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Evaluating the Soil Block Method and Growing Media in Organic Vegetable Transplant Production

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Abstract. **Organic vegetable growers are interested in using the "soil block" method for transplant production as an alternative to plastic flats. The soil block method compresses growing media into a freestanding block in contrast to the cells of a plastic flat. Anecdotal evidence of soil block–grown transplants with increased vigor and root development exists, but limited research has been conducted to evaluate these claims. Furthermore, identifying commercial growing medium for certified organic transplant production is needed. The objective of this study was to compare growth parameters and root development of cucumber (*Cucumis sativus*) and pepper (*Capsicum annum*) transplants grown in soil blocks and plastic flats, in combination with four commercially available certified organic media (Beautiful Land Products "Soil Blocking Mix," Purple Cow Organics "Seed Starter Mix," Cowsmo "Green Potting Soil," and Vermont Compost Company "Fort Vee"). A volume-based 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite growing medium was also evaluated. A split-plot randomized complete block design with four replications was used with growing method as the whole plot factor and medium as the subplot factor. 'Marketmore 76' cucumbers and 'Yankee Bell' peppers were seeded in 50-cell flats and soil blocks made with Johnny's Selected Seeds Stand-up 12 Soil Blocker. Data were collected on growth parameters by destructively sampling cucumbers 3 weeks after seeding, and peppers 5, 6, and 7 weeks after seeding. Root development was evaluated using WinRHIZO^{TM} at the last sampling. Cucumber and pepper transplants performed differently in soil blocks and flats. Cucumbers grown in flats had a significantly greater dry weight than those grown in soil blocks, by 20% in 2022 and by 38% in 2023. In contrast, pepper transplants grown with the soil block method had between 50% and 130% greater dry weight in the final sampling in 2022. Cucumber and pepper transplants grown with Cowsmo "Green Potting Soil" performed poorly, with an up to 144% lower dry weight and up to 167% lower root surface area than transplants grown with the other media. Root development correlated with shoot development, without a specific advantage in soil blocks, although differences in root system architecture should be investigated. The evaluated Beautiful Land Products, Purple Cow Organics, and Vermont Compost Company media can all be considered suitable for growing certified organic vegetable transplants in both soil blocks and flats. Further research is warranted to better optimize the soil block technique, investigate optimum soil block bulk density, and inform growers of appropriate commercially available certified organic growing media for organic vegetable transplant production.**

Organic fruit and vegetable production is a $19 billion industry in the United States (Skorbiansky 2023). Vegetable growers use transplants to secure high yields, compete with weeds and pests, and ensure field establishment (Salter 1982). An important indicator of transplant success is seedling root morphology and development (Balliu 2017; Kubota et al. 2013; Qin and Leskovar 2020), including a large root surface area, the number of lateral and basal roots (Feng et al. 2018; Leskovar and Stoffella 1995), root dry weight, and the root-to-shoot ratio (Kubota et al. 2013). These qualities may reduce transplant shock, allowing the plant to establish quickly, exhibit higher resource efficiency, and lead to an increase in yield (Kerbiriou et al. 2013; Leskovar and Stoffella 1995).

Root malformations, such as root spiraling or circling, threaten transplant success. In closed containers, plant roots reach the wall of the pot and redirect downward, circling near the bottom. Exposing roots to copper or air prevents root circling, known as chemical or air pruning, causing the roots to turn inward to form a concentrated root ball in the center (Balliu 2017; Tresemer 1983). The impact of root circling is widely studied in forestry, where it is known to cause a reduction in lateral root growth, potential root death, and a lack of soil anchoring (Aguilera-Rodriguez et al. 2021) but is underexplored in vegetable transplants.

Specific transplant production methods allow for air pruning by growing transplants in freestanding form, providing exposure to air on all sides (Coleman 1995; Pill and Stubbolo 1986). These methods include expandable peat pellets, such as Jiffy 7®, and soil blocks (Greer and Adam 2005). Also known as "peat blocks" or "compressed substrate," soil blocks for vegetable production were developed in the 1970s in Western Europe. Blocks are formed by compressing growing media with a specialized tool into the form of a cube, into which seeds can be sown. Mechanization has helped this method of transplant production remain popular in Western Europe. Although the use of multicellular trays made of plastic or polystyrene is the dominant method of transplant production in North America (Greer and Adam 2005; Maltais et al. 2008), many small-scale market farmers use the soil block method, most commonly using a Ladbrooke soil blocker tool (Kuepper and Everett 2004).

