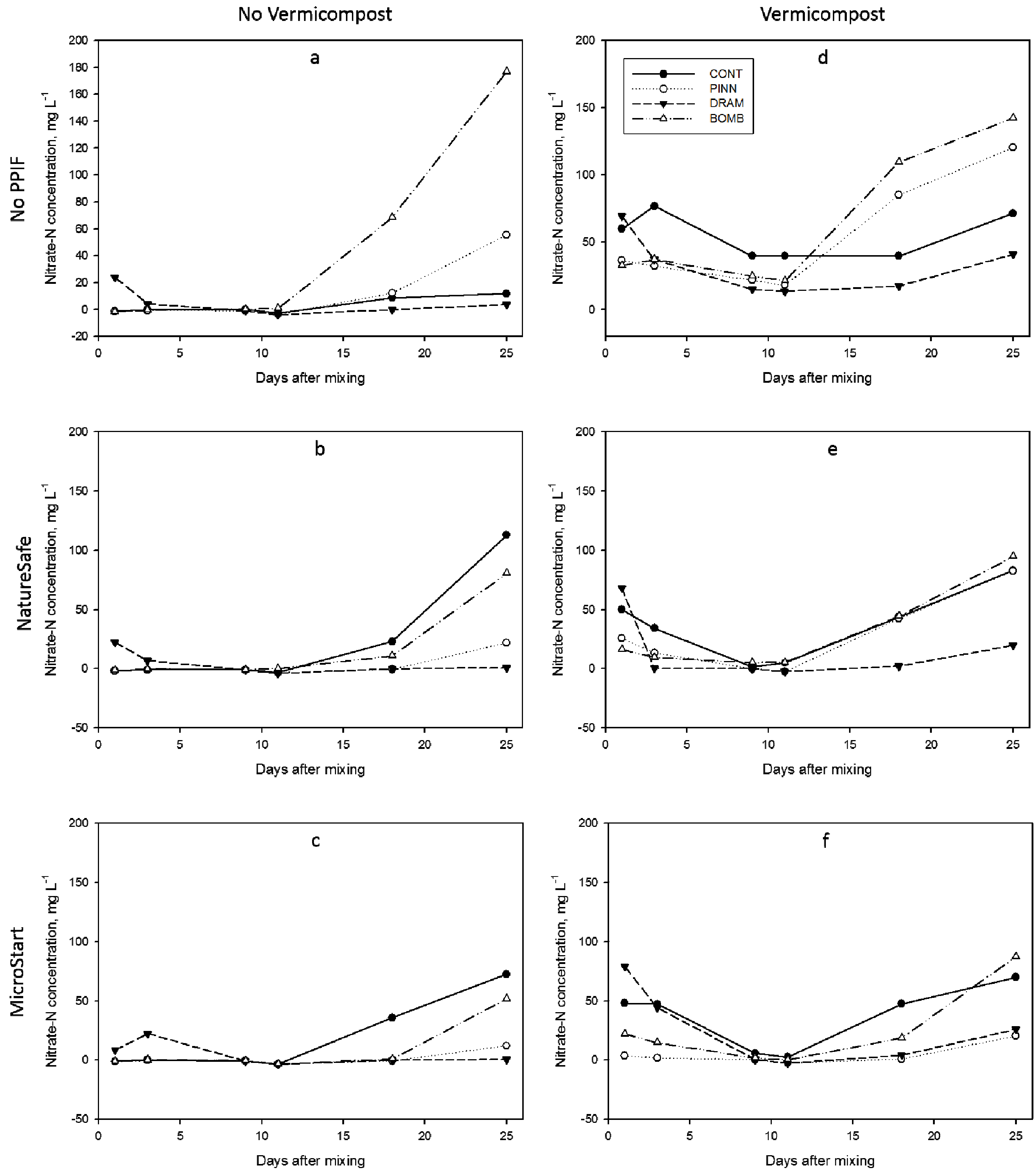

Figure 2.3. Mean SME nitrate-N concentration from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

