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Undergraduate Sustainable Learning: Effects of Sustainable Soilless Media on Production and Sensory Evaluation of Cucumbers, Basil, Parsley, and Lettuce

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Abstract: Modern greenhouse production has been ~100% reliant on fossil fuels for all inputs (glazing, heating, fertilization, lighting, post-harvest). Recent innovations may reduce fossil fuel dependence but their effectiveness may not be thoroughly tested. To promote education in sustainable production, undergraduate students in Greenhouse Management class (Hort 3002W; University of Minnesota) tested the effectiveness of two organic or ‘sustainable’ soilless media (Sunshine Natural and Organic Growing Mix, Sungro Metro-Mix Special Blend) with a control (Sunshine LC8 Professional) for crop production (height, leaf/flower number, yield) and sensory evaluations (appearance, texture, taste, purchase) of cucumbers (‘Big Burpless Hybrid’, ‘Sweet Burpless Hybrid’), basil (‘Opal Purple’, ‘Redleaf’), parsley (‘Green River’, ‘Extra Curled Dwarf’, ‘Hamburg’), and lettuce (Flying Saucer ‘Green’, ‘Red’). Significant differences between sustainable vs. control soils occurred for plant growth, depending on vegetative or

reproductive traits, crops, and cultivars. These differences occasionally disappeared for sensory evaluation of edible components. In most crops, however, cultivars were highly significant factors. Undergraduate research can be used to provide directionality for future vegetable and herb plant breeding to focus on creating cultivars with increased yield and high consumer acceptance when grown in sustainable greenhouse soilless mixes.

Keywords: sustainability; horticultural crop production; organic soilless media; sensory evaluation; plant breeding

1. Introduction

Greenhouse crop production in northern latitudes has undergone a continuing cycle of change, from traditional vegetable and fruit production prior to WWII, subsequently to flowers (floriculture) and recently a shift back to vegetables and herbs [1]. The most recent shift has been spurred by high energy costs for transport of edible crops as well as the ‘locavore’, ‘organic’, and ‘sustainable’ movements [2-4]—prompting consumers to think globally but buy locally produced and ‘safer’ crops as much as possible. Participants within the horticultural distribution chain (breeder, producer, distributor, grower, and retailer companies) [5] have had to respond accordingly to meet such demands. Nowhere in horticulture has this been more challenging to implement than in greenhouse production, the world’s most intensive form of agriculture with the lowest energy ratio (output/input) and highest GigaJoules (GJ)/ha⁻¹-year input to produce crops in heated greenhouses [6-8]. For instance, tomato (*Solanum lycopersicon*) crop production in a heated Venlo greenhouse in southern England requires 29,286.36 GJ/ha⁻¹-year versus 72.30 GJ/ha⁻¹-year in an open field of southern California, USA [9].

In protected crop culture, particularly greenhouses, virtually all components of production (soilless media, fertilizer, irrigation, mechanization, chemicals, labor, heating, pasteurization, ventilation, CO₂ enrichment, equipment, plant support, glazing material, greenhouse structure) involve at least some level of fossil fuel inputs [6,9]. The costs associated with these inputs are spiraling due to ever-increasing fossil fuel prices and reduced supply levels [9]. In response to consumer interest in and demand for sustainable and/or organic edible products [10,11], numerous transformations to existing production systems have been initiated. These include shifts to organic forms of soilless culture and hydroponics, as well as a reversion to composted wastes and other organic nutrient sources for crop nutrient needs [12-14].

Soilless production of crops alleviates drainage issues in small volume containers (compared to field soils), enhances root aeration, minimizes pathogens, and increases buffering capacity [15,16]. Some, but not all, components are ‘sustainably’ produced or ‘organic’ in origin. Common constituents widespread in soilless greenhouse vegetable, herb, fruit, and flower production worldwide include materials to increase aeration, improve water- and nutrient-holding capacity, increase drainage and cation exchange capacity, modify pH levels, *etc.* [17,18]. A partial list of such materials includes peat moss, bark (composted), compost, pumice, worm castings, vermiculite, perlite, sand, rice hulls, sheep wool, and coconut coir [19,20]. Crop growing requirements, shipping cost, local usage experience with

products, disposal (compost ability) and economics all influence selection of the type of materials included in a particular soilless medium or hydroponic growing block [17,21].

Example greenhouse-produced edible crops grown in soilless media include *Cucumis sativus* L. (cucumber), *Basilicum ocimum* L. (sweet and Thai basil), *Petroselinum crispum* Mill. (parsley), and *Lactuca sativa* L. (leaf and head lettuce). Cucumber fruits are harvested for fresh or pickled consumption [10,11]. Basil is harvested for fresh or dry leaf yield as well as essential oils [22]; it has been studied for use in long-term space missions [23,24]. Maximum yield was realized with a $500 \mu\text{mol m}^{-2}\text{s}^{-1}$ canopy irradiance level [23]. Parsley is a cultivated herb, harvested for fresh or dried leaves and/or petioles, as well as essential oils [25]. Leaf and head lettuce is an important salad crop and is also of interest for long-term space missions by The U.S. National Aeronautics and Space Administration [26]. Lettuce requires $>4,550 \text{ GJ/ha}^{-1}$ -year to produce in heated greenhouses in northern latitudes for a low energy output/input ratio of 0.002 [6,7]. Increased demand for these crops to be produced either sustainably or organically has created new market opportunities for protected crop growers [10,11]. Crop growth and yield components have been studied for these crops, but such research is rarely linked with consumer sensory evaluations for directives in crop improvement by plant breeders [27].