Growers may choose to use the soil block method because of the many anecdotal claims about the superiority of soil block–grown transplants, including a more developed root system due to the plant's ability to air prune (Coleman 1995; Pill and Stubbolo 1986; Tresemer 1983). Root air pruning results in reduced root damage when the plant is pulled from the tray at time of transplanting (Yang et al. 2018), less transplant shock (Maltais et al. 2008), and, ultimately, leads to shortened production times and greater yields (Coleman 1995; Kerbiriou et al. 2013; Maltais et al. 2008; Tresemer 1983).

Forestry nursery production research supports the claims of benefits from root air pruning. Studies have found an increase in overall root surface area and average root length in perennial, woody species grown in soil blocks that allow for air pruning (Feng et al. 2018). Research on vegetable transplants and soil blocking is limited. Considering the impact of transplant root system development and morphology on overall increased crop yield, a need exists to examine the root systems of vegetable transplants grown in soil blocks.

Haskell and Newell (1954) reported an earlier harvest from lettuce (*Lactuca sativa*), tomato (*Solanum lycopersicum*), and cucumbers (*Cucumis sativus*) grown as transplants in soil blocks as compared with those grown in pots, but limited details regarding research methods are available. An informal, on-farm trial in Iowa found higher yields in tomatoes grown as transplants in soil blocks compared with those grown in plastic flats, but results may have been because of differences in substrate volume between methods (Kolbe et al.

2016). In contrast to the findings by Kolbe et al. (2016), Schuh and Jaquinde (2019) reported no difference in tomato yield when tomato transplants were grown in soil blocks or plastic pots, but no root system analysis was performed.

Another factor determining the health and success of transplants is the growing medium (Balliu 2017; Gruda et al. 2013). Research has explored the specific components of growing media for transplant production, including the addition and proportion of compost (Sánchez-Monedero et al. 2004) and vermicompost (Paul and Metzger 2005), replacements for peat, such as rice hulls (Zanin et al. 2011) or biochar (Nair and Carpenter 2016), and specific recipes for growing medium mixes (Biernbaum 2006). Yet, many commercial vegetable growers prefer to rely on the expertise of a company to synthesize this research and often purchase commercially available growing medium products (Kuepper and Everett 2004). Certified organic producers have the additional need to follow organic regulations when producing transplants, including the use of certified organic growing medium.

One of the most popular certified organic growing media is made by the Vermont Compost Company (Montpelier, VT, USA). Although shipped to growers around North America, interest in supporting regional economies through purchasing products from local companies is important to small-scale growers (Iles et al. 2021) and central to the foundational philosophy grounding certified organic production (Jouzi et al. 2017; Vos 2000). In the midwestern United States, numerous locally produced certified organic growing medium products are available, but questions remain about their performance and quality (Liddle et al. 2021). This study supports the efforts of organic vegetable producers in the North Central region of the Midwest, through an assessment of three Midwest-produced certified organic growing media ("Soil Blocking Mix," Beautiful Land Products, Tipton, IA, USA; "Green Potting Soil," Cowsmo, Cochrane, WI, USA; "Seed Starter Mix," Purple Cow Organics, Middleton, WI, USA) in comparison with "Fort Vee" (Vermont Compost Company, Montpelier, VT, USA) for organic vegetable transplant production. This research project i) compares growth parameters and root system development of organic bell pepper (*Capsicum annuum*) and cucumber (*Cucumis sativus*) transplants grown with the soil block method and in plastic flats, and ii) evaluates the suitability of four commercially available certified organic growing media and an in-house growing medium for vegetable transplant production in both soil blocks and plastic flats.

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Methods

Environmental conditions. The experiment was conducted in the Iowa State University Department of Horticulture greenhouse in Ames, IA, USA (lat. 42.020370°N, long. −93.633790°W) in 2022 and 2023. Day and night temperatures were maintained between 21 °C and 23 °C. Supplemental light was provided by 1000-W high-pressure sodium lamps (AgroMax; Summerdale, AL, USA) to maintain a 16-hour daylight period with a light intensity of at least 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at bench height.