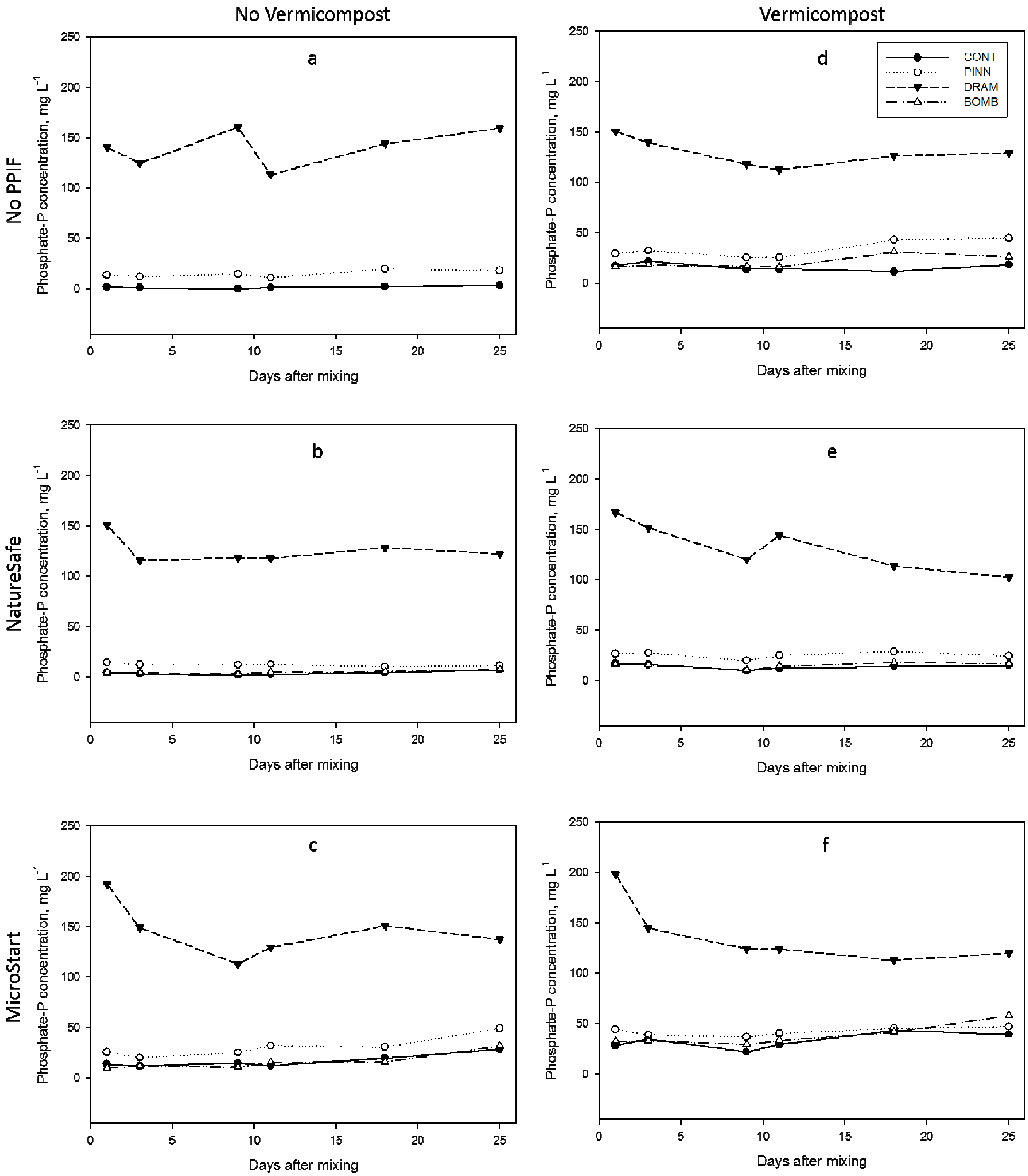

Figure 2.4. Mean SME phosphate-P concentration from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

