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Evaluation of Flue-Gas Desulfurization gypsum in Poultry Litter as a Substrate Component for Greenhouse Horticultural Crops

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Abstract

A study was conducted to evaluate the growth response and consumer preference of three plant species to substrate blends containing flue gas desulfurization gypsum (FGDG). Substrate blends used in this study were derived from a previous experiment that evaluated the use of FGD Gas a bedding material for broiler chicken production. Five litter treatments chosen from the broiler study were mixed at a 50:50 ratio with crushed pine bark (CPB) giving rise to the following treatments: Pine shavings (PS)+CPB (50:50 v/v); FGDG + PS + CPB(25:25:50 v/v/v); FGDG +CPB(50:50 v/v), Pine bark (PB)+ CPB (50:50 v/v); and FGDG + PB + CPB (25:25:50v/v/v). These treatments were compared to CPB + Farfard 3B (50:50 v/v) as the control (industry stand and).The five broiler litter based substrates (treatments) contained poultry manure while the control did not. There were differences in consumer preference, plant growth, foliar greenness (SPAD values), and drainage rates among substrates (treatments) and their suitability for growing plants. In the substrate based on poultry litter from 100% FGDG bedding, flocculation created good drainage, higher CEC, and greater pore space. This 1: 1 FGDG: CPB substrate had a lower, more desirable pH level, a higher calcium level, and less phosphorus leached from the substrate after watering suggesting the possibility of calcium binding excess phosphorus in the leachate water.

Substrates components for greenhouse crops have changed over the years for various reasons. One reason is the availability and costs of substrate components that fluctuate, forcing growers to seek less expensive, readily available alternative substrate components. The primary substrates used in the nursery and greenhouse industry since the 1970's have been pine bark and peat moss. However, in recent years other uses for pine bark have caused a constriction of pine bark availability for horticultural substrates [1]. Increased availability of alternative substrates for the nursery and greenhouse industry has been a justified pursuit for much research [2,3]. Poultry litter has been one of the materials considered for potential use in the nursery industry [4-6], but most of the litter evaluated in the past has been pine wood shavings or sawdust, with very few studies evaluating litter based on pine bark bedding [7]. Gypsum has also been considered as a substrate component for growing horticultural crops [8,9].

An important influence on best practices across a number of agricultural and industrial industries has been federal environmental protection regulations. Two industries, the poultry industry and coal-fired electric companies, are currently required to manage their waste differently than in the past. For example, large poultry operations are required to submit and use a Water and Nutrient Management Plan [10].

There are numerous reasons why alternative substrate options are needed. Costs of materials can become prohibitive, availability may change [2], consumer preferences may change [5,11], and environmental concerns [3,6,8,10,12-16] and regulations Agriculture and Agri-Food Canada [17], may alter recommended best practices [10].

Research seeking alternative substrates increased in the 1970s resulting from increased populations with an increased demand for container grown plants nationwide [18], erratic supplies of peat moss, and a need to reduce landfill use [3-5,13,14,17,19-21]. Horticulturists are in a unique position to help solve pollution problems caused by the disposal of certain waste materials, which would otherwise become environmental problems [3,13,16,22].

Some materials evaluated for use as horticultural substrate components have included spent tea grinds [23], gasifier residue [24], clean chip residual and processed whole pine trees [2]. Results from studies using composted chicken litter as an alternative to inorganic fertilizers in the landscape and as a substrate component for containers proved suitable in both cases [6]. In another study bio-solids saturated newspaper crumbles or composted poultry litter was added at 25% vol:vol to either ground pine chips or pine bark. Substrates amended with composted poultry litter produced the largest plants across all treatments [3]. Gypsum has been studied both as a substrate component as well as a fertilizer and chemical stabilizer of phosphorus in poultry litter, with the intent of minimizing negative environmental impact on local ground water and waterways with great success [8,16,25,22].

Keywords: Agricultural wastes; Industrial wastes; Re-use; Alternative potting media

The Poultry Industry

The poultry industry is the largest agricultural industry in however, a problem with poultry production is what to do with the waste produced, primarily from processing plant waste and bedding material or poultry litter. Processing plant waste is generally cooked for use in pet food Sibley 2016 however utilization of the bedding is still an issue for the industry [3-5,13,17,20,21,22,26].

In recent years, a growing need for alternative methods of managing wastes for poultry production coupled with increased need for alternative components for use in horticulture industry substrates was the focus of much research [2,3,6,10,16,19,22,27]. There is good reason for this interest in planned manure management that includes re-use. Generally, animals only use about 25% of the nutrients they receive in their feed with manure trapping about 75% of the nutrients in the original feed (N, P, K), nutrients that are potentially useful to crops and plants.

Two methods of composting poultry litter (PL), windrow and in-vessel digester, with the potential for use in the green industry were compared by Brymer [19]. Data indicated electrical conductivity and pH levels for in-vessel derived compost might not be suitable for production without pre-plant leaching when growing salt and pH sensitive plants. Burning poultry litter for energy production and using the poultry litter ash in greenhouse crop production, specifically as an alternative fertilizer, was successful in Louisiana [22]. The burning process changed the phosphorus (P) in the poultry litter from a soluble form (that is readily available) to strong bonds of P, specifically tricalcium phosphate. The heat burned off the organic materials like nitrogen and carbon, therefore, only minerals remained, with the minerals (in this case Ca and P) forming tight bonds with each other. The substrates with poultry litter ash (PLA) incorporated leached only 10 to 20ppm P, unlike monocalcium phosphate with 2,000ppm P solubility, or dicalcium phosphate with 200ppm P. This reduced phosphorus runoff from greenhouse-grown plants, but still provided the phosphorus required for healthy growth [22].

The poultry industry is interested in bedding materials that are inexpensive, available in large quantities without excessive shipping costs, and that take up and release moisture without damaging effects to bird health or product quality. Numerous materials have been considered for poultry bedding [28,29]. In one study, pododermatitis was generally low in pine shavings, pine bark, sand and gypsum [29]. Bird mortality rates were lowest with gypsum bedding and birds had higher body weights and feed efficiency with gypsum bedding [29].