Plant material. Bell pepper (*Capsicum annum*, 'Yankee Bell') and cucumber (*Cucumus sativus* L., 'Marketmore 76') seeds were sown in either plastic propagation trays (referred to as flats) or soil blocks on 17 Jan 2022 and 16 Jan 2023. Flats with 50 cells (Product Code: 720463; T.O. Plastics, Otsego, MN, USA) were cut in half to create 25-cell flats and filled by hand with desired growing medium. Soil blocks were made as described by Coleman (1995). Each growing medium was hand mixed in a plastic tub with water at a ratio of three to one (by volume). Additional water was added as needed to achieve the necessary consistency for block release and growing medium adherence. The moistened growing medium was mounded and the Stand-up 12 Soil Blocker (Product ID: 7861.0; Johnny's Selected Seeds, Fairfield, ME, USA) was repeatedly pressed into the growing medium until each block well was filled. Blocks were released into a web-bottom carrying tray (Item#CF 2; Nolt's Greenhouse Supplies, Charles City, IA, USA) and arranged so each tray held 25 soil blocks. Cell and block size were chosen from available products to ensure the most equal size possible, taking into consideration the compression of the growing medium with the blocking tool. Flat cells measured 4.83 cm × 4.83 cm × 6.03 cm (140.7 cm^3) and soil blocks measured 4.76 cm × 4.44 cm × 4.13 cm (87.3 cm^3).

Pepper transplants were fertilized with 150 $mg \cdot L^{-1}$ Aqua Power™ 5-1-1 (JH Biotech, Inc., Ventura, CA, USA) 38 and 45 d after seeding (DAS) in 2022 and 2023. Cucumber transplants did not receive supplemental fertilization.

Growing media. The product information of all growing media evaluated specifically stated their appropriateness for use with the soil block method and flats and approval for use in certified organic production by the Organic Materials Review Institute. The growing media evaluated were Purple Cow Organics® "Seed Starter Mix" (Middleton, WI, USA), Cowsmo, Inc. "Green Potting Soil" (Cochrane, WI, USA), Beautiful Land Products® "Soil Blocking Mix" (Tipton, IA, USA), Vermont Compost Company® "Fort Vee" (Montpelier, VT, USA), and an in-house formulated custom laboratory mixture. In the text, the growing media are referred to as Purple, Cowsmo, BLP, Vermont, and Lab, respectively. Lab was composed of 50% peat (Sphagnum Peat Moss 0128; Premier Tech, QC, Canada), 25% compost, 12.5% perlite (Therm-O-Rock East, Inc., New Eagle, PA, USA), and 12.5% vermiculite (Premium Grade; Sungro Horticulture, Agawam, MA, USA) by volume. Compost was supplied by the Iowa State University Compost Facility (Ames, IA, USA), and made using certified organic methods from plant material and livestock manure. New growing media were purchased directly from the supplier or from an approved retailer in 2022 and 2023 (Gardener's Supply Company, Burlington, VT, USA).

Before seeding, in 2022 and 2023, samples of each growing medium were sent to AgSource Laboratories, LLC (Lincoln, NE, USA) for nutrient analysis by saturated media extraction method. In 2023, we performed additional physicochemical tests (bulk density and water-holding capacity) to better understand differences found among treatments in the previous year. The bulk density of each growing medium in flats was measured by hand-filling 50-cell flats of known volume with the growing medium, emptying the contents into a beaker, and oven-drying the sample. For the soil block method, blocks were made, weighed, and oven dried. Bulk density was calculated by dividing the oven-dry weight by the volume of the sample (Ali 2010). To determine the water-holding capacity of each growing medium, 10 g of air-dried medium were placed in a funnel with Whatman #1 filter paper, wetted with deionized water until fully saturated, covered with plastic wrap, left to drain for 6 hours, and weighed (Robertson et al. 1999). The water-holding capacity was calculated by first finding the water mass, by subtracting the dry medium weight from the wet medium weight. The water mass value for each medium was then divided by the dry medium weight, and multiplied by 100, resulting in the percent water-holding capacity. Bulk density and water-holding capacity measurements were averaged over three replicates to account for random variation in growing medium samples. Chemical and physicochemical properties for each growing medium are reported in Table 1 and Table 2, respectively. In addition, temperature probes (HOBO U12-008; Onset Computer Corporation, Bourne, MA, USA) were deployed 1 DAS to 38 DAS in 2023 to record the growing media temperature on an hourly basis. Probes were placed 2 cm below the medium surface in the center of the block or cell in the interior of the tray. Because of supply constraints, probes were placed in one flat and one soil block in one replication of BLP, Vermont, and Lab, for a total of six probes.