The objective of these experiments was to determine whether growth, yield, and consumer acceptance of four representative edible leafy vegetable/herb (basil, parsley, lettuce) and fruit (cucumber) greenhouse crops, grown in two sustainable or organic mixes, were similar to standard soilless media. Our null hypothesis tested for each crop was: $H_0 =$ There is no difference between soilless substrates for growth, yield, and sensory evaluation components. Sub-objectives within this study included testing cultivar (genetic) components within each crop and comparative sensory evaluations at the consumer level to determine the implications for future plant breeding endeavors of sustainable greenhouse crops. All experiments were conducted by undergraduate students enrolled in the Spring, 2010 semester course of Greenhouse Management, Sustainable Horticulture Production in Controlled Environments (Hort 3002W, University of Minnesota).

2. Results and Discussion

2.1. Cucumbers

While genetic (cultivars) and/or soilless media differences occurred throughout the experiment for rate of growth (node or leaf number), these differences varied over time. Mean number of nodes/plant ranged from 2.1 in week 9 for the Sunshine Natural and Organic (pooled by cultivars) to 45.25 by week 17 for 'Sweet Burpless Hybrid' grown in LC8 medium (Table 1). Cultivars did not differ significantly from each other in week 9 so the data were pooled. The Sunshine Natural and Organic had significantly lower node number than the SunGro Metro-Mix while the LC8 control overlapped with both (Table 1). A lack of cultivar differences disappeared by week 10 such that 'Big Burpless Hybrid' in Sunshine Natural and Organic, and 'Sweet Burpless Hybrid' grown in all media had significantly less nodes than 'Big Burpless Hybrid' grown in SunGro Metro-Mix and LC8 media (Table 1). By week 17 only 'Sweet Burpless Hybrid' grown in LC8 had significantly greater numbers of nodes (45.25)—inferring a higher flower/fruit production potential than all other soilless media in

both cultivars (Table 1). Node numbers during week 17 were similar to those reported for ‘Armada’ (44.2 nodes/plant) and higher than ‘Gordion’ (31.7 nodes/plant) [10]. Node numbers of ‘Sweet Burpless Hybrid’ grown in LC8 (45.45 nodes/plant, Table 1) were the most similar to ‘Armada’.

Mean plant height or stem length (week 17) ranged from 286.07 cm/plant (‘Big Burpless Hybrid’, Sunshine Natural and Organic) to 357.19 cm/plant (‘Sweet Burpless Hybrid’, SunGro Metro-Mix) (Table 1) and were similar to those reported for ‘Armada’ (334.6 cm/plant) [10]. Cultivars and soilless media differed significantly with ‘Big Burpless Hybrid’ grown on LC8 and Sunshine Natural and Organic being statistically shorter than this cultivar grown on SunGro Metro-Mix and ‘Sweet Burpless Hybrid’ grown on all three media types (Table 1).

Flowering did not commence until week 12 and sample means ranged from 0.25 flowers / plant (‘Big Burpless Hybrid’ in SunGro Metro-Mix) in week 12 to 52.75 in week 13 for ‘Sweet Burpless Hybrid’ in LC8—the latter of which had the highest node number by week 17 (Table 1). In week 12, ‘Sweet Burpless Hybrid’ grown on Sunshine Natural and Organic and LC8 had significantly higher flower numbers than all other cultivar and soilless media combinations (Table 1). One week later ‘Sweet Burpless Hybrid’ in both LC8 and SunGro Metro-Mix had the significantly highest flower number while ‘Big Burpless Hybrid’ had the lowest on these two soilless media. This demonstrates that LC8 and SunGro Metro-Mix were similar for flower production in week 13.

Fruit set was synchronous with flowering in the female (gynoecious) flowers although during weeks 12, 14 and 17 there were no cultivar differences and data was pooled (Table 1). In week 12, Sunshine Natural and Organic produced significantly less mean number of fruits / plant (0.63) than either LC8 (1.5) or SunGro Metro-Mix (1.88; Table 1). In week 17, the significance trend was the same except the number of fruits had increased from a mean of 2.50 fruits / plant (Sunshine Natural and Organic) to 5.13 (LC8, Table 1); only in week 14 did the order switch to SunGro Metro-Mix (2.75) having significantly lower mean fruit number than either Sunshine Natural and Organic (3.38) or LC8 (3.5). Fruit number (total number of fruit/plant) could not be compared with prior results [19,20,28] since we had to terminate the experiment at the end of the semester, prior to completion of the cucumber life cycle. Fruit production differed between cultivars only in week 13 where ‘Sweet Burpless Hybrid’ had significantly lower production than ‘Big Burpless Hybrid’ for all media (Table 1). Thus, with only one exception (week 13), cultivar effects on fruit production did not exist while soilless media had a significant impact. Previous studies have shown soilless media and its components to have significant impacts on cucumber fruit production. Gül *et al.* [10] found that cucumber yield increased when perlite was a media component due to its increased water holding capacity; all of the soilless media used in the current study include perlite. Thus, even with the use of different cultivars in the present study, cucumber yields of specific cultivars and media matched those reported by Gül *et al.* [10,11].

The lack of fruit length differences between cultivars further illustrates that soilless media has a greater impact on production in this study. LC8 had significantly lower mean fruit length in week 17 (31.15 cm) than both SunGro Metro-Mix (34.23 cm) and Sunshine Natural and Organic (35.26 cm, Table 1). Fruit lengths were similar in range to those found for ‘Galileo’ cucumbers (30–34 cm) grown in pumice media [19].