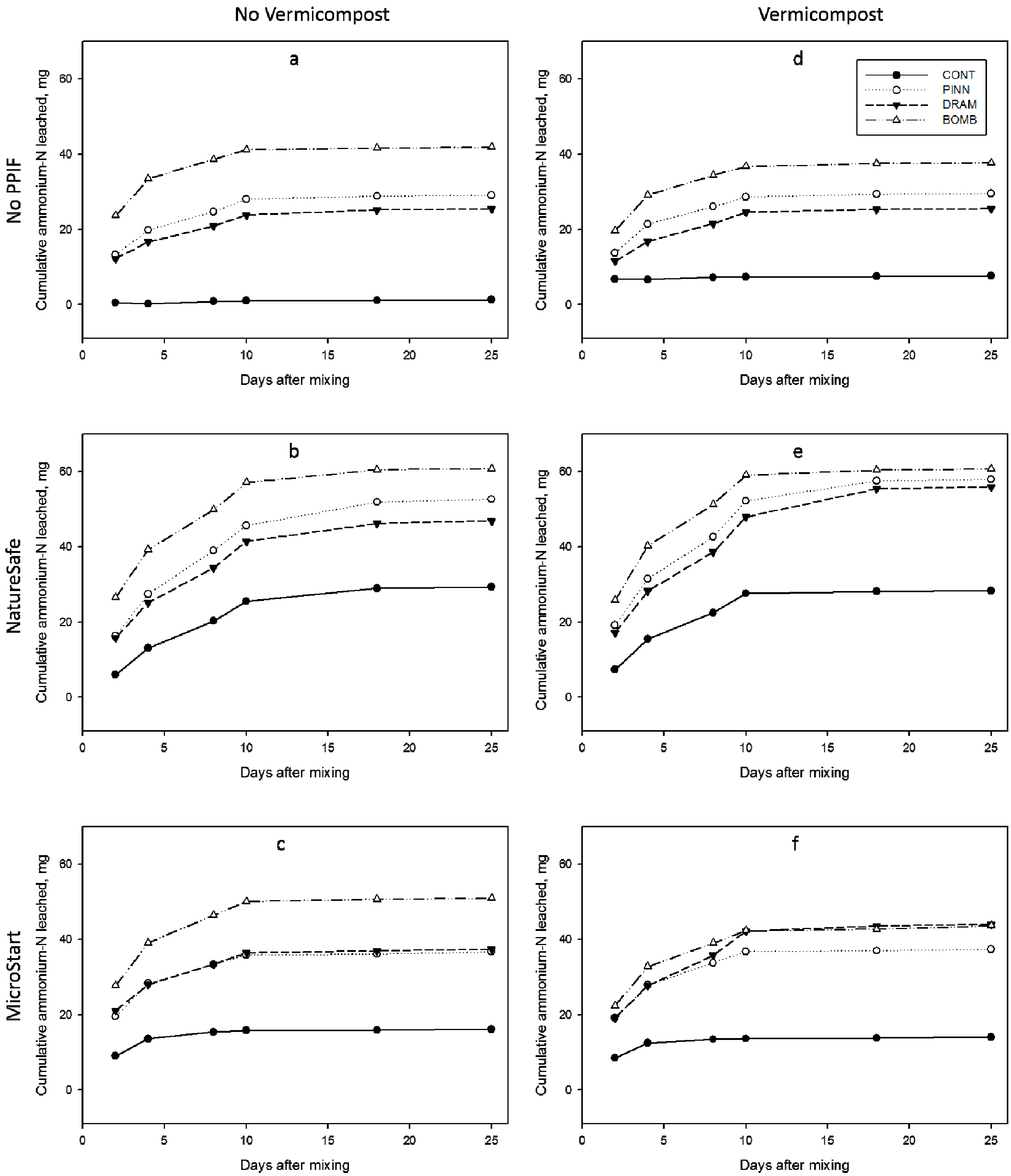

Figure 2.5. Mean cumulative ammonium-N leached from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