Table 1. Saturated media nutrient concentrations (in g·kg^{-1}) of five organic growing media in 2022 and 2023.

Media	Nitrate-N	Ammonium-N	P	K	Ca	Mg
			2022			
BLP[i]	4.2	139.0	53	509	87	50
Cowsmo	5.1	3.6	61	471	25	14
Lab	151.0	24.7	27	1432	66	39
Purple	251.0	26.3	31	256	153	141
Vermont	454.0	5.1	35	528	533	142
			2023			
BLP	20.0	95.5	50	609	82	48
Cowsmo	9.0	13.8	36	640	48	25
Lab	26.3	17.6	41	1005	64	35
Purple	194.0	6.0	13	1089	249	116
Vermont	364.0	6.9	49	697	424	124

[i] BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

On a weekly basis for the duration of pepper transplant growth, data were collected on the pH and electrical conductivity (EC) of the leachate of each growing medium by performing the pour-through extraction method (Torres et al. 2010). Pour-through leachate data were only collected from flats. The lack of division between soil blocks prohibited proper leachate collection, so pour-through extraction was not performed on soil blocks. In addition, pour-through was not performed on flats containing cucumbers because of the short growing time. Deionized water quantities were adjusted to ensure 50 mL of leachate was extracted from each flat after the removal of pepper transplants from destructive sampling.

Experimental design. The experimental design was a split-plot randomized complete block design with four replications. The transplant method was the whole plot factor and growing medium was the subplot factor. Pepper and cucumber transplants were grown with each growing medium in four 25-cell plastic trays and in four 25-block carrying trays (peppers, n = 1000 and cucumbers, n = 1000).

Table 2. Bulk density and water-holding capacity (WHC) of five organic growing media in 2023.

	Bulk density (g·cm^{-3})		
Media	Flat	Soil block	WHC (% of volume)
BLP[i]	0.06 f[ii]	0.21 d	680 a
Cowsmo	0.14 e	0.31 c	390 bc
Lab	0.14 e	0.37 b	287 c
Purple	0.16 e	0.46 a	296 bc
Vermont	0.13 e	0.40 b	402 b

[i] BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

[ii] Means followed by the same letter within the same column and year are not significantly different ($P \leq 0.05$).

Growth parameters. Seedling emergence data were collected for cucumbers 10 DAS and for peppers 15 DAS by counting the number of emerged seedlings in each flat and tray of soil blocks. Plant count data were collected at the time of the first destructive sampling of peppers, 36 DAS, and cucumbers, 22 DAS, by counting the number of plants in each flat and tray of soil blocks.

Five cucumber plants were selected for destructive sampling 22 DAS from the center of the flat or soil block carrying tray, leaving the exterior plants as guard plants. Pepper transplants were destructively sampled three times: 36 DAS, 43 DAS, and 50 DAS. At each sampling, three pepper plants were selected from the center of the flat or soil block tray, leaving the exterior plants as guard plants. Pepper destructive sampling data are only presented from the final sampling, 50 DAS.

Growth measurements collected include plant height and stem diameter. Plant height was measured from the surface of the growing medium to the apical meristem with a ruler. Stem diameter was measured 1 cm below the cotyledon leaves with digital Vernier calipers (VWR International, LLC, Radnor, PA, USA).