Table 1. Mean no. of nodes/week (weeks 9, 10, 17), plant height (cm), no. of flowers/week (weeks 12, 13), no. of fruits/week (weeks 12, 13, 14, 17); harvested fruit length (cm) and fresh weight (kg; week 17) were pooled for cucumber (*Cucumis sativus*) cultivars grown with three soilless media (Sunshine Natural and Organic, Sungro Metro-Mix, LC8). Tukey's 5% HSD mean separations within columns for each trait; means followed by different letters denote significant differences. **Data were pooled (bold typeface)** if there were no differences between cultivars or soilless media.

Trait	Cultivar	Soilless Media	Week 9	Week 10	Week 12	Week 13	Week 14	Week 17
No. of nodes/week	Big Burpless Hyb.	Nat. and Org.	2.10 a	4.75 a				33.25 a
		Metro-Mix	2.50 b	6.75 b				36.00 a
		LC8	2.30 ab	5.75 b				38.00 a
	Sweet Burpless Hyb.	Nat. and Org.		4.50 a				39.50 a
		Metro-Mix		5.50 a				40.50 a
		LC8		5.00 a				45.25 b
Plant height (cm)	Big Burpless Hyb.	Nat. and Org.						286.07 a
		Metro-Mix						352.11 b
		LC8						325.76 a
	Sweet Burpless Hyb.	Nat. and Org.						356.55 b
		Metro-Mix						355.28 b
		LC8						357.19 b
No. of flowers/week	Big Burpless Hyb.	Nat. and Org.			1.25 a	12.50 ab		
		Metro-Mix			0.25 a	3.00 a		
		LC8			1.50 a	4.75 a		
	Sweet Burpless Hyb.	Nat. and Org.			11.50 b	29.50 b		
		Metro-Mix			6.75 a	45.00 bc		
		LC8			10.25 b	52.75 c		
No. of fruits/week	Big Burpless Hyb.	Nat. and Org.			0.63 a	7.00 b	3.38 b	2.50 a
		Metro-Mix			1.88 b	9.25 bc	2.75 a	4.50 b
		LC8			1.50 b	9.75 bc	3.50 b	5.13 b
	Sweet Burpless Hyb.	Nat. and Org.				1.50 a		
		Metro-Mix				1.50 a		
		LC8				2.00 a		
Fruit length (cm)	---	Nat. and Org.						35.26 b
		Metro-Mix						34.23 b
		LC8						31.15 a
Fresh wt. (kg)	---	Nat. and Org.						0.61 a
		Metro-Mix						0.65 a
		LC8						0.57 a

Mean pooled fruit weight, ranging from 0.57 kg (LC8) to 0.65 kg (SunGro Metro-Mix), did not differ between cultivars or soilless media (Table 1). Fruit weight of the cultivars and media tested herein were greater than those reported for ‘Beit’ Alpha type cucumbers (0.124–0.131 kg) [20], ‘Palmera’ (0.26–0.39 kg) [28], and ‘Galileo’ (0.3–0.32 kg) [19]. These differences may be genetic, environmental, or media-based.

Sensory evaluations showed that appearance and texture did not differ significantly between cultivars or soilless media treatments (Table 2). Appearance had the tightest mean score range of 3.2/5.0 (‘Sweet Burpless Hybrid’, Sunshine Natural and Organic) to 3.29/5.0 for all others, whereas texture ranged from 3.57/5.0 (‘Sweet Burpless Hybrid’, Sungro Metro-Mix and LC8; Table 2). Taste scores, however, differed significantly with ‘Sweet Burpless Hybrid’ in LC8 having the lowest score (2.74/5.0) and ‘Big Burpless Hybrid’ LC8 and Sungro Metro-Mix with the highest (4.43/5.0 and 4.52/5.0, respectively; Table 2). Overall, panelists preferred the taste of ‘Big Burpless Hybrid’ over ‘Sweet Burpless Hybrid’ regardless of the soilless media treatment. Consumer purchase ratings were equally balanced between yes/no responses (non-significant 1:1 χ^2 ; Table 2). This lack of purchase preferential most likely may be due to the lack of appearance differences, despite significant taste effects, since a primary motivator in consumer purchasing is appearance [29] whereas texture and taste are not visual responses.

Table 2. Sensory evaluations (1–5 scale for appearance, texture, taste; yes/no for consumer purchase ratings) of four greenhouse vegetable (*Cucumis*, *Lactuca*) and herb (*Ocimum*, *Petroselinum*) crops grown with three soilless media (Sunshine Natural and Organic, Sungro Metro-Mix, LC8). Quantitative ratings analyzed with Tukey’s HSD test at $\alpha = 0.05$ after ANOVA (means followed by different letters denote significant differences) and qualitative scores tested with 1:1 Chi-square (χ^2) test.