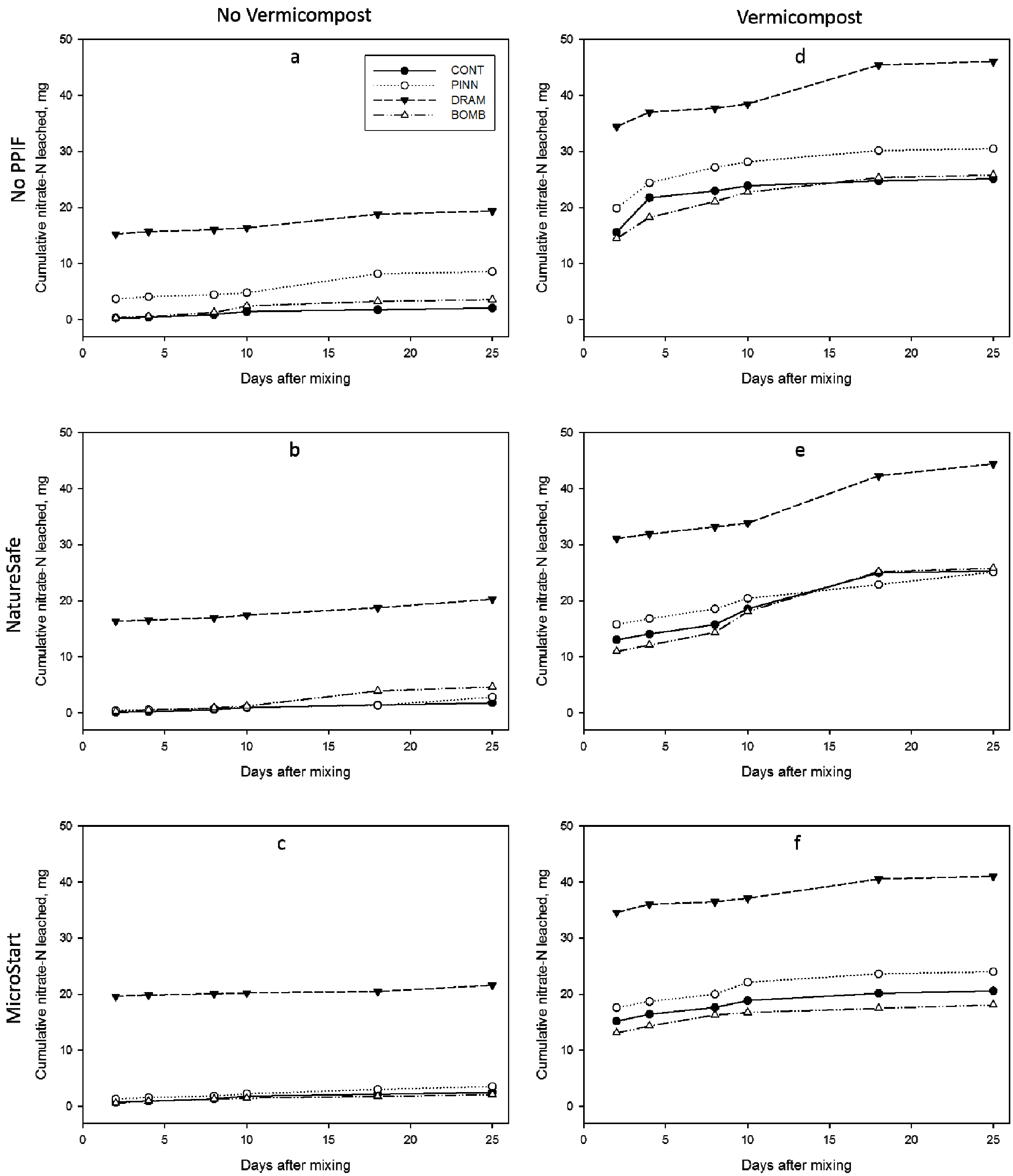

Figure 2.6. Mean cumulative nitrate-N leached from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

