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Recycling for Sustainability: Plant Growth Media from Coal Combustion Products, Biosolids and Compost

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***Abstract*—**Generation of electricity from coal has increased over the years in the United States and around the world. Burning of coal results in annual production of upwards of 100 millions tons (United States only) of coal combustion products (CCPs). Only about a third of these products are being used to create new products while the remainder goes to landfills. Application of CCPs mixed with composted organic materials onto soil can improve the soil's physico-chemical conditions and provide essential plant nutritients. Our objective was to create plant growth media utilizing CCPs and compost in way which maximizes the use of these products and, at the same time, maintain good plant growth. Media were formulated by adding composted organic matter (COM) to CCPs at ratios ranging from 2:8 to 8:2 (v/v). The quality of these media was evaluated by measuring their physical and chemical properties and their effect on plant growth. We tested the media by 1) measuring their physical and chemical properties and 2) the growth of three plant species in the experimental media: wheat (*Triticum sativum)*, tomato (*Lycopersicum esculentum)* and marigold (*Tagetes patula*). We achieved significantly ($p < 0.001$) higher growth (7-130%) in the experimental media containing CCPs compared to a commercial mix. The experimental media supplied adequate plant nutrition as no fertilization was provided during the experiment. Based on the results, we recommend the use of CCPs and composts for the creation of plant growth media.

***Keywords*—**Coal ash, FGD gypsum, organic compost, and plant growth media.

I. Introduction

ENERGY production from coal has increased over the years with 57 % of the electricity in the United States and more than 40 % of the world's electricity produced by combustion of coal. Burning of coal produces coal combustion products (CCPs). Bottom ash, fly ash, broiler slag, and flue-gas desulfurization (FGD) products are four important CCP materials produced in large quantities. In the United States, 131 million tons of CCPs were produced in 2007, of which around 75 million tons were discarded in landfills. An EPA non-hazardous classification did not increase the recycling and reutilization of CCPs to more than 42%. Present uses of CCPs include constructing roads [6], reclaiming acid mine sites and use in agriculture [15], [31], grouting and sealing abandoned mine shafts, and reducing acid mine drainage [30]. Efforts are being made to find additional innovative uses of CCP materials such as using the CCPs to remove mercury from aqueous solutions, silts and soils [25].

CCPs possess several key soil and agronomic properties that qualify them for use in agriculture and land management processes. Plant nutrients such as Ca, Mg, S and B are present in large amounts in CCPs [32]. Application of CCPs can also create better soil physical and chemical conditions by facilitating water infiltration and soil aggregation, ameliorating sodic soils [7] and reducing phosphorus pollution by preventing phosphorus transport off the field.

Among the different types of CCPs, fly ash, bottom ash and FGD materials have been studied for potential use in agriculture. Fly ash is a very fine powdery material with pozzolanic nature, i.e. cement-like characteristics. Bottom ash, also referred as bed ash, is a granular material with an average diameter of 2 – 3 mm. Bottom ash has been used as a soil amendment and was found to provide plant nutrients, and increase pH, water infiltration and crop yields [8], [23]. Because of the chemical and physical properties of bottom ash, it may be a very good substitute for vermiculitic materials in soilless plant growth media. FGD gypsum is produced when SO_2 is removed from flue gas in power plants. FGD materials contain high amounts of S and, when applied to soil, have been reported to supply the plant's requirements of S and increase productivity [9], [10], [13].

Studies have shown that amending soils with compost can improve many soil physical and chemical properties [17], [19], [22] and provide essential plant nutrients required for growth [26]. Pruning waste (yard trimmings) compost has been used as a raw material for creation of soilless growth media [3].

Use of compost and CCPs, for growing plants, has been investigated by several researchers and both materials were reported to support excellent plant growth. Black et al. [4] tested the use of bottom ash as a substitute for sand in growing highbush blueberry in soil free media and also as a soil amendment. Several other studies reported the possible use of CCP materials for growing plants either mixed with soil or other organic materials [2], [12], [16], [29]. Several compost

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products have been used as a soil amendment or in potting media [2], [21], [28], [35]. Application of compost to soil increases pH, electrical conductivity, cation exchange capacity and nutrient content [26] and also increases natural control of many plant diseases [18].