Poultry litter (PL) has been used as a substrate, a soil conditioner, and fertilizer, but given the quantity of PL produced in some states like Alabama and Georgia, excess PL creates challenges in waste disposal and concerns about pollution. Pollution can come from erosion of amended soils, farm pasture runoff, leachates coming from nursey, or greenhouse containers that have PL as a substrate component. Leachates or runoff often contain highly soluble phosphorus and other nutrients that pose pollution concerns if they are able to enter local waterways, potentially causing algae blooms, which can use up the oxygen in bodies of water creating fish kills and making the water unfit for human consumption [3,6,13,14,20,21].

In a study evaluating PL in amended raised landscape beds with cotton gin waste and/or pine bark, cotton gin waste removed the odor from the PL, and the composted waste material performed equally to the standard peat moss [5]. Also in 1991, bagged soilless potting mix amended with composted PL was acceptable to consumers [4].

Use of gypsum as a way of treating PL to reduce the concentration of P loss from PL amended soils and substrates was evaluated. Gypsum was applied at four rates with the concentration of soluble reactive phosphorus (SRP) significantly reduced even at the lowest gypsum application rate compared with no gypsum application at all sampling periods [16].

Flue Gas De-sulfurization Gypsum

Gypsum has been used in the United States for over 250 years as a fertilizer to provide the essential nutrients calcium and sulfur and to improve overall plant growth. Gypsum added to the soil can also improve the chemical and physical properties of some soils (especially heavy clay soils– causing flocculation of the soil and creating aggregates), and thus can reduce surface crust formation and increase water infiltration rates and movement of water and gases through the soil profile, ultimately reducing erosion and nutrient losses (especially of phosphorus) in surface water runoff. Chemical properties improved by application of gypsum include the mitigation of subsoil acidity and aluminum toxicity, while enhancing deeper root growth and the ability of plants to take up water and nutrients, especially during drought periods. Gypsum is the most common amendment for sodic soil reclamation and can be included as a component in synthetic soils for nursery, greenhouse and landscape uses [8].

There are several sources of gypsum available for agricultural use in the United States. These include the traditional gypsum that is mined, reclaimed casting gypsum from industry, recycled wallboard and flue gas desulfurization gypsum (FGDG) from power plants. FGDG is a somewhat newer source that produces a large volume of gypsum that, as of today, does not have clear re-use solutions. Instead, large quantities of gypsum are being placed in landfills, deposited in surface impoundments, or beneficially recycled [8].

In 2001, combustion of coal was producing 52% of the electricity in the U.S. [8]. Because of the Clean Air Act of 1970 (amended in 1990), coal fired electric plants were mandated to capture all sulfur dioxide (SO_2) emissions and other components of air pollution from burning coal by the year 2010. To do this, the utility companies installed SO2 scrubbers, which use calcium carbonate or hydrated lime ($CaCO_3$) in a slurry form, to filter fumes as they are passed through. This process converts the slurry into calcium sulfate (gypsum - $CaSO_4 \bullet 2H_2O$) and CO_2,

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which is not considered a pollutant. As a result, since 1970, every coal-fired plant has either closed or been outfitted with scrubbers.

The good news is, FGD Gis high quality, suitable for agricultural use, and qualifies as a recycling process itself [30]. The bad news is that current distribution channels of gypsum are unable to utilize the quantities of the new gypsum supplies produced from flue gas desulfurization filters. In 2008, approximately 18 million tons of FGDG were produced, of which 60% (10.6 million tons) was used (mainly in wallboard) with less than 2% used in agriculture. Because it is well known that mined gypsum can improve soil structure and help prevent pollution of local waterways, there is great interest in using the high-quality FGDG produced by utilities to replace mined gypsum [8]. In 2011, the Ohio State University Cooperative Extension Service created a comprehensive bulletin to inform the public and industry about the potential agricultural uses of gypsum. Topics include everything from reviewing properties of gypsum, to benefits for agriculture, application uses, economic considerations, analytical and technical support, and gypsum handling and storage [8].

Because of the increased availability of FGDG, in 2013, the USDA-ARS ran a FGDG project at several locations including Mississippi, Tennessee, Georgia, and Alabama to look at the potential value of FGDG as a soil amendment in agriculture [25]. Further research investigated the impact of FGDG application on water quality in a coastal plain area in combination with PL used in field application [16].

The objective of this study was to evaluate different pine bark and pine shaving litter blends with or without gypsum used as a substrate material for greenhouse horticultural crops.

Materials and Methods

Substrate used for this study came from a previous experiment watts et al. 2017 evaluated the influence of different bedding materials on broiler chicken production after rearing three flocks. Five poultry litter (PL) treatments (PL; used bedding + broiler manure) chosen from the broiler study were mixed at a 50:50 ratio with crushed pine bark (CPB) giving rise to the following treatments: 100% Pine shavings (PS) + CPB(50:50v/v); 50% FGDG + 50% PS + CPB (25:25:50v/v/v); 100% FGDG + CPB (50:50v/v), 100% Pine bark (PB) + CPB (50:50v/v); and 50% FGDG + 50% PB+CPB (25:25:50v/v/v). These treatments were compared to CPB + Farfard 3B (50:50v/v) as the control (industry stand and). Each of these PL treatments were mixed with crushed pine bark (CPB) at a 50:50 ratio and compared to a control composed of CPB (3/8" sieve) + Fafard 3B (50:50). Thus, the resultant substrate treatments used were: A - PS+CPB (50:50v/v), B - FGDG+PS+CPB (25:25:50v/v/v); C - FGDG+CPB (50v/v/v), D - PB+CPB (50:50v/v), E - FGDG+PB+CPB (25:25:50v/v/v), and control - CPB+Farfard3B (50:50v/v). All five of the treatments derived from the broiler study contained manure, while the control treatment did not. For the control, Fafard 3B was substituted for the broiler manure. The substrates (treatments) were combined by mixing one cubic foot ($0.03m^3$) of each PL treatment with one cubic foot of CPB, thoroughly mixed using an automatic mixing machine before use with no additional amendments.