Soilless medium	Cultivar	Appearance	Texture	Taste	Consumer purchase ratings		
					Yes	No	1:1 χ^2
<i>Cucumis sativus</i>, cucumber (n = 24 sensory evaluators)							
Sunshine Nat/Org	Big Burpless Hybrid	3.29 a	3.96 a	4.39 cd	14	10	0.67 ns ^z
	Sweet Burpless Hybrid	3.20 a	4.04 a	3.70 bc	14	10	0.67 ns
Sungro Metro-Mix	Big Burpless Hybrid	3.29 a	3.61 a	4.52 d	14	10	0.67 ns
	Sweet Burpless Hybrid	3.29 a	3.57 a	3.57 b	15	9	1.5 ns
LC8	Big Burpless Hybrid	3.29 a	4.13 a	4.43 d	14	10	0.67 ns
	Sweet Burpless Hybrid	3.29 a	3.57 a	2.74 a	13	11	0.17 ns
<i>Ocimum basilicum</i>, basil (n = 24 sensory evaluators)							
Sunshine Nat/Org	Opal Purple	3.36 a	3.88 a	3.28 a	13	11	0.17 ns
	Redleaf	3.29 a	3.88 a	3.33 a	14	10	0.67 ns
Sungro Metro-Mix	Opal Purple	3.29 a	3.88 a	3.33 a	14	10	0.67 ns
	Redleaf	3.29 a	3.88 a	3.33 a	13	11	0.17 ns
LC8	Opal Purple	3.29 a	3.88 a	3.33 a	14	10	0.67 ns
	Redleaf	3.29 a	3.88 a	3.33 a	14	10	0.67 ns

Table 2. Cont.

Soilless medium	Cultivar	Appearance	Texture	Taste	Consumer purchase ratings		
					Yes	No	1:1 χ^2
<i>Petroselinum crispum</i>, parsley (n = 25 sensory evaluators)							
Sunshine Nat/Org	Green River	3.76 c	3.24 b	2.88 cde	12	13	0.04 ns
	Extra Curled Dwarf	3.60 b	3.52 bc	3.00 def	13	12	0.04 ns
	Hamburg	2.72 a	2.72 a	2.40 ab	3	22	14.44 ***
Sungro Metro-Mix	Green River	3.56 b	3.20 b	2.48 abc	4	21	11.56 ***
	Extra Curled Dwarf	3.64 b	3.60 bc	2.72 bcd	9	16	1.96 ns
LC8	Hamburg	3.00 ab	2.40 a	2.36 ab	6	19	6.76 *
	Green River	3.24 b	3.36 bc	2.76 bcd	6	19	6.76 *
	Extra Curled Dwarf	3.44 b	3.68 c	3.36 f	15	10	1.0 ns
	Hamburg	2.84 a	2.64 a	2.24 a	4	21	11.56 ***
<i>Lactuca sativa</i>, lettuce (n = 24 sensory evaluators)							
Sunshine Nat/Org	Flying Saucer Green	3.96 bc	4.04 bc	4.08 c	18	6	6.0 *
	Flying Saucer Red	3.42 a	3.83 ab	3.62 ab	15	9	1.5 ns
Sungro Metro-Mix	Flying Saucer Green	3.79 b	4.12 c	3.83 b	17	7	4.2 *
	Flying Saucer Red	3.79 b	3.83 ab	3.50 ab	15	9	1.5 ns
LC8	Flying Saucer Green	3.42 a	3.58 a	3.92 bc	18	6	6.0 *
	Flying Saucer Red	3.50 a	4.04 bc	3.17 a	13	11	0.17 ns

^{ns}=not significant, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

2.2. Basil

Mean number of basil leaves / plant ranged from 13.0 ('Red Leaf', LC8) to 28.08 ('Opal Purple', SunGro Metro-Mix; Table 3) in week 10, but were slightly lower than those reported for 'Genovese', 'Italian Large Leaf' and 'Nufar' basil grown under higher light (300–600 $\mu\text{mol m}^{-2}\text{s}^{-1}$) and temperature (25 °C day/night) regimes [23]. Temperature could enhance leaf number and yield as at least one study has shown higher yield at 30/12 °C day/night [30]. While LC8 and Sunshine Natural and Organic media did not differ in leaf production (Table 3), LC8 produced the lowest number of leaves. Both cultivars grown in SunGro Metro-Mix had significantly higher leaf numbers than all other treatments. Thus, the critical harvestable unit for yield in basil (leaf number) with 'Red Leaf' and 'Opal Purple' is not genotype dependent but is based on media with the highest yield occurring in SunGro Metro-Mix (Table 3). This makes commercial basil grower choices easier since growers choose basil cultivars for high yield, disease resistance, and growth habit [24,31]. Either cultivar can be chosen to produce high yields when grown in the best soilless medium.

Plant height ranged from 6.08 cm ('Opal Purple', Sunshine Natural and Organic) to 10.95 ('Red Leaf', SunGro Metro-Mix) (Table 3). 'Opal Purple' with LC8 and Sunshine Natural and Organic had significantly lower plant height than 'Red Leaf', SunGro Metro-Mix while all other cultivar and media combinations overlapped (Table 3). Since both 'Opal Purple' and 'Red Leaf' are dwarf, compact cultivars, the plant height of 'Genovese', 'Italian Large Leaf' and 'Nufar' were higher (14–18 cm) [23]. Internode lengths did not differ for cultivars and pooled means ranged from 0.479 (SunGro Metro-Mix) to 0.647 (LC8) but also did not differ significantly (Table 3).

Table 3. Mean leaf number, plant height (cm), and internode length (cm) for basil (*Ocimum basilicum*) cultivars (week 10) grown in three soilless media (LC8, Sunshine Natural and Organic, SunGro Metro-Mix). Tukey’s 5% HSD mean separations within each trait; means followed by different letters denote significant differences. **Data were pooled (bold typeface)** if there were no significant differences between cultivars.