Traditionally, soilless plant growth media has been prepared from materials such as peat, pine bark, cocoa fiber, perlite, and vermiculite. However, growth media can be prepared from any materials that can provide good physical condition and supply enough nutrients for plant growth. Coal combustion products also have a great potential to be used in production of greenhouse and nursery media. Compost materials and organic wastes, if mixed with CCPs, can provide good physical condition for seed germination and plant growth as well as supply plant nutrients. Most CCPs have alkaline properties while most organic composts are acidic in nature. Growth media prepared by mixing the right proportion of CCPs with organic composts will help provide proper pH characteristics as well as supply essential plant nutrients, thus supporting good plant growth. Recent studies have proposed the use of several waste materials, listed above, as components for creating soilless media to grow plants in greenhouse and nursery conditions such as horticultural wastes [28], biochips, sludge and fly ash [29], pruning waste compost [3], bottom ash and compost [2], [4] and FGD-residues [27].

The objective of the present work was to create soilless greenhouse and container growth media using CCPs and organic composts, in a manner, which maximizes the use of CCPs as well as maintaining economic plant growth. Beneficial re-use of CCPs and organic composts in agriculture and greenhouse industry will help ameliorate the problem of waste disposal and reduce the use of natural resources such as peat [5], which is used as substrate for preparation of soilless plant growing media.

II. Materials and Methods

A. Creation of Experimental Media

We obtained different raw materials from university and industry facilities from around the state of Ohio, USA (Table I). For our experiment fly ash was mixed with spent perlite at the rate of 4% and the mixed product was called perlite. Bottom ash and FGD-gypsum were used as received from the source. For the organic fraction, three different compost materials were obtained from facilities located in Ohio, USA. Leaf compost was manufactured mainly from leaves, twigs and yard clippings at the Kurtz Brothers Composting facility (Groveport, OH).

Biosolids compost, primarily prepared from biosolids mixed with woodchips, was obtained from the Akron Municipal Sludge Treatment plant, (Akron, OH). Cow manure compost was prepared (windrow composting method) from dairy cow manure and sawdust at the Ohio State University-OARDC composting facility (Wooster, OH). Bottom ash and all three composts were sieved through a 2-mm sieve because the particle size ranged from about 1 mm to larger than 5 cm diameter.

After sieving, the materials were mixed in different proportions to prepare the experimental media. All 44 media were prepared [2] by changing the proportions of different materials, based on literature and prior knowledge, from a low of 20% to a high of 80% (v/v) inorganic material. Three media contained garden soil obtained from the OARDC Wooster farm (Wooster silt loam). In ten media, peat was used at a rate from 10 to 20% to supplement the organic fraction of the media.

TABLE I
DIFFERENT RAW MATERIALS OBTAINED FOR CREATION OF EXPERIMENTAL MEDIA AND THE SOURCE AGENCY THEY WERE OBTAINED FROM.

Item	*Source*
Bottom Ash	AEP, Cardinal Plant, Brilliant, Ohio
Fly Ash	Ohio University Power Plant, Athens, Ohio
Spent Perlite	Sorbent Technologies, Akron, Ohio
Gypsum	Cinergy Power Generation, Moscow, Ohio
Biosolids Compost	Akron Municipal Sludge Company, Akron, Ohio
Leaf Compost	Kurtz Brothers, Groveport, Columbus, Ohio
Cow Manure Compost	OARDC Compost facility, Wooster, Ohio
Peat	Premier Horticulture, Quebec, Canada

TABLE II
LIST OF GROWTH MEDIA TESTED USED IN THE PLANT GROWTH EXPERIMENTS.