The experiment was initiated on August 19, 2016in a $2300ft^2$ fan and padat the Paterson Greenhouse Complex, Auburn University, AL. Pots (5" x 6.5") (12.7 x 16.5cm) were loosely filled with substrate and shaken to level. Australian sword fern (*Nephrolepis obliterata R. Br.*), Japanese painted fern (*Athyriumniponicum var.* Pictum Mett.), and Gerbera daisy (*Gerbera jamesonii L.*'Revolution Yellow') were transplanted from either 50- or 72-cell pack into the pots (Gerbera daisy 50-cell packs; both ferns 72-cell packs (Casa Flora, Texas)) containing the different substrates. Each substrate treatment was subjected to a fertilized vs. non-fertilized regimen [31]. After transplanting, each treatment was arranged by species and fertilizer regimen in a randomized complete block design. Both fern species had 10 single pot replications x 2 fertilization regimens for each treatment. The Gerbera daisy had 8 single pot replications x 2 fertilization regimens for each treatment. Thus, there were a total of 336 plants for this experiment, all of which were grown for 50 days. All plants were irrigated daily and fertilized plants received 150ppm N solution (beginning 2 wk after transplanting) through the irrigation system. The irrigation water had an average pH of 7.0 during this study.

Before substrates were mixed with the CPB, a sample was taken from each treatment and submitted to Auburn University Soil Testing Laboratory (AUSTL) for analysis of pH, EC, SS, NO_3-N, Ca, K, Mg, and P, plus micronutrients. Bulk density was determined on a total of three pots of dry substrate per treatment including the control prior to and after combination with the CPB. Substrates were leached 10 times before planting and then leachates were collected weekly from four pots per treatment until terminating the experiment using the Virginia Tech Pour Thru Method [32]. Growth indices (in cm) ((height + widest width + width perpendicular to the first)/3) were measured 14, 31, and 50 days after transplanting (DAT). Leaf chlorophyll content was quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) at 31 and 50 DAT for Australian sword fern and Gerbera daisies. General health and growth vigor was assessed the day of termination (50 DAT) using a scale varying from 1 to 7 depending on the species, where 1 was assigned to plants with the poorest growth and color, and 7 was assigned to plants with the greatest growth, vigor and healthy color. Consumer preference was evaluated by use of a survey. Twelve plants were selected from each species, (one plant from each substrate and fertilizer combination),and were presented to the public with instructions to choose at least one or not more than three plants from each species that they would consider purchasing at a retail location (or none if they would not purchase). The survey ran for 3 days and had 46 participants. An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The Gaussian distribution was used for all responses except consumer preferences where the multinomial

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distribution was used. Where residual plots and a significant covariance test for homogeneity indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity in Gaussian data. Least square means comparisons among treatments and comparisons of treatments to the control were determined using the simulated method. Least squares mean group comparisons of all FDG versus no FDG and high FDG versus low FDG were determined using the simulated method. Differences among treatments of consumer preferences were estimated. All significances were at α=0.05 [33,34].

Results

Consumer preference

Production of marketable plants is the real verification of suitable cultural practices, therefore this discussion begins with the consumer preference results and relates data collected about the plants grown in substrates with and without gypsum to the ratings.

In general, the survey revealed that FGDG and fertilizer were important substrate components in producing ferns the survey participants said they would purchase. For both fern species, treatment "C", (the substrate that began as 100% FGDG in the broiler study), was one of the top two plants chosen for potential purchase in the survey (Tables 1-4). Treatment "C" for the Australian sword ferns received 31 "yes" votes (out of 121). Treatment "C" for the Japanese painted ferns received 38 "yes" votes (out of 94). The other top substrate for the Australian sword ferns was treatment "D" (which began as 100% pine bark in the broiler study), which received 36 "yes" votes (out of 121). The Japanese painted fern in the control treatment consisting of 1:1CPB+ Fafard 3B potting mix received 37 "yes" votes (out of 94). The top two treatments for each fern species were statistically equal. The two substrates other than the gypsum, were pine bark based, either 50% or 100% which currently is an industry standard. Among the 94 "yes" votes for Japanese painted ferns, the top two rated far above any other substrates. The Australian sword fern had 19 votes given to treatment "E" (50:50 FGDG: PB from the broiler study) and 11 "yes" votes for treatment "B" (50:50 PS:FGDG from the broiler study) out of the 121 "yes" votes. A possible reason for the success of the plants could be that both "B" and "E" treatments contained gypsum as well, (as did treatment "C" that began as 100% gypsum and was a top vote getter) (Tables 1-4).

Table 1: Consumer preferences and leachate readings at termination for Australian Sword in six substrates.

	Consumer Preference[z]		Rating[y] Substrate	Dry Weight[x] Substrate	Hieght[w]	Spad[v]		Size[u]		
	Fertilized				Fertilized	Fertilized		Fertilize x days		
Substrate[t]	No	Yes			Yes	No	yes			
A	2d	5cd[S]	4.0abc	4.0ab	14.1ns	35.1abB*	47.9nsA			Fertiliszed
B		11bc	5.0a*r	4.5ab	14.9A	38.5aB*	49.6A	Days	No	Yes
C	1d	31a	4.0bc	3.7b	14.5	26.9bcB	44.5A	14	18.8ns	18.9
D	8cd	36a	5.0a	5.3a	14.1	31.5abcB*	51.8A	31	18.9b	20.1a
E	19b	0d	5.0ab*	3.5b	14.1	23.9cB	46.2A	50	20.4b	25.0a
Control	2d	6cd	3.5c	3.4b	14.8A	23.9cB	49.8A	sign.[q]	L**	Q**
With Fertilizer										
All gyspum			4.0ns[p]	3.9ns	14.5ns		46.7ns			
No gypsum			4	4.6	14.1		49.8			
50% gysum			4.5ns	4.0ns	14.5ns		47.9ns			
100% gypsum			4	3.7	14.5ns		44.5			
Fertilizer										
No			3.0b	3.0b						
Yes			5.0a	5.4a						

zThe consumer preference Survey had 41 participants

yReported are medians for rating

xOnly the substrate and fertilizer main effects were significant at a=0.05.

wThe Substrate by fertilizer Interaction was significant at α=0.05.

vOnly the substrate by fertilizer interaction and the days after planting main effect were significant at α=0.05.

tA=1:1 Pine Shhavings/crushed pine dark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB+CM, C=1:1 Gypsum/CPB+CM,

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D=1:1PB/CPB+CM, E=1:1 Gypsum/PB to 2 CPB+CM, Control= 1:1 Crushed Pine Bark/Fafard 3B Plotting Mix.