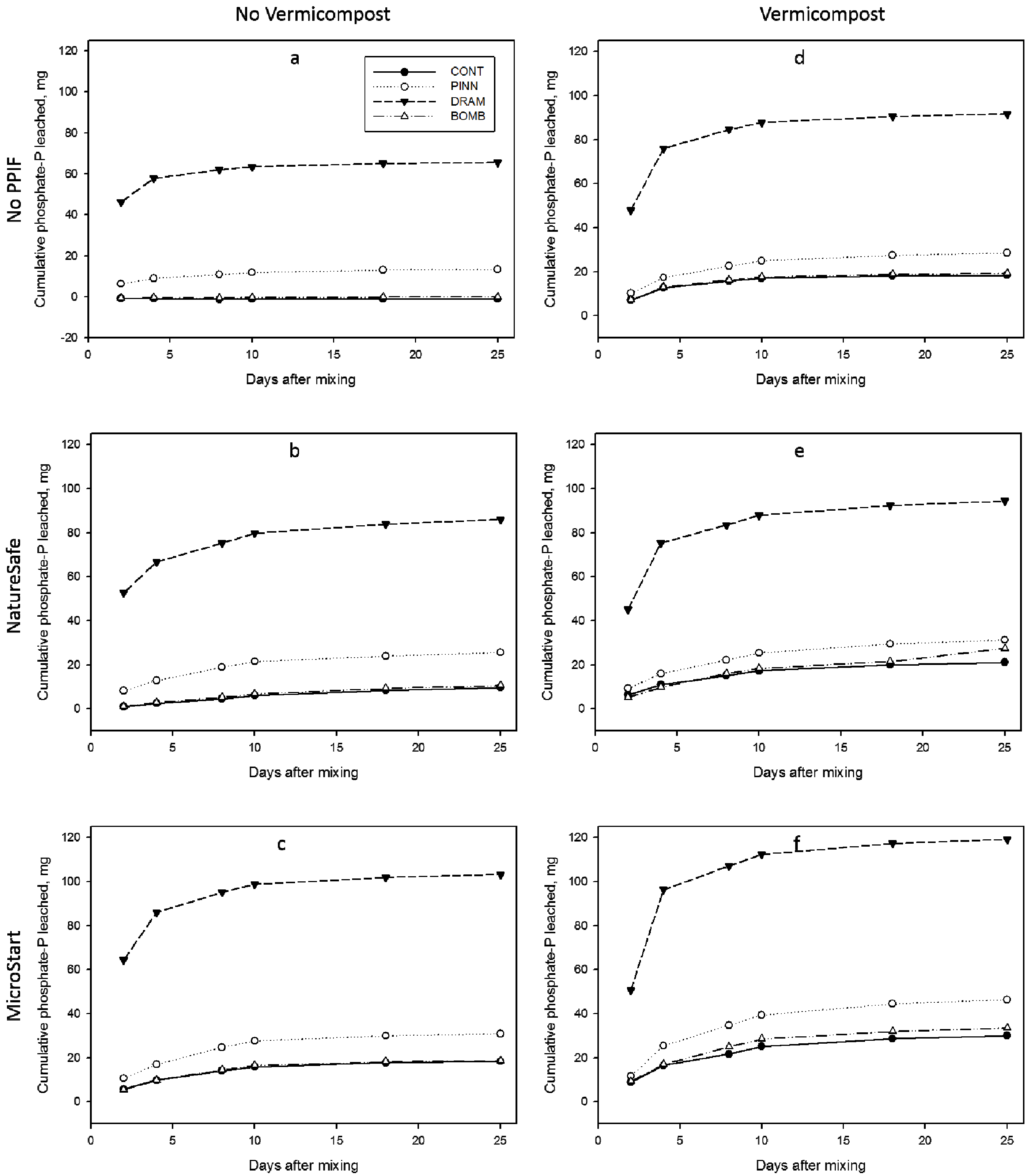

Figure 2.7. Mean cumulative phosphate-P leached from unplanted pots containing media mixed with three liquid organic fertilizers with and without PPIF NatureSafe (center row) or MicroStart (bottom row) and with (right column) or without (left column) vermicompost over approximately 4 weeks.