Media #	*Composition*
* 33	Peat 20%, CMa 35%, Gypsum15%, Bottom Ash 30%
45	50% BA: 50% M
46	30% BA: 70% CM1
47	30% BA: 70% CM2
48	20% CAM: 80 % CM1
49	40% BA: 20% Perlite: 40% CM1
50	40% BA: 20% Gypsum: 40% CM1
51	30% BA: 30% Gypsum: 40% CM3
* 52	20% BA: 40% Gypsum: 40% CM3
* 53	20% BA: 40% Gypsum: 40% CM5
* 54	Peat 15%, CMa 30%, Gypsum 20%, Bottom Ash 35%
* 55	Peat 10%, CMa 30%, Gypsum 25%, Bottom Ash 35%
* 56	Peat 15%, CMa 35%, Gypsum20%, Bottom Ash 30%,
* CT1	MetroMix 360
* CT2	MetroMix 510

*Only wheat was grown in media containing an asterisk during Experiment 2.

Based on the biomass growth measured from the wheat experiment, the five best media were selected and adjustments were made to prepare another eight media (Table II) that we felt would provide even better growth response. By making minor adjustments of media 33, three new media closely related in composition to Media 33 were created. Media 33 was composed of 55 % organic materials and 45 % CCPs. In the three new media, the proportions of organic materials were kept at 40, 45 and 50 % organic materials and the remaining consisted of CCPs. The proportion of CCP was not raised to more than 60% of the total mass of the media because the results from Experiment 1 suggested that economic growth declines above that rate. Media 33 had a bottom ash content of 30 % while among the three new media, two had 35 % and one 30 % bottom ash. Gypsum content in Media 33 was 15 % whereas in these three new media, two had 20 % gypsum and one had 25 %. We selected seven media from the 13 in Experiment 2 for future studies. All tables, from this point on, in this paper have been prepared on those seven best performing media.

B. Media Analysis

The prepared media were analyzed for chemical properties including nutrients and heavy metal concentration. Saturated water extracts method [36] was used for the chemical analysis. Four hundred (400) ml growth media were put in a beaker and water was added slowly, while mixing continuously, until saturated. The substrate was then again mixed with a spatula and left for one hour at room temperature. After one hour a pH electrode was inserted into the beaker and pH recorded. The liquid was then extracted with a vacuum pump by placing the contents in a funnel fitted with filter paper (Whatman 1). Electrical conductivity was measured with an electrode using 2 – 5 ml extract and recorded. Around 30 – 40 ml of extract were transferred into a collection tube and sent to the STAR Laboratory (http://www.oardc.ohio-state.edu/starlab/) at The Ohio Agricultural Research and Development Center, Wooster, OH, USA for complete elemental analysis with an ICP-AES.

The physical properties of the media were measured in Dr. Yona Chen's laboratory in Israel. Selected physical properties (bulk density, particle density, porosity, water content at saturation), hydraulic conductivity and water retention curves were measured [1], [11], [14], [20], [24], [33], and [34]. For the saturated hydraulic conductivity measurements, the media were packed in a glass column (5 cm internal diameter) and saturated with water. The column was left submerged in water for a period of 24 hours. After the substrates were well saturated, measurements were initiated. A Marriot bottle was used to maintain constant head. The outflow volume was measured by collecting the water in a flask and weighing it, using a semi-analytical scale (± 0.01g). The weight of the water was converted into volume. The measurements were conducted at three to five different gradients. At each gradient, five replicates were measured.

The water retention curves were measured using a Sand Box Apparatus model 08.03 manufactured by Eijkelkamp. The substrates were packed in cylinders (42 mm diameter and 50 mm deep). The cylinders were placed on the sand surface while they were at saturation. Suction was gradually created by lowering the hanging-water-column. The media were weighed at every height and only after equilibrium had been reached (i.e. when no significant weight loss was detected between successive weighing) was the suction further increased. The first measurement was conducted when the suction applied was 5 cm and the last one at 100 cm. Zero suction level corresponds to the value of water content at saturation. The saturated water content was considered to be 85% of the porosity of the mixes.

C. Plant Growth Response

For the first screening experiment, pots (1000 cc) were filled with each experimental media leaving about 5 cm of open head space at the top. Wheat (*Triticum sativum*) was used as test plants for our growth experiment. Approximately 16–17 wheat seeds (Arthur 71) were sown in each pot and the pots were watered at a rate of 100–150 ml/pot/day. A commercial product MetroMix 360 (Scotts Brothers, Columbus, OH) was used as a positive control. No fertilization was added to any of the pots for the entire duration of the experiment. The wheat plants were harvested after 30 days by cutting the plants at soil level. The plant tissues were dried at 60 ^{o}C until constant weight and the total biomass produced in each pot recorded.