Trait	Cultivar	Soilless media		
		LC8	Nat. and Org.	Metro-Mix
Leaf number	Red leaf	13.0 a	18.75 a	22.83 b
	Opal Purple	15.67 a	18.17 a	28.08 b
Plant height (cm)	Red leaf	9.18 ab	9.47 ab	10.95 b
	Opal Purple	7.88 a	6.08 a	10.09 ab
Internode length (cm)	(pooled)	0.647 a	0.502 a	0.479 a

Sensory evaluations for basil samples showed absolutely no discrimination ability of the panelists for any trait (appearance, texture, or taste) or consumer purchasing (Table 2). Mean values for texture were identical for all treatment combinations (3.88) and differed only slightly for appearance (3.29–3.36) and taste (3.28–3.33; Table 2). Thus, while yield components of leaf number and plant height varied significantly, panelists could not discern any flavor component differences at the retail level. Since plant height is not a harvestable unit, growers would have the greatest yield (number of leaves) and profitability growing these either or both of these two cultivars in the SunGro Metro-Mix medium without sacrificing consumer purchasing.

2.3. Parsley

Mean mature leaf number/plant was 4.67 (‘Green River’, Sunshine Natural and Organic) to the highest yield of 7.33 (all three cultivars, LC8 and ‘Green River’, SunGro Metro-Mix) in week 10 (Table 4), similar to Italian ‘Dark Green’ parsley) [25]. While the photoperiod used herein (16 hr) maximizes yield over shorter light durations [32], yield could increase slightly if grown under cooler temperatures, as ‘Titan’ had the highest yield at 20 °C rather than 25 °C [32]—provided, of course, that the three cultivars tested herein have similar genetic responses to temperature. Thus, when growing any of these cultivars in the LC8 medium equally high yields occur such that growers could choose tailor parsley production to the leaf type preferred by their customer base. However, if growers want a sustainable or organic soilless medium, the choice for maximum yield and profitability would be ‘Green River’ grown in SunGro Metro-Mix only (Table 4).

Tallest leaf height ranged from 6.92 (‘Green River’, LC8) to 13.33 (‘Hamburg’, SunGro Metro-Mix; Table 4). Leaves of ‘Hamburg’ grown on all three media were significantly taller than all other cultivars on any media (Table 4). Since leaf height is a combination of the petiole length and terminal leaflet positioning, and if longer petioles were preferred by a grower’s customers, then ‘Hamburg’ grown in LC8 would not reduce leaf number yield (Table 4). However, if growers need to use sustainable or organic mixes, growing ‘Hamburg’ on either SunGro Metro-Mix or Sunshine Natural and Organic would result in significantly lower yield and profitability.

Table 4. Mean leaf number and tallest leaf height parsley in parsley (*Petroselinum crispum*) cultivars (week 10) grown in three soilless media (LC8, Sunshine Natural and Organic, SunGro Metro-Mix). Tukey's 5% HSD mean separations within each trait; means followed by different letters denote significant differences.

Trait	Cultivar	Soilless media		
		LC8	Nat. and Org.	Metro-Mix
Leaf number	Extra Curled Dwarf	7.33 b	6.00 a	5.67 a
	Green River	7.33 b	4.67 a	7.33 b
	Hamburg	7.33 b	5.33 a	5.00 a
Leaf height (cm)	Extra Curled Dwarf	9.16 a	9.81 a	9.33 a
	Green River	6.92 a	9.29 a	7.80 a
	Hamburg	12.16 b	12.38 b	13.33 b

Unlike the results for cucumber and basil sensory evaluations (Table 2), both cultivars and soilless media had significant effects on appearance, texture, taste, and consumer purchasing preferences for parsley. Appearance values were distributed from 2.72/5.00 ('Hamburg') to 3.76/5.00 ('Green River')—both of which were grown in the Sunshine Natural and Organic medium (Table 2). 'Hamburg' had significantly lower appearance ratings in all media types whereas 'Green River', Sunshine Natural and Organic was significantly better in appearance than all other media and cultivars. High yielding 'Green River' in SunGro Metro-Mix (Table 4) ranked in the second highest statistical grouping for appearance (Table 2). Parsley texture sensory ratings ranged from 2.40/5.0 for 'Hamburg' grown in SunGro Metro-Mix to 3.68/5.00 for 'Extra Curled Dwarf' in LC8 (Table 2). 'Hamburg' in all three media combinations were significantly lower than all other treatments and cultivars. 'Extra Curled Dwarf' in LC8 had significantly more favorable texture than other cultivars, although it overlapped with the two other media types for this cultivar as well as 'Green River' in LC8 (Table 2). 'Hamburg' grown in LC8 had the significantly lowest score for taste (2.24/5.00) when compared with 'Extra Curled Dwarf' grown in the same soilless medium (3.36/5.00; Table 2). All other treatment and cultivar combinations overlapped between groups. Since 'Extra Curled Dwarf' in LC8 had the significantly highest scores for texture and taste (Table 2) and, coupled with equal yield (leaf number, Table 4) for all cultivars in this medium, growers could potentially get higher profit growing this cultivar. However, when consumer purchasing preferences are factored in, 21/24 said they would not purchase it (Table 2). Sensory evaluation panelists also had a significant aversion to purchasing 'Green River' grown in SunGro Metro-Mix (Table 2), despite its significantly highest yield among the sustainable and organic soilless media (Table 4).

2.3. Lettuce

Mean number of leaves/plant ranged from 10.17 ('Flying Saucer Red', LC8) to 14.17 ('Flying Saucer Green', SunGro Metro-Mix) in week 10 (Table 5). Both cultivars grown in SunGro Metro-Mix had significantly higher leaf numbers than all other media, regardless of genotype (Table 5).