SLeast Squares means comparisions between substrates (Lower acse inrows) using the stimulated method at s=0.05, ns=not significant.

rLeast Squares means followed by an asterisk were significantly different from the control using the stimulated method at α=0.05.

Table 2: Consumer preferences[z] and leachate readings[y] at termination of Australian Sword ferns grown in six substrates[x].

	Consumer Preferences[z]		pH[y]		EC[x]		Ca ppm[w]	P ppm[v]	
	Fertilized		Fertilized		Fertilized		Fertilzer x Substrate = Not Significant	Fertilized	
Substrate[u]	No	Yes	No	Yes	No	Yes		No	Yes
A	2d	5cdt	7.50aA*s	6.62abB	0.42bB	0.92cA	82.0bc*	43.4aB*	109.4aA*
B		11bc	7.40abNS	7.16a*	2.08aB*	2.45abA*	564.3a*	9.7bNS*	14.1cff
C	1d	31a	6.56cNS	6.49ab	2.08aNS*	2.14b*	581.5a*	16.9bB*	36.8bA
D	8cd	36a	7.26abA	6.02bcB	0.47bB	1.04cA	105.2b*	60.5aB*	135.8aA*
E	19b	0d	7.52aA*	7.02aB	2.20aB*	2.54aA*	623.0a*	8.3bNS*	29.6b
Control	2d	6cd	7.07bA	5.63cB	0.21bB	0.79cA	28.2c	0.8cB	45.8bA
With fertilizer									
All gypsum				6.89a[r]		2.4a		589.6a	26.8b
No gypsum				6.32b		1.0b		93.6b	122.6a
50% gypsum				7.09a		2.5a		593.7ns	21.8b
100% gypsum				6.49 b		2.1 b		581.5	36.8 a

zThe Consumer Preferences Survey had 46 participants.

yThe substrate by fertilizer interaction was significant at α=0.05.

xThe substrate by fertilizer interaction was significant at α=0.05.

wOnly the substrate and fertiizer main effects were significant at a=0.05.

vThe substrate by fertilizer interaction was significant at α=0.05.

uSubstrates: A=1:1 Pine shavings/crushed pine bark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB + CM, C=1:1 Gypsum/CPB+CM, D=1:1 PB/CPB + CM, E=1:1 Gypsum/PB to 2 CPB + CM, Control=1:1 Crushed Pine Bark/Fafard B Potting Mix.

tLeast squares means comparisons between fertilizers (lower case in rows) using the simulated method at α=0.05, ns=not significant.

sLeast squares means followed by an asterisk were significantly different from the control using the simulated method at α=0.05.

rLeast squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α=0.05. ns=not significant.

Table 3: Consumer preferences and leachate readings at termination of Japanese Painted ferns grown in six substrates.

	Consumer Preferencez		Ratingy		Dry Weightx		Heightw				Sizev					
	Fertilized		Fertilized		Fertilized		Fertilized			Fertilized			Fertilizer x Days			
Substrate	No	Yes	No	Yes	No	Yes	No	Yes	Fertilizer/Height		No	Yes				
A	1nsB	5bA[t]	3.0nsNS	3.0c*s	1.2aNS*	0.9ns	14.7aA*	12.5abB			16.2aNS*	15.7ab			Fertilized	
B	1nsB	1bc	3.0NS	4.5b*	0.3bB	0.9A	12.1bNS	12.9a	Days	Yes	14.8abNS	15.7ab		Days	No	Yes
C	3B	38aA	3.0B	7.0aA	0.6abB	1.6A	12.0bNS	10.4b	14	13.9	14.1bNS	15.1ab		14	15.9NS	16
D	4NS	1bc	4.0NS	4.5b*	0.6abNS	1	11.1bNS	11.4ab	31	12.4	13.4bNS	14.8b		31	14.5B	15.8A
E	1nsB	0c	3.5NS	5.0b	0.5bB	1.2A	12.2bNS	12.4ab	50	10.1	14.2abB	16.8aA		50	13.0B	15.5A
Control	2B	37aA	3.5B	7.0aA	0.6abB	1.6A	11.5bNS	12.5abB	Sign.r	L***	14.1bB	16.3abA	Sign.		L***	NS
With fertilizer																
All gypsum				4.5a[q]		1.2ns		11.9ns				15.9ns				

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No gypsum				3.5b		1.0		11.9				15.3				
50% gypsum				4.5b		1.0ns		12.6a				16.3ns				
100% gypsum				7.0a		1.6		10.4b				15.1				
[z]The Consumer Preference Survey had 46 participants.																
[y]Reported are medians for rating.																
[x]The substrate by fertilizer interaction was significant at α = 0.05.																
[w]Only the substrate by fertilizer interaction and the days after planting main effect were significant at α=0.05.																
[v]Only the substrate by fertilizer interaction and the days after planting main effect were significant at α= 0.05.																
[u]A=1:1 Pine shavings/crushed pine bark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB + CM, C=1:1 Gypsum/CPB +CM,																
D=1:1 PB/CPB + CM, E=1:1 Gypsum/PB to 2 CPB + CM, Control=1:1 Crushed Pine Bark/Fafard 3B Potting Mix.																
[t]Least squares means comparisons between fertilizers (lower case in rows) using the simulated method at α=0.05, ns=not significant.																
[s]Least squares means followed by an asterisk were significantly different from the control using the simulated method at α=0.05.																
[r]Not significant (NS) or significant linear (L) trend using model regressions at α=0.001 (***).																
[q]Least squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α=0.05. ns=not significant.																

Table 4: Consumer preference and leachate readings at termination of Japanese Painted ferns grown in six substrates.