Three different plant species, i.e. wheat (*Triticum sativum*), tomato (*Lycopersicum esculentum*) and marigold (*Tagetes patula*), were used for the plant growth assay, representing three distinct categories of field crop, fruit crop and flowering plants. These plants were also selected because of their contrasting physiological functions. Tomato is considered tolerant while wheat is very sensitive to boron (B). Tomato and wheat also have different uptake strategies for iron (Fe). The variety of tomato seed used was OH 9242, a bushy type plant. The same variety (Arthur 71), as in Experiment 1, was used for wheat. Seed for a French marigold variety (Marvelous Flame, Park Seeds, SC) was obtained from a seed supply store. Identical procedures were used for sowing the seeds and harvesting the plant tissues as described for Experiment 1. Since wheat was already tested in the initial 44 different media in experiment 1, we used only 6 experimental media for growing wheat during Experiment 2 (Media marked with * in Table II). Another commercial product (MetroMix 510) was added as control to better compare the commercial media with the experimental media.

D. Greenhouse Condition

Two greenhouse pot experiments were carried out to determine the best composition of media for plant growth. The suitability of the media to support plant growth was first evaluated by testing growth of wheat in all 44 media. We tried to maintain a daytime temperature of 25^{o} C (± 5^{o} C) inside the greenhouse at all times during the growing period. Night temperatures usually were between 14 – 21^{o} C. Similar conditions were maintained for the plant growth assay.

E. Experimental Design and Data Analysis:

The experiments were done using a statistical block design and four replicates for each media. In total there were 45 soilless growth media (44 experimental media + commercial product) and 180 total pots. The pots were placed on two greenhouse benches, each holding 2 blocks (i.e. 90 pots).

The biomass weights obtained from each pot were analyzed statistically using SAS (SAS Institute) and Minitab statistical software while the graphs were generated by with Sigma Plot 9.0. Assumption of homogeneity of variance was tested using Levene's test. The PROC-GLM procedure was used to do the analysis of variance (ANOVA). Comparison of media, at a predetermined level of significance (p<0.05) was done using the least significant difference (LSD) method. (SAS Institute). Letters are significantly different (p<0.05).

III. Results And Discussion

A. Physical and Chemical Properties of The Media

The texture of the prepared media depended on the composition of the various materials used. Even after sieving through a 2 mm sieve, media that contained high bottom ash had a lower bulk density (Table III) probably due to the rather large granular particles of bottom ash. When water was applied for the first time in such media, there was very little settling or compaction observed against the rim of the container. Media with high amount of bottom ash also drained quickly compared to other media, giving an impression that they contained more air space and less water holding capacity (WHC) when compared to media containing FGD-gypsum or perlite.

In contrast, after the first application of water, media containing perlite and gypsum settled downwards from the rim of the container and packed more tightly compared to the media containing bottom ash. Such media formed a crust and became dense and hard. The small particle size of fly ash and spent perlite led to the particles filling pore spaces in the media.

The physical properties differed among the experimental soilless media. The commercial product, MM 360, had markedly different physical properties than the other media (Table III). Bulk density of MM 360 was very low (0.17 gm/cm^3) in comparison to other media.

Comparatively, MM360 had a lower particle density, higher porosity and more water content at saturation. The difference in the physical properties can be attributed to the wide variety of materials used to create the media and also the ratios in which they were incorporated. Bottom ash granules, when used in a media, created more pore space in comparison to the other two CCP materials.

As expected from Darcy's law, the saturated hydraulic conductivity (Ks) was found to be almost the same for all gradients, provided the media were completely saturated. Hydraulic gradient influences the driving force for water movement and, is defined as the difference in total hydraulic head per unit distance, or in other words, the water head maintained at the top of the column. One of the most important factors for a good container media is the relationship between soil water content and suction. This determines the soil water status and water availability to plants.