The tallest leaf heights peaked at 14.85 cm ('Flying Saucer Red', SunGro Metro-Mix) while the shortest height, also in this cultivar, was in the LC8 medium (12.23 cm; Table 5). 'Flying Saucer Red'

in SunGro Metro-Mix and ‘Flying Saucer Green’ in Sunshine Natural and Organic both had significantly taller leaf heights than any other soilless media or cultivar combination.

Table 5. Mean leaf number, tallest leaf height (cm) and fresh weight (g) for lettuce (*Lactuca sativa*) cultivars (week 10) grown in three soilless media (LC8, Sunshine Natural and Organic, SunGro Metro-Mix). Tukey’s 5% HSD mean separations within each trait; means followed by different letters denote significant differences.

Trait	Cultivar	Soilless media		
		LC8	Nat. and Org.	Metro-Mix
Leaf number	Flying Saucer Red	10.17 a	11.00 a	13.50 b
	Flying Saucer Green	10.50 a	12.00 a	14.17 b
Tallest leaf height (cm)	Flying Saucer Red	12.23 a	13.30 a	14.85 b
	Flying Saucer Green	12.87 a	14.08 b	15.27 a
Fresh weight (g)	Flying Saucer Red	13.43 a	14.46 a	18.76 b
	Flying Saucer Green	13.64 a	15.80 ab	15.03 ab

Fresh weight was distributed from 13.43 g/plant (‘Flying Saucer Red’, LC8) to 18.76 g/plant (‘Flying Saucer Red’, SunGro Metro-Mix; Table 5). ‘Vardac’ lettuce had higher mean shoot weight at commercial maturity (200–260 g) [19], most likely due to our harvesting the lettuce prior to that stage due to the end of the semester. ‘Flying Saucer Red’ grown in SunGro Metro-Mix was significantly more productive for fresh weight than when grown on the other two media types or ‘Flying Saucer Green’ in Sunshine Natural and Organic; it overlapped with ‘Flying Saucer Green’ grown in both Sunshine Natural and Organic and SunGro Metro-Mix (Table 5). Based on all three yield components, the best grower decision when choosing the most productive cultivar and media combination would be to grow ‘Flying Saucer Red’ in SunGro Metro-Mix.

Sensory evaluations of lettuce appearance ranged from a low of 3.42/5.0 (‘Flying Saucer Red’ in Sunshine Natural and Organic, ‘Flying Saucer Green’ in LC8) to 3.96/5.0 (‘Flying Saucer Green’ in Sunshine Natural and Organic; Table 2). The lowest scores for texture were the same treatment x cultivar combinations for appearance while ‘flying Saucer Green’ in SunGro Metro-Mix had the highest texture rating (4.12/5.0; Table 2). Taste preferences ranged from 3.17/5.0 (‘Flying Saucer Red’, LC8) to the significantly highest rating of 4.08/5.0 for ‘Flying Saucer Green’ grown in Sunshine Natural and Organic (Table 2). Panelists preferred purchasing ‘Flying Saucer Green’ grown in all media types compared with ‘Flying Saucer Red’ which had non-significant 1:1 χ^2 tests (Table 2). Only one cultivar x soilless medium combination was superior for all sensory evaluation traits and purchasing preference, namely ‘Flying Saucer Green’ grown in Sunshine Natural and Organic (Table 2). This contrasts with the highest yielding cultivar for the grower, specifically ‘Flying Saucer Red’ in SunGro Metro-Mix (Table 5); again demonstrating that the highest yielding cultivar x media combination may not correlate with consumer preferences.

3. Experimental Section

3.1. Crop Growth Conditions

Four seed-propagated crops (1-fruit and 3-leaf types) were included in this study during Spring 2010 semester and experiments were conducted by students enrolled in Hort 3002W, Greenhouse Management class at the University of Minnesota—a writing intensive course which focuses on sustainable horticulture production in enclosed environments. Germination conditions for the crops were sowing the seeds during weeks 3–4, 2010, in 288 plug trays filled with Berger BM2 Germination Mix (Berger Peat Moss, Saint-Modeste, Quebec Canada) and placing them under mist (21 °C/21 °C, day/night, 16 hrs (0600–2200 HR) lighting at 150 $\mu\text{mol m}^{-2}\text{s}^{-1}$). The mist frequency was every 10 min for 7 sec in duration [23]. Following germination, plug trays were removed from the mist and placed on capillary mats, until true leaves appeared, whereupon they were transplanted into the soilless media treatments. After transplanting, seedlings were grown under similar conditions of 24.4 ± 3.0 °C/ 18.3 ± 1.5 °C day/night and 16 hrs (0600–2200 HR) at a minimum of 150 $\mu\text{mol m}^{-2}\text{s}^{-1}$ with the only varying factor being the crop-specific germplasm tested. Parsley (*Petroselinum crispum*), lettuce (*Lactuca sativa*), and basil (*Ocimum basilicum*) and cucumbers (*Cucumis sativus*) were grown with 125 ppm N (15–5–15; Cal-Mag, The Scotts Co., Marysville, Ohio USA) constant liquid feed (CLF). The 125 ppm N CLF rate was low enough levels to prevent high nitrate levels in leafy crops, such as basil, which can cause methemoglobinemia and carcinogenesis upon consumption [33]. Monthly fungicide drenches were applied. Pesticides were not applied since the crops were grown for future sensory evaluations; integrated pest management (IPM) techniques were implemented as needed. Crops were grown until all harvestable units were mature or, in the case of some crops until the semester ended (week 17).