Table 2.7. P-values of main effects and interactions for figures 2.2-2.7

	Figure					
Effect	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**
PPIF	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LF	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
VERM	0.0918	<.0001	<.0001	0.2561	<.0001	<.0001
Day	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
PPIF x LF	0.0579	0.0001	0.0126	0.1275	0.0150	<.0001
PPIF x VERM	0.3099	0.0004	0.9759	0.0642	0.0005	<.0001
LF x VERM	0.6575	0.2810	<.0001	0.0095	0.0739	0.2688
PPIF x LF x VERM	0.3879	0.0990	<.0001	0.2277	0.9655	0.3170
PPIF x Day	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LF x Day	<.0001	<.0001	<.0001	<.0001	0.0001	<.0001
VERM x Day	<.0001	<.0001	<.0001	0.0475	<.0001	<.0001
PPIF x LF x Day	<.0001	<.0001	<.0001	0.0020	0.0028	0.1775
PPIF x VERM x Day	<.0001	0.0189	0.0073	0.6321	<.0001	0.0684
LF x VERM x Day	0.0003	<.0001	<.0001	<.0001	0.0336	<.0001
PPIF x LF x VERM x Day	<.0001	<.0001	<.0001	0.4923	0.9308	0.9818

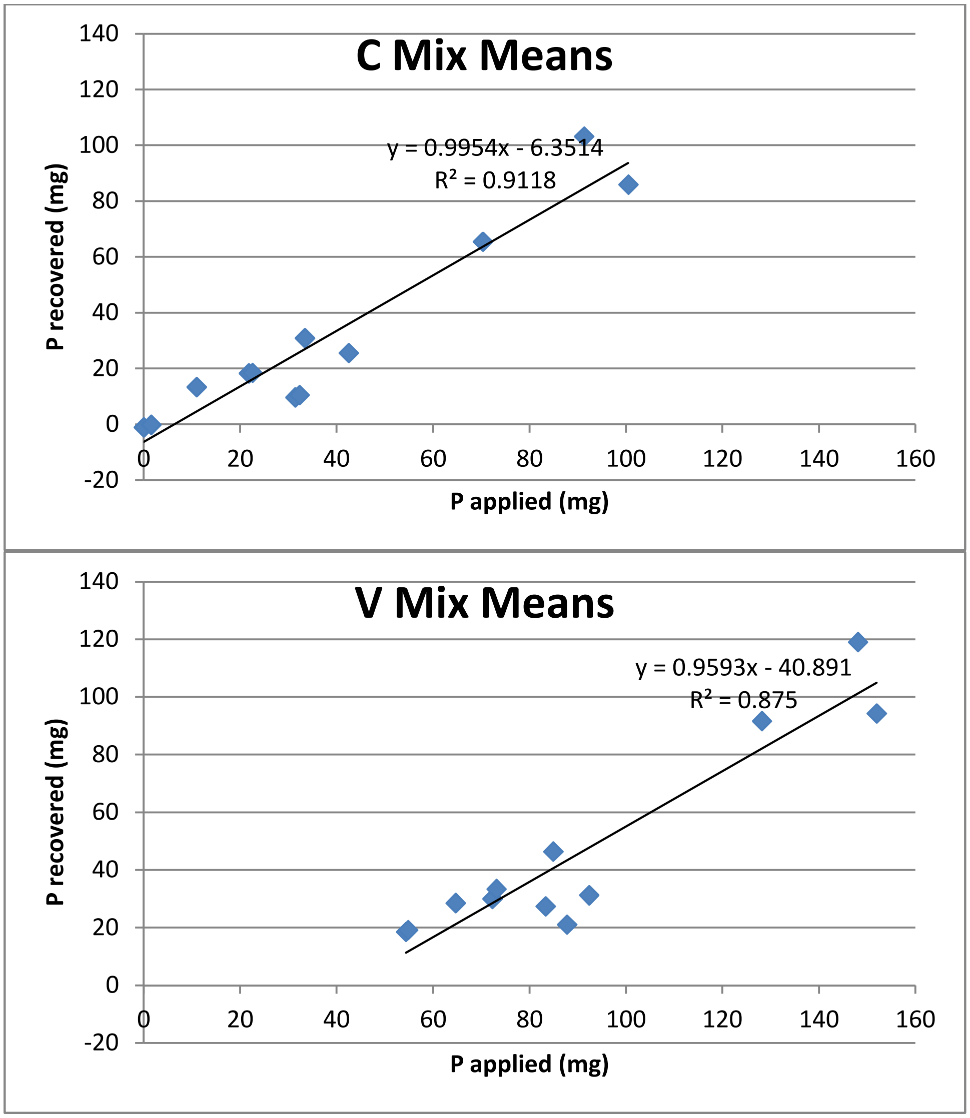

Figure 2.8. Mean PO_4-P recovered in leachate Incubation II trial for treatments with and without vermicompost. Nominal P applied based on guaranteed analysis of fertilizers used.