TABLE III
SELECTED PHYSICAL PROPERTIES OF DIFFERENT SOILLESS GROWTH MEDIA

Media #	*Bulk density*	*Particle density*	*Porosity*	*Water content at saturation*	*Average Hydraulic Conductivity*
	------kg/m^3------		-------%-------		--- cm/sec---
33	430	2120	79	68	0.011
45	420	1930	78	66	0.079
46	330	2230	85	72	0.069
51	560	2300	75	64	0.013
54	490	2240	78	67	0.015
55	560	2140	74	63	0.015
56	470	2290	79	68	0.015
MM 360	170	1810	91	77	0.018

Bulk density among the created media differs slightly but not as much as compared to the commercial product. These physical properties affect other properties of the media which ultimately influences plant growth response.

Hydraulic conductivity at saturation was measured for each media. Media 2 and 3 exhibited very high hydraulic conductivity due to their coarse source materials. All other media, however, exhibited levels of hydraulic conductivity that were considered to be very rapid and appropriate for mixes being used for plant growth media (media 1, 8 and 11-14) (unpublished data).

TABLE IV
WATER CONTENT AT SATURATION, AIR SPACE, EASILY AVAILABLE WATER (EAW), WATER BUFFERING CAPACITY (WBC) AND THE AIR CONTENT AT A SUCTION OF 25 CM, IN THE VARIOUS MEDIA.

Media #	*Properties*	*Air Content 25[a]*	*WBC 50-100[a]*	*EAW 10-50[a]*	*Air space 0-10[a]*	*Water content at saturation*
		-------------------------------- % --------------------------				
Ideal	Release water at required rate	-	4-10	20-30	20-30	85
Group I	Release water at low suction	35-47	6-13	24-36	17-26	64-77
Group II	Release water at high suction	18-25	13-21	13-21	15-21	63-68

[a] Amount of suction applied in cm. WBC (Water buffering capacity), EAW (Easily available water).

The shape of the water retention curves was different for each substrate representing the significant difference among the media in their water holding properties. The retention curves were grouped according to their shape. Media that had different water holding capacity were identified and placed into different groups i.e. group I and II (Table IV). Media classified in Group I released water at very low suctions and 30% or more of the water was lost when the suction reached 25 mbars (25cm). Group II media retained most of the water until the suction was increased to 35 cm. In these mixes, generally 30% of the water or less was lost when the suction reached 50 cm. The main difference between Group I and

Group II media is the air content at a suction of 25 cm.

Group II media also had a high air-entry suction. The significance of this high value is that the medium will remain saturated at the bottom up to a container height of 35 cm. Plant roots require a constant supply of O_2 for respiration while at the same time they release CO_2. Adequate aeration of the root zone is vital for normal plant growth. Lack of O_2 may pose a severe problem to the plants. If containers with such media are watered in excess, growth inhibition, CO_2 accumulation, reduced nitrification, and increased denitrification may occur.

TABLE V
C/N RATIO, PH AND ELECTRICAL CONDUCTIVITY OF THE DIFFERENT RAW MATERIALS USED FOR THE CREATION OF THE EXPERIMENTAL MEDIA

Material	*C/N Ratio*	*pH*	*EC[a]*
Cow Manure Compost	10	6.5	15.9
Leaf Compost	18	8.2	4.0
Biosolids Compost	12	5.1	7.5
Bottom Ash	-	4.2	0.1
FGD Gypsum	-	7.4	2.3

Perlite	-	8.3	2.3

[a]EC = electrical conductivity measured in dS m^{-1}.

The coal combustion products, except bottom ash, were alkaline. Perlite had the highest pH (8.3) while pH values of bottom ash and FGD gypsum were 4.2 and 7.4, respectively. Compost materials, except leaf compost (pH 8.2), were generally acidic to neutral. In general CCPs had a greater pH value while compost materials had a higher salt concentration (EC). Among the three compost materials, cow manure compost had the highest salt concentration (15.9 dS/m) and media that contained largest amounts of cow manure compost had the highest electrical conductivities (EC). The pH of the media prepared ranged from 5.9 to 9.7. The broad range in the pH of the experimental media is explained by the difference in the ratio of organic (compost) and inorganic (CCPs) components in our experimental media and their individual pH values. The media with a pH of 9.7, contained 80% coal combustion products and the media with pH 5.9 (Media 33) contained only 45% coal combustion products. The varied properties of the raw materials (Table V) influenced the overall physical and chemical properties of the prepared media.