3.2. Soilless Media Tested

Sustainable soilless mixes tested on each crop were one organic type: Sunshine Natural and Organic Planting Mix #1 and two standard soil less mixes: Sun Gro Metro-Mix 830 R.H. (Sun Gro Horticulture, Bellevue, WA USA). Custom Blend (Sun Gro Horticulture, Bellevue, WA USA and Sunshine #8/LC8 Professional Growing Mix (Sun Gro Horticulture, Bellevue, WA USA). Wholesale 2010 price differentials between the three soilless media ranged from US \$9.50/2.8 ft³ (Sunshine Natural and Organic) to US \$10/2.8 ft³ (Sun Gro Metro-Mix) and US \$11.82/2.8 ft³ (LC8) (N. Anderson, price quote from Carlin Horticultural Supplies, St. Paul, MN). Sun Gro Metro-Mix 830 RH is comprised of 40–50% Canadian Sphagnum peat moss, 20–30% composted pine bark, 10–20% par boiled rice hulls, 5–10% horticultural grade vermiculite, starter nutrient charge (with gypsum) and slow release nitrogen (N) and wetting agent (non-organic). The presence of rice hulls in this mix reclassified it as ‘sustainable’ by the undergraduate students, based on interviews with Minnesota growers and suppliers. Thus, one organic (Sunshine Natural and Organic), one ‘sustainable’ (Sun Gro Metro-Mix) and a standard control (LC8) were used. Sun Gro Metro-Mix has a bulk density of 5.7–7.5 kg/ft³ (12.5–16.5 lbs/ft³; Sun Gro Horticulture, Bellevue, WA USA). Sunshine Natural and Organic #1 is comprised of 75–85% Canadian sphagnum peat moss, 15–25% horticultural grade perlite, dolomitic lime, an organic starter nutrient charge, and an organic wetting agent (*Yucca* extract) with approved

organic labeling by the Organic Materials Review Institute (OMRI). This differs slightly in components from the Sunshine LC8 and Metro Mix media with the former containing ‘organic’ components of nutrient starter charges and *Yucca* as the wetting agent; while the latter contains 70–80% grower grade peat moss, 15–25% coarse grade perlite, 5–10% horticultural grade vermiculite, dolomitic limestone, starter nutrient ‘charge’, gypsum and a wetting agent (‘non-organic’). All media tested contain Canadian Sphagnum peat moss (varying in type and %), horticultural grade perlite, dolomitic limestone and wetting agents, while only Sun Gro Metro-Mix contains composted bark and added rice hulls. These tested media components match similar types commonly used for greenhouse cucumber production [17,20,34–36].

3.3. Crop Germplasm

Cucumis sativus (Cucumber). Two cultivars within one series were grown: ‘Big Burpless Hybrid’ and ‘Sweet Burpless Hybrid’ (Burpee Seed Co., Warmister, PA, USA). ‘Big Burpless Hybrid’ (55 d) is described as ‘dark green cucumbers’ that grow to be ~30.5 cm–35.6 cm in length. They are advertised as “sweet and never bitter” [37]. ‘Sweet Burpless Hybrid’ cucumbers (55 d) are ~25.4 cm to 30 cm long and advertised as “mild and refreshing”; it is claimed to be Burpee[®]’s highest yielding cucumber cultivar. These cultivars have little to no cucurbitacin which causes bitter flavor and increases the likelihood of ‘burping’ after ingestion (<http://www.burpee.com/vegetables/cucumbers/burpless/>). Five reps/cultivar/treatment were transplanted into the soilless test media and later reduced to 4 reps/cultivar/treatment due to greenhouse space constraints. All plants were grown on the floor in 11.4 L containers and trellised using ~2 m bamboo stakes; greenhouse production followed recommended guidelines [10,15,19]. Despite being dichogamous, the tested cultivars are parthenocarpic and pollinators were not required for fruit set.

Ocimum basilicum (Basil). Two cultivars were grown: ‘Dark Opal Purple’ (Richters Herb Specialists, Goodwood, Ontario, Canada) and ‘Red Leaf’ (also sold as ‘Opal’ or ‘Red Rubin’; Tasteful Garden, Helflin, Alabama, USA). ‘Dark Opal Purple’ (also known as ‘Dark Opal’) was bred by the University of Connecticut and was a 1962 All America Selections winner [38]. Its leaves are dark purple with occasional mottling, grown for both ornamental and culinary value. Twelve reps/cultivar/treatment were grown; final container size was 11.4 cm (dia.).

Petroselinum crispum (Parsley). Three cultivars were sown: ‘Green River’, ‘Extra Curled Dwarf’, and ‘Hamburg’ (Germania Seed Co., Chicago, Illinois USA). ‘Green River’ and ‘Extra Curled Dwarf’ are dwarf, curled types whereas ‘Hamburg’ is a rooted form with an edible tap root. There were 5 reps/cultivar/treatment grown in a final container size of 11.4 cm (dia.). Growth conditions were similar to commercial grower recommendations [39].

Lactuca sativa (Lettuce). Two cultivars within the same series were sown for this crop: ‘Flying Saucer Green’ and ‘Flying Saucer Red’ (Burpee Seed Co., Warmister, PA, USA). Six reps/cultivar/treatment were grown in 11.4 cm (dia.) containers. Both cultivars were 50 d ‘Frisee’ type leaf lettuce cultivars, differing in leaf coloration.