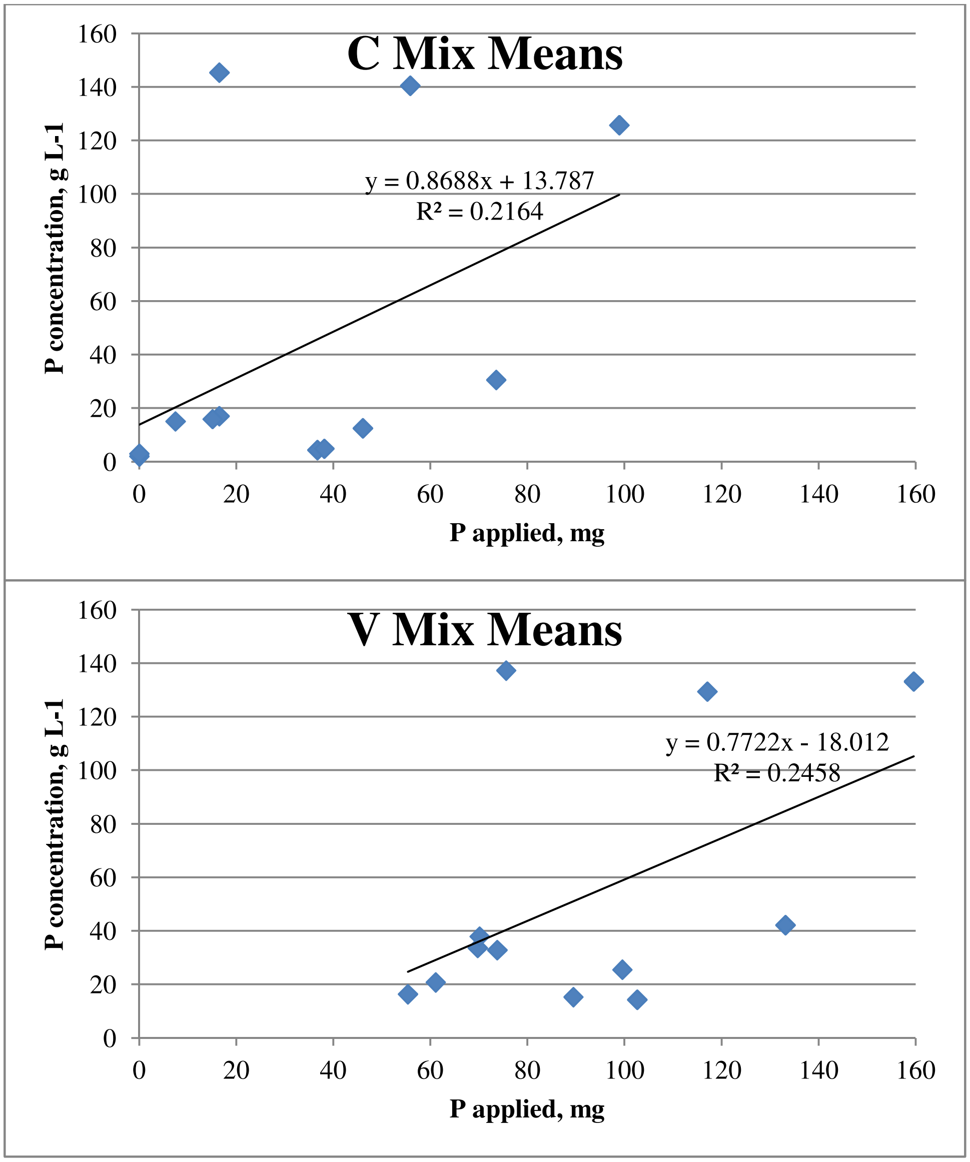

Figure 2.9. Mean PO_4-P concentrations measured throughout Incubation II for treatments with and without vermicompost. Nominal P applied based on guaranteed analysis of fertilizers used.

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