	Consumer Preferencez		pHy		ECx		Ca ppmw		P ppmv	
	Fertilized		Fertilized		Fertilized		Fertilized		Fertilized	
Substrateu	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
A	1nsB	5bAt	7.43nsA	6.60abB	0.42bB	1.01cA*	45.2bB*	106.3bA*	57.3bB*	125.9aA*
B	1nsB	1bc	7.21A	6.96aB	1.86aB*s	2.45aA*	460.3aB*	639.7bA*	10.7dNS*	18.3b
C	3B	38aA	7.16NS	6.04bc	2.01aNS*	2.05b*	691.8aNS*	763.0a*	19.3cB*	50.1bA
D	4NS	1bc	7.26A	6.52abB	0.55bB	1.24cA*	75.3bNS*	147.8b	68.2aB*	132.6aA*
E	1nsB	0c	7.16A	6.40bB	2.08aB*	2.61aA*	685.6aNS*	736.4a*	9.8dNS*	25.4b
Control	2B	37aA	7.09A	5.70cB	0.21bB	0.67dA	14.9cB	35.2bA	1.7eB	40.0bA
With fertilizer										
All gypsum				6.5nsr		2.4a		713.0a		31.3b
No gypsum				6.6		1.1b		127.1b		129.3a
50% gypsum				6.7		2.5a		688.0ns		21.9b
100% gypsum				6		2.1b		763		50.1a
[z]The Consumer Preference Survey had 46 participants.										
[y]The substrate by fertilizer interaction was significant at α=0.05.										
[x]The substrate by fertilizer interaction was significant at α=0.05.										
[w]The substrate by fertilizer interaction was significant at α=0.05.										
[v]The substrate by fertilizer interaction was significant at α=0.05.										
[t]Least squares means comparisons among substrates (lower case in rows) using the simulated method at α=0.05, ns=not significant.										
[s]Least squares means followed by an asterisk were significantly different from the control using the simulated method at α = 0.05.										
[r]Least squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α= 0.05. n=not significant.										

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Gerbera daisy plants that received the most "yes" votes were those that received fertilizer, which was true for the other species (Tables 5-6). However, different from the ferns, treatment "C" (100% gypsum) received no votes. The top three were Treatments "B", "D" and "F" (control). The top performing treatment was the control that had no gypsum (received 41 out of 108 votes), the second was treatment "B" that contained 50% gypsum (originally) (received 31 out of 108 votes), and treatment "D" that was 100% pine bark (originally) (received 24 votes out of 108). Gerbera daisy performed best either without any gypsum, or only up to 25% (originally 50% gypsum from the broiler study) in the substrate. Each species had a potential of receiving 135 "yes" votes. Gerbera daisy received 108 "yes" votes in the survey, Australian sword ferns received 121, and Japanese Painted ferns received 94 "yes" votes.

Table 5: Consumer preferences and leachate readings at termination of Gerbera Daisies grown in six substrates.

	Consumer Preferencez		Heighty						Sizex						Dry Weightw	
	Fertilized		Fertilized						Fertilized						Fertilized	
Substratev	No	Yes	No	Yes					No	Yes					No	Yes
A	0nsB	7dAu	9.8abNS	10.1b*t	Fertilizer/Height				16.9abNS*	17.3ab	Fertilizer/Size				2.3abB*	4.5abA
B	1B	31bA	10.4aNA*	11.0ab	Days		No	Yes	18.0aNS*	17.3ab		Days	No	Yes	3.1aNS*	3.8ab*
C	2NS	0e	9.4abB	11.1abA		14	11.5NS	12.1	15.9bcNS*	16.6b*		14	16.1NS	15.5	1.4bB*	3.0bA*
D	0B	24Ac	10.0abNS	10.8ab		31	9.1NS	9.6	16.8abNS*	17.8ab		31	16.1NS	16.9	2.6aB*	4.9abA
E	0NS	1de	8.3bB	10.0bA		50	7.7B	11.1A	14.9adB	17.3abA		50	15.9B	20.4A	2.0abB*	4.1abA
Ctrl	1B	41aA	8.4bB	12.7aA	Sign.s		L***	Q***	13.7dB	19.2aA	Sign.		NS	L***	0.6cB	6.6aA
With fertilizer																
All gypsum				10.7nsr						17.1ns						3.6ns
No gypsum				10.5						17.6						4.7
50% gypsum				10.5ns						17.4ns						4.0ns
100% gypsum				11.1						16.6						3

zThe Consumer Preference Survey had 46 participants.

yOnly the substrate by fertilizer and fertilizer by days after planting interactions were significant at α=0.05.

xOnly the substrate by fertilizer and fertilizer by days after planting interactions were significant at α=0.05.

wThe substrate by fertilizer interaction was significant at α=0.05.

vA=1:1 Pine shavings/crushed pine bark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB + CM, C=1:1 Gypsum/CPB+CM, D=1:1 PB/CPB + CM, E=1:1 Gypsum/PB to 2 CPB + CM, Control=1:1 Crushed Pine Bark/Fafard 3B Potting Mix

uLeast squares means comparisons between fertilizers (lower case in rows) using the simulated method at α=0.05, ns=not significant.

tLeast squares means followed by an asterisk were significantly different from the control using the simulated method at α=0.05.

sSignificant linear (L) or quadratic (Q) trends using model regressions at α=0.001 (***).

rLeast squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α=0.05. ns=not significant.

Table 6: Consumer preferences and leachate readings of Grbera Daisies at termination in six substrates.