TABLE VI
PH, ELECTRICAL CONDUCTIVITY AND IMPORTANT NUTRIENT CONCENTRATION IN THE DIFFERENT MEDIA

Media #	pH	EC	P	K	Ca	Mg	S
		dS/m	----------------mg/L----------------				
33	5.8	8.2	15.7	1710	850	405	726
45	5.9	12.4	37.2	3370	490	330	914
46	6.4	9.3	7.2	1520	570	290	412
51	6.8	20.4	10.9	4730	860	620	1070
54	5.9	9.0	12.6	1330	750	340	641
55	6.0	13.5	10.8	2550	970	620	795
56	5.4	14.3	22.2	2750	1000	590	780
MM 360	6.0	1.7	27	113	180	60	119

The chemical properties of the mixes, such as pH, electrical conductivity, nitrate and phosphorus concentration, (Table VI) depended largely on the ratios of the different materials used to create the mixes. All experimental media had EC values equal or greater than 8.2. Since we used cow manure compost and biosolids compost in the media, both of which had high salt concentration, the media that contained these materials had higher EC values. Since, CCPs are a rich source essential nutrients such as Ca, Mg, S and K, most of the experimental media had similar or greater concentration of all essential plant nutrients such as K, Ca, Mg and S as the commercial control. However, some media had P content less in comparison to the commercial media. Phosphorus concentrations in the extracts were very low for media created with CAM in comparison to media created with bottom ash materials (Fig. 1). Phosphorus forms insoluble precipitates with Fe, Al and Ca. Perlite, in comparison with bottom ash, had very high concentration of Ca (21 and 2 mg/g), Fe (20 and 7 mg/g) and Al (17 and 2 mg/g) which facilitated the formation of insoluble precipitates with phosphorus and the lower concentration of phosphorus in the media containing CAM materials.

For example, Fig. 1 and 2 provide data for how these properties changed as the proportion of manure compost in the media increased.

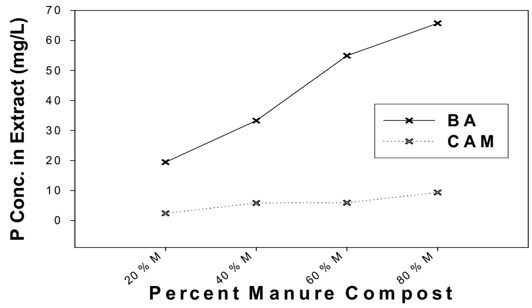

Fig. 1 P concentration in media extract affected by cow manure compost in media and types of coal ash BA=Bottom Ash and CAM=BA + Perlite + FGD gypsum Mix.

It is important to note that these values are from a single replicate and so cannot be compared statistically. However, the data strongly suggests that as the volume of cow manure compost was increased in the media, it altered the variables.

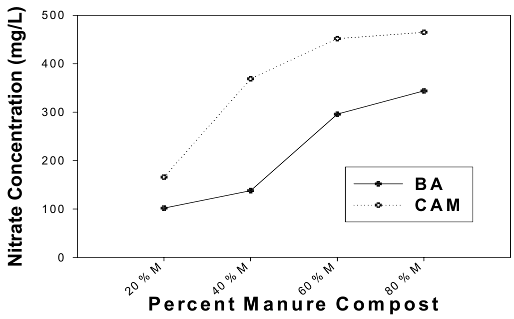

Fig. 2 Relation between nitrate-N concentration in media extract and cow manure compost in media BA=Bottom Ash and CAM=BA + Perlite + FGD gypsum mix.

Cow manure compost had the highest salt concentration (15.9 dS/m) and with a greater proportion of cow manure compost, salt concentration increased in the media. Similar observations were made for the NO_3-N concentration in the media (Fig. 2).