3.4. Data Collection and Analyses

For cucumbers, the data collected included final plant height (cm); number of nodes (leaves) for weeks 9, 10, and 17; no. of flowers (weeks 12–13); no. of fruit (weeks 12–14, 17) during the experiment as well as final fruit length (cm) and weight (g) in week 17 [10,11]. Plant height (cm), leaf (node) number, and internode length (=plant height/leaf number) were recorded for basil. Parsley leaf number harvested/week and tallest leaf height (cm) were determined. Lettuce leaf (node) number, tallest leaf height (cm), plant diameter (cm), and fresh weight (g) were taken. Stem or plant height and internode lengths were not recorded for parsley and lettuce since both crops are rosetted and vegetative (non-bolting) during this phase of production.

All crops were submitted to in-class sensory evaluations (taste tests) by undergraduate students using evaluative criteria developed by the instructor [40] for edible greenhouse crops in Hort 3002W for 10 years (Figure 1) [27]. Crops were harvested, cleaned, and placed in clear plastic bags identified with a sample number for the taste panels. Students ($n = 24\text{--}25$ in each panel) ranked each sample for appearance, texture and taste (1–5 scale with 1 denoting the worst and 5 the best sample) as well as scoring each for “I would buy this product” (yes/no) (Figure 1). Scores for appearance were based on leaf or fruit coloration and other traits. Texture was scored as 1 = unpalatable; soggy, slimy, amorphous or repulsive; 2 = nearly unpalatable; 3 = OK; 4 = not quite the best and 5 = excellent with a desirable texture (Figure 1). Taste scores were an overall rating, including sweetness or bitterness. In between each tasted sample, the panelists cleansed their palettes by eating an unsalted cracker (Premium Saltine Crackers, Kraft Foods, Northbrook, Illinois USA) and sipping tap water.

Analyses of Variance (ANOVA) and Tukey’s Honestly Significant Difference (HSD) at $\alpha = 0.05$ mean separations were performed for all quantitative data [10,11]. Linear regression of plant height and node (leaf) numbers and soilless media were determined. Purchasing data (qualitative) were submitted to a 1:1 Chi-square (χ^2) test for equal likelihood of yes/no responses at $\alpha = 0.05$.

4. Conclusions

All tested soilless media could produce high growth rates and yield in specific combination with crops and cultivars (genotypes) over time in the duration of this study. The implications of these results vary, depending on the crop, soilless media, and genotypes. For some traits, specific combinations had the highest growth rates, yield and consumer sensory evaluative responses, e.g., cultivars did not differ during week 9 for node number but later differed significantly with the highest no. of nodes/plant occurring with ‘Sweet Burpless Hybrid’ cucumber in LC8 (week 13, Table 1). Cucumbers grown in Sunshine Natural and Organic produced significantly fewer nodes than Sungro Metro Mix. In general, however, fruit production did not differ between cultivars but was due to soilless media (Table 1). Sensory evaluations for cucumber appearance and texture were not affected by cultivars or soilless media whereas both factors impacted taste. Sensory panelists preferred the taste of ‘Big Burpless Hybrid’ in LC8 and Sungro Metro-Mix (Table 2) but there was an equal response in whether or not they would purchase this cucumber. From this study, it is clear that cucumber breeders must develop new cultivars with superior growth and yield in specific soilless media as well as integrate sensory evaluation tests into their breeding objectives and selection criteria to produce this crop in an increasingly sustainable manner.

Soilless media, rather than genotype, had a greater impact on yield (leaf production) of basil (Table 3). Such effects disappeared for internode length where neither soilless media nor cultivars differed significantly. Plant height, however, was genotype- and soilless media-dependent. Sensory evaluation panelists could not discern any differences between genotypes and soilless media treatments (Table 2). The recommendation for highest yield is to grow either basil cultivar (‘Opal Purple’ or ‘Red Leaf’) in SunGro Metro-Mix. Basil breeders should include this soilless media in breeder trial yield tests to ensure maximal yield. It is unknown, however, whether additional genotypes (cultivars, unnamed selections) would have the same non-significant sensory evaluation scores, so these should be integrated into trials to ensure not overlooking any potential significant effects.

All parsley cultivars had the highest yield (leaf number) when grown in LC8 whereas only ‘Green River’ was comparable in Sungro Metro-Mix by week 10 (Table 4). Unlike basil and cucumbers, parsley cultivars grown in soilless media treatments significantly affected all sensory evaluation traits and consumer purchasing preferences (Table 2). ‘Extra Curled Dwarf’ parsley grown in LC8 had the highest scores for texture and taste as well as equally high yield with other cultivars grown in LC8 (Table 4) and would be a productive choice for growers. Parsley breeders could use ‘Extra Curled Dwarf’ as a market comparison for future breeding selections and incorporate sensory evaluations.

Genotype effects in lettuce leaf production were non-significant compared with soilless; SunGro Metro-Mix produced the highest yield (Table 5). A different effect was found for leaf height and fresh weight where both cultivars and soilless media had significant impacts. The best grower decision to maximize yield is ‘Flying Saucer Red’ lettuce grown in SunGro Metro-Mix. However, for maximal consumer sensory evaluation and purchasing, ‘Flying Saucer Green’ lettuce grown in Sunshine Natural and Organic soilless medium was preferred. Thus, lettuce breeders will need to formulate their breeding objectives to balance grower preferences for high yielding and economically profitable cultivars with consumer preferences. Breeding for yield and consumer preferences are often divergent

but critical breeding objectives. Directed selection of new genotypes in all crops should seek to integrate both grower and consumer preferences.

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