	Consumer Preferencez		Ratingy		Spadx	
	Fertilized		Fertilized		Fertilized	
Substratew	No	Yes	No	Yes	No	Yes
A	0nsB	7dAv	4.0aNS	2.0b*	29.6bcB	36.2bcA*
B	1B	31bA	4.5aNS*u	2.5b*	33.9abNS*	38.7bc*
C	2NS	0e	1.0bB	3.5abA	29.9bcB*	43.5abA
D	0B	24Ac	2.0bB	5.0aA	36.5aNS*	40.7abc
E	0NS	1de	2.0bNS	2.0b*	30.3abcNS	33.5c*
Ctrl	1B	41aA	1.0bB	6.0aA	26.6cB	47.9aA
With fertilizer						
All gypsum				3.0nst		38.6ns
No gypsum				4		38.5

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50% gypsum				3.0ns		36.1b
100% gypsum				3.5		43.5a
[z]The Consumer Preference Survey had 46 participants.						
[y]Reported are medians for rating.						
[z]The substrate by fertilizer interaction was significant at α=0.05.						
[w]A=1:1 Pine shavings/crushed pine bark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB + CM, C=1:1 Gypsum/CPB+CM,						
D=1:1 PB/CPB + CM, E=1:1 Gypsum/PB to 2 CPB + CM, Control=1:1 Crushed Pine Bark/Fafard 3B Potting Mix						
[v]Least squares means comparisons among substrates (lower case in rows) using the simulated method at α=0.05, ns=not significant.						
[u]Least squares means followed by an asterisk were significantly different from the control using the simulated method at α=0.05.						
[t]Least squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α=0.05. ns=not significant.						

Plant dry weight

In all three species, fertilizer and substrate determined plant dry weights, and gypsum was not important. For Japanese painted ferns (Table 3) and Gerbera daisy (Table 5), the interaction between substrate and fertilizer was significant, but not for Australian sword ferns. The substrate and the fertilizer were the significant main effects on dry weight for Australian sword ferns (Table 1).

Australian sword ferns

The interaction between substrate and fertilizer was not significant, but both were significant main effects. The least squares mean of plants not fertilized was 3.0g and those fertilized was 5.4g. Substrates with the highest dry weights were "A"- 4.0g (1:1 PS:CPB), "B"- 4.5g (1:1:2 PS:G:CPB), and "D"- 5.3g (1:1 PB:CPB) and were statistically the same. However, the other three treatments "C" (1:1FGDG:CPB), "E" (1:1:2FGDG:PB:CPB) and the control (1:1 PB: Fafard 3B) were not far behind (3.4 to 3.7g) and were statistically the same, which included the control (Table 1).

Japanese painted ferns

The interaction between substrate and fertilizer was significant. Substrates "B" (1:1:2 FGDG:PS:CPB), "C" (1:1FGDG:CPB), "E"(1:1:2 FGDG:PB:CPB) and the control (1:1 CPB:Fafard3B) had an increase in dry weight with fertilizer but were statistically the same (0.9 to 1.6g). Substrate "C" and the control were both 1.6 g. Interestingly, substrate A (1:1 PS:CPB) had a greater dry weight without fertilizer and the substrate E did not have a significant increase with fertilizer (Table 3).

Gerbera daisies

There was a significant interaction between substrate and fertilizer and no significant benefit from gypsum. Plants in all treatments increased in dry weight from receiving fertilizer. Dry weights for all treatments except "C" were statistically the same, ranging from 3.8 to 4.9g with the control at 6.6g. Treatment "C" had slightly less dry weight of 3.0g. Therefore, the biggest gain was in the control and the least in "C" (Table 5).

All species and treatments performed best with fertilizer with one exception; where Japanese painted ferns, showed no increase in dry weight with fertilizer for treatment "A" (1:1 PS:CPB). Also, for all three species gypsum had no significant effect on dry weight of plants that received fertilizer. The two species that had an interaction between substrate and fertilizer were Gerbera daisy and Japanese painted ferns, which suggest that plants receiving fertilizer, regardless of which substrates were used would more increase in dry weight.

Size (Table 1,3&5)

Australian sword ferns

There were no significant interactions for plant size. Overall, all plants receiving fertilizer were significantly larger than those not receiving fertilizer on each day after transplanting that measurements were taken (Table 1).

Japanese painted ferns

Interactions between substrate and fertilizer at each measurement date were significant. All substrates were statistically the same with fertilizer except for "D" (1:1 PB:CPB) which was a bit smaller. Without fertilizer, substrates "A", "B", and "E" were statistically the same, and "C", "D", and "F" (control) were the same. For substrates "A", "B", "C", and "D" the difference in size between those fertilized and those that were not was not significant. Only substrates "E" and control were significantly different, and those fertilized were significantly larger in size (Table 3).

Gerbera daisy

Interaction between substrate and fertilizer was significant as well as the interaction between fertilizer and date of measurement. Overall, plants that were not fertilized had no significant change in size, but those that were fertilized had significant increases in size progressively and consistently from day 14 to day 50. Similar to the Japanese painted ferns, substrates "A", "B", "C", and "D" with and without fertilizer were not different. However, like the Japanese painted ferns, substrates "E" and control that were fertilized were significantly larger than those that were not fertilized (Table 5).

SPAD

Both Australian sword ferns and Gerbera daisy had significant interactions between substrate and fertilizer, and SPAD Values for Gerbera daisy were also different between substrates that had 25% vs. 50% gypsum.

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Australian sword ferns

In general, SPAD readings increased over time. The difference between Day 31 (38.7) and Day 50(42.1) was significantly higher. The interactions between substrate and fertilizer indicate that all substrates increased in chlorophyll content with fertilization. Substrates "A", "B", "D" and "E" without fertilizer were significantly different from the control (in this case, the control had a much lower reading. Substrate C (50% gypsum) and the control increased with fertilizer (almost double). The differences between substrates that had 25%, 50% or no gypsum were not statistically different (Table 1).

Gerbera daisy

Interactions between substrate and fertilizer were significant and there were significant differences between substrates with 25% and 50% gypsum (Table 5). Substrates "A" (1:1 PS: CPB), C and the control were significantly higher with fertilizer, however, the SPAD readings for substrates "B" (1:1:2 G:PS:CPB), "D" and "E" were not significantly different or increased with fertilizer. The substrates with 50% gypsum were not significantly different from those with no gypsum, however, the difference between 25% gypsum (36.1) vs. 50% gypsum (43.5) was significant and higher with more gypsum.

pH

All three species of plants had a significant interaction between substrate and fertilizer in regards to pH. With only one exception, all substrates for all species had a higher than recommended pH without fertilizer, including the industry standard control. The one exception was the substrate "C" (1:1 FGDG: CPB) for the Australian sword ferns that was within BMP range both with and without fertilizer (without fertilizer: pH of 6.56 and with fertilizer: pH of 6.49) (SNA, 2013). The pH decreased in all plants for all substrates and all species that were fertilized. The only substrate that was consistently within the recommended pH range for all species was the control (1:1 PB: Fafard 3B) only when it received fertilizer. Without fertilizer, the control was above recommended range, the same as the other substrates.