B. Biomass Yield

In the initial experiment, wheat grew best in Media 33. This media contained 20% sphagnum peat, 15% gypsum, 30% bottom ash, and 35% compost mix. The compost used in Media 33 was prepared by mixing manure, leaf and biosolids compost at the ratio of 2:2:1.

Media that contained greater concentrations of gypsum and perlite in the inorganic fraction performed poorly. Media 35 contained perlite along with soil and compost fractions and also performed poorly in Experiment 1. Most media that contained significant amounts of perlite became dense and compact upon watering as observed from the shrinking in volume of the media in the container. Plant growth response was not uniform across different media for individual plant species (Fig. 3). Media that proved to be excellent for one species did not always support similar growth for another species. Several of the experimental media performed better than the commercial product, Metromix 360 and Metromix 510 (Fig. 3). For marigold and tomato trials, the 13 experimental media prepared for Experiment 2 and the two commercial products (MetroMix 360 and MetroMix 510, Scotts Brothers, Columbus, OH) were used. Marigold performed well in a variety of media, based on composition, but the best performance was in Media 55 (Fig. 3).

Media 55 was similar to Media 33, which was prepared by slightly adjusting the original composition. For wheat and marigold, the best performing media was either Media 33 or one of the three new media created for Experiment 2 (Media 54, 55 and 56). Tomato, however, showed best response in Media 45 (Fig. 3) that contained 50% bottom ash and 50%compost materials but no peat. Compost used in Media 45 consisted of an equal amount of composts prepared from dairy manure, biosolids and tree leaf material.

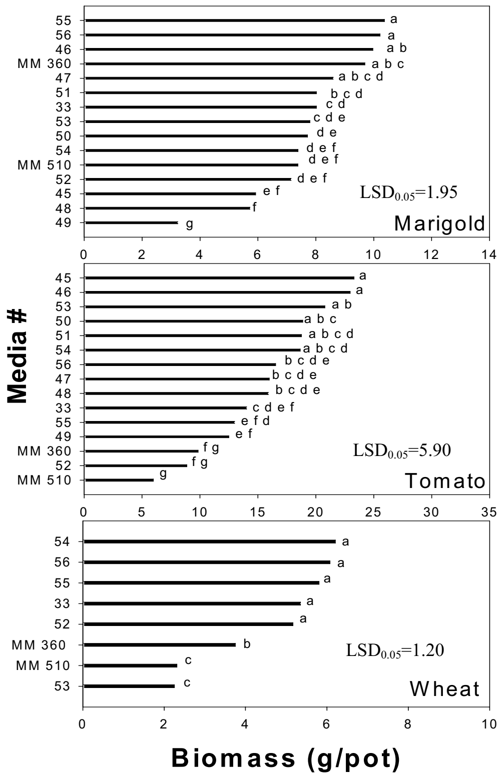

Fig. 3 Growth of Marigold, tomato and wheat in different experimental media. Means with different letters represent significant difference ($p<0.05$)

IV. Conclusions

We conclude that CCPs and organic composts can be utilized to produce greenhouse and container media that support good plant growth, although more exhaustive studies need to be done for determination of the best recipe mix for a particular plant species. Additional studies that evaluate the concentration of heavy metals and other toxic elements in the plant tissues are needed if these media are used for growing food plants. CCPs can be a good source of Ca, Mg, S, and B while organic composts provide adequate amounts of N and P required for plant growth. Several of our experimental media performed better than the commercial product when no external fertilizer was added. By not needing to apply any fertilizer, for good plant growth on the experimental media, there might be some added economic benefit to the grower.

In addition, the utilization of CCPs and organic composts may provide environmental advantage compared to other commercial products available at present. This is because the raw materials are not derived from original sources but are recycled materials that often are disposed without further use. However an economic feasibility study is required to calculate the exact cost-benefit analysis. Our results indicate that very good growth can be achieved by using CCP materials in concentration as high as 60% v/v. More importantly use of such materials to create greenhouse and container media will ameliorate the problem of waste management and disposal for several industries while providing economic benefit.

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