Australian sword fern

Ph for three substrates fell into recommended levels after fertilizing: "C" (1:1FGDG: CPB 6.49), "D" (1:1 PB: CPB 6.02), and control (1:1CPB:Fafard3B 5.63). The data indicated two of the substrates with gypsum (that received fertilizer) were both statistically significant (Table 2).

Japanese painted ferns

Among fertilized substrates, there was no statistical difference with or without gypsum (of any amount) (Table 4).

Gerbera daisy

Only the control substrate with fertilizer decreased in pH to an acceptable recommended level (5.63). All other fertilized substrates ranged between 6.66 to 7.27 pH (Table 7).

Table 7: Consumer preferences and leachate readings at termination of Gerbera Daisies grown in six substrates.

	Consumer Preference[z]		pH[y]		EC[x]		Ca ppmw	P ppmv	
	Fertilized		Fertilized		Fertilized			Fertilized	
Substrateu	No	Yes	No	Yes	No	Yes		No	Yes
A	0nsB	7dAt	7.75aA*s	6.75bB*	0.39aB*	1.00bA	74.72bc	51.27a*	131.70a*
B	1B	31bA	7.36bcNS*	7.27a*	2.05abB*	2.36aA*	637.64a*	12.28b*	12.82d*
C	2NS	0e	7.03cNS	6.78b*	1.92bB*	2.33aA*	652.42a*	15.68b*	40.90c
D	0B	24Ac	7.38abcA*	6.66bB*	0.40cB*	1.03bA*	91.38b*	55.74a*	115.48ab*
E	0NS	1de	7.41abA*	7.17aB*	2.08aNS*	2.20a*	686.26a*	10.00b*	10.71d*
Control	1B	41aA	6.81cA	5.63cB	0.19dB	0.61bA	34.11c	0.49c	71.54bc
With fertilizer									
All gypsum				7.07ar		2.30a	658.8a		21.5b
No gypsum				6.71b		1.01b	83.1b		123.6a
50% gypsum				7.22a		2.28ns	661.2ns		11.8b
100% gypsum				6.78b		2.3	652.4		40.9a

[z]The Consumer Preference Survey had 46 participants.

[y]The substrate by fertilizer interaction was significant at α=0.05.

[x]The substrate by fertilizer interaction was significant at α=0.05.

[w]The substrate by fertilizer interaction was significant at α=0.05.

[v]The substrate by fertilizer interaction was significant at α=0.05.

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uA=1:1 Pine shavings/crushed pine bark (and chicken manure), B=1:1 PS/Gypsum to 2 CPB + CM, C=1:1 Gypsum/CPB+CM,
D=1:1 PB/CPB + CM, E=1:1 Gypsum/PB to 2 CPB + CM, Control=1:1 Crushed Pine Bark/Fafard 3B Potting Mix
[t]Least squares means comparisons among substrates (lower case in rows) using the simulated method at α=0.05, ns=not significant.
[s]Least squares means followed by an asterisk were significantly different from the control using the simulated method at α=0.05.
[r]Least squares means comparisons among selected substrate groups receiving fertilizer using the simulated method at α=0.05. ns=not significant.

Data for all substrates had a higher than recommended pH without fertilizer and all substrates had a decrease in pH where fertilizer was used. However, there was a wide range of results in the number of substrates that fall into an acceptable level (with fertilizer use) among the three species of plants used in this research. Gerbera daisy did not have any substrate except the control that fell into an acceptable level of pH (after fertilizing), but Australian sword ferns had three substrates that decreased to an acceptable range, and Japanese painted ferns had four.

EC

The sufficiency range for EC for ferns at 1.5-2.0mmhos/cm (per Casa Flora recommendations) is different from Gerbera daisy, at 1.2-1.5mmhos/cm (2:1 extraction method). For all three species of plants, there was a significant interaction between substrate and fertilizer, and data indicated that fertilizer increased the EC for all substrates within all three species. This increase was not a benefit; none of the fertilized plants were within recommended ranges and only one substrate (1:1:2 PS: FGDG: CPB) of the Japanese painted ferns was within range (1.86 EC), and this was without fertilizer.

Gerbera daisy

Did not have one substrate (fertilizer or not) fall within the recommended range. The industry standard represented by the control had a 0.61 EC reading and the rest had a 1.00 or close to 2.36 value (desired range: 1.2-1.5). Interestingly, the three plants chosen as the best plants in the consumer survey were substrates with fertilizer: "B" (2.36), "D" (1.03) and "F" (control) (0.61) with three different EC levels, none of which were within BMP recommendations. Gypsum evaluations indicated that fertilized substrates without gypsum (1.01ECmmhos/cm) were closer to BMP recommendations than the substrates with gypsum (range of 2.28-2.33mmhos/cm).

Australian sword ferns

Have a recommended EC sufficiency range of 1.5-2.0mmhos/cm (per Casa Flora). Here, there was a wide range of results from 0.21mmhos/cm without fertilizer in the control representing the industry standard, with an increase to 0.79mmhos/cm with fertilizer, to 2.54mmhos/cm for substrate "E" (1:1:2 FGDG: PB: CPB) with fertilizer. The closest to BMP values were substrates "B" (1:1:2 FGDG: PS: CPB) at 2.08mmhos/cm without fertilizer, and "C" (1:1 FGDG: CPB) both without (2.08mmhos/cm) and with fertilizer (2.14mmhos/cm), which is very close to their commended range (1.5-2.0mmhos/cm) (Table 2). Substrate "C" (1:1 FGDG: CPB) also was one of the top two Australian sword fern plants chosen in the consumer preference survey.

Japanese painted ferns

Had almost the exact EC value results as the Australian sword ferns. Substrate "B" (1:1:2 G:PS:CPB) without fertilizer was within range (1.86mmhos/cm), and substrate "C" (1:1 FGDG:CPB) with (2.05mmhos/cm) and without fertilizer (2.01mmhos/cm) were both close to the preferred BMP EC range (1.5-2.0mmhos/cm) (Table 4). Here too, besides, the control, substrate "C" was one of the two top Japanese painted ferns to receive "Yes" votes in the Consumer Preference Survey as did substrate "C" for the Australian sword ferns).

Calcium (Ca)

For all three species, there was a significant difference between substrates with no gypsum compared to the substrates that had some gypsum. For the Australian sword ferns and Gerbera daisy, the substrate was a significant main effect, but for the Japanese painted ferns, the interaction between the substrate and fertilizer was statistically significant.

Australian sword ferns

The substrate was a main effect. Substrates that contained gypsum had the highest Ca ("B", "C" and "E") and were statistically the same with a range of 564-623ppm. Calcium levels in substrates "A" and "D" were statistically the same (82-105ppm) and the control was the lowest at 28.2ppm. The difference between substrates with 25% vs. 50% gypsum was not significant, but the substrates with any amount of gypsum had the highest amount of Ca (589.6ppm) vs. substrates without any gypsum averaged 28.2ppm. Interestingly, one of the top substrates in the Consumer Preference Survey for Australian sword ferns was substrate "C" which originated as 100% gypsum This suggests that any amount of gypsum in the substrate would benefit this species. It also demonstrates that substrate "C" with 50% gypsum would be a viable alternative to one of the industry standards, which is substrate "D", which consists of all pine bark (plus PL) (Table 2).

Japanese painted ferns

The interaction between substrate and fertilizer was statistically significant. Ca levels in "A", "B" and "F" were statistically the same and were significantly increased by fertilizer. Ca levels in substrates "C", "D" and "E" were not significantly increased with fertilizer. The results between the two substrates with 25% gypsum vs. 50% gypsum were not significant. However, the difference between the substrates that had some gypsum vs. none was significant. The substrates that had gypsum averaged 713ppm and those without any gypsum

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averaged 127.1ppm. Substrate "C" had 763.0ppm with fertilizer, but the control only had 35.2ppm with fertilizer. The ideal range is 10-15ppm; they both meet that minimum criterion (Table 4).

Gerbera daisy

Substrate was a main effect, and the difference between substrates with some gypsum or none was significant as well. Ca levels in substrates "B", "C" and "E" were statistically the same, having a range of 652-686ppm. Substrates with no gypsum ranged from 34-91ppmCa. The results between the two substrates with 25% gypsum (661ppm) vs. 50% gypsum (652ppm) were not different (Table 7).

Phosphorus (P)

All three species had a statistically significant interaction between substrate and fertilizer. All three species had increased P with fertilizer, but for all three, the P increases for substrates "B" and "E" were not significant. In addition, P in all three species was different between treatments containing gypsum and those with no gypsum. P was also different between the two substrates with 25% vs. 50% gypsum.

Australian sword ferns

Substrate x fertilizer interactions was statistically significant with all substrates increasing in P with fertilizer, even though substrate B and E increases were not significant (Table 2). Also, substrates "A" and "E" with fertilizer were statistically the same and were the highest (109.4-135.8ppm), compared to the control with fertilizer (45.8ppm), "B" with fertilizer (14.1ppm) and "E" with fertilizer (29.6ppm). In the case of phosphorus, more is not always better (as in most nutrients) and when comparing no gypsum to some gypsum in the substrate, the gypsum reduced the amount of phosphorus could be a helpful benefit if trying to limit excess P runoff by binding with Ca.

Japanese painted ferns

The substrate x fertilizer interactions was significant. Just like in the other two species, P in all substrates increased with fertilizer but the difference in substrate "B" and "E" were not significant. The results from treatments containing gypsum compared with no-gypsum and the two 25% gypsum treatments compared with 50% gypsum treatments were almost identical to those of the Australian sword ferns (Table 4). The statistically significant reading is much higher, again, indicating the usefulness of calcium in binding with excess phosphorus.

Gerbera daisy

The results for Gerbera dasies were similar to the other two species. The substrate x fertilizer interaction was statistically significant. P in all substrates increased with fertilizer with substrates "B" and "E" not significant. Leachates from substrates containing gypsum had the lowest amounts of P indicating the binding capacity of the Ca from gypsum. Substrates "A" and "D" which contained no gypsum had the highest P (Table 7).

Final Discussion

The Consumer Preference Survey was a useful tool in discerning the value of substrates as a potential alternative substrate. It should be noted that all top vote earners had been fertilized. For Australian sword ferns and Japanese painted ferns, the substrates with gypsum or those grown in the industry standard of PB:Fafard 3B received the most votes. For Gerbera daisy, "F" (the control) received the top votes (41), with the second level of votes (31) going to substrate "B" (25% gypsum). However, surprisingly, substrate "C" (originating from 100% gypsum poultry bedding) did not receive any votes for Gerbera daisy. Therefore, from this, substrate "C" would not be recommended for Gerbera daisy, but could be used as an alternative substrate for both Australian sword ferns and Japanese painted ferns if the economics and availability worked out to the grower's advantage.

Phosphorus did not seem to correlate with success in the Consumer Preference Survey but substrate x fertilizer interaction proved significant in how much P was available. This is significant in light of the green industry's ever present concern about environmental impact and water quality. P increased in all substrates when fertilized, however, the greatest increase in P were the substrates with no gypsum, indicating that Cain the gypsum served to bind P, thereby decreasing leachable P. However, not all P was bound, and all substrates retained sufficient P for the needs of the plant. The evidence of the benefit of Ca can be seen in the Consumer Preference Survey as well where substrates with gypsum consistently received the most number of votes, along with the two substrates that are already industry standards (PB:Fafard 3B and 100% PB).In addition, the substrates with gypsum flocculated, forming aggregates, which facilitated drainage. Poor or slow drainage was an issue for other substrates, and the growth and performance in these substrates was not as strong.

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