After growth parameter measurements were taken, the roots of each cucumber and pepper transplant were thoroughly and carefully washed to remove the remaining growing medium. After washing, plants were placed in a forced-air oven at 67 °C for 7 d until a constant weight was reached. The whole plant dry weight was recorded. Dry cucumber whole plant tissue was ground to a uniform size and sent to Ward Laboratories, Inc. (Kearney, NE, USA) for plant tissue analysis (Table 4). Pepper plant tissue was not analyzed because supplemental fertilization remediated growing medium induced nutrient deficiencies in the plant tissue.

Root system parameters. One transplant was reserved from the final pepper sampling and from the cucumber sampling from each treatment for further root system analysis. The day following destructive sampling, roots were removed at the crown from each plant and placed in water to rehydrate. Roots were prepared, scanned (Epson Perfection V800; Epson America, Inc., Los Alamitos, CA, USA), and analyzed with the WinRHIZO® Reg software (Regent Instruments Inc., Quebec City, Quebec, Canada) according to methods described by Suchoff et al. (2017) for root surface area. In 2023, data of pepper roots from soil blocks were not analyzed because of damage during sampling. Therefore, pepper root analysis was only performed in 2022.

Statistical analysis. Analysis of variance was performed with the PROC GLIMMIX procedure in SAS (version 9.4; SAS Institute, Cary, NC, USA). Data from each year and week of pepper transplant sampling were analyzed separately because of significant interactions between years and between weeks. Pour-through extraction data from each year were analyzed separately by week, because of a significant week by media interaction. All response variables were tested with method and growing medium as the fixed terms and replication as the random term. When no significant interaction was found for a response variable, the effect of the fixed terms was analyzed individually by partitioning method and media variables with the "slice" statement. The least significant differences were found for response variables at $P \leq 0.05$.

Results

Growing media properties

pH and EC. The pH increased on average by 0.8 in 2022 and 0.9 in 2023 throughout the weeks of sampling (WOS) (Table 3). Lab displayed a higher pH than the other growing media in all 6 WOS in both years, except Cowsmo had a similar pH to Lab in all WOS in 2022. In 2022, Purple and Vermont had the lowest pH in 1 and 2 WOS, and in 6 WOS Vermont (6.1) and BLP (6.1) had the lowest pH. In 2023, BLP and Vermont consistently had the lowest pH.

The EC of all media decreased on average by 5.03 mS·cm^{-1} in 2022 and 4.76 mS·cm^{-1} in 2023 throughout the 6 WOS (Table 3). In 2022, Vermont exhibited a higher EC than the other media from 1 WOS (7.82 mS·cm^{-1}) until 5 WOS (2.69 mS·cm^{-1}). In 2022, the EC of Purple reached 1.64 mS·cm^{-1} in 3 WOS, whereas the other growing media did not reach an EC below 2.00 mS·cm^{-1} until 5 WOS (BLP, Cowsmo, and Lab) or 6 WOS (Vermont). In 2023, all growing media reached an EC below 2.00 mS·cm^{-1} in 6 WOS, except Cowsmo, which had an EC of 3.19 mS·cm^{-1} in the final WOS.

Bulk density. Growing media bulk density was between 76% and 111% greater in soil blocks than in flats (Table 2). In soil blocks, Purple displayed the greatest bulk density (0.46 g·cm^{-3}), whereas BLP had the lowest (0.21 g·cm^{-3}). In flats, all media displayed a similar bulk density.

Table 3. pH and electrical conductivity (EC) of five growing media in 2022 and 2023.[i]

Media	pH						EC ($mS \cdot cm^{-1}$)					
	Week 1	Week 2	Week 3[ii]	Week 4	Week 5	Week 6	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
						2022						
BLP[iii]	5.7 b[iv]	5.9 b	—	5.9 c	6.0 b	6.1 c	6.29 b	4.29 b	2.84 b	2.21 b	1.41 bc	1.04
Cowsmo	6.8 a	7.0 a	—	7.3 a	7.3 a	7.4 a	4.77 c	3.44 bc	2.77 b	2.18 b	1.93 b	1.40
Lab	6.8 a	6.9 a	—	7.2 a	7.3 a	7.3 a	6.48 b	4.62 b	2.94 b	2.19 b	1.88 b	1.24
Purple	5.2 c	5.4 c	—	6.1 b	6.1 b	6.5 b	5.65 b	2.94 c	1.64 c	1.47 c	1.16 c	0.98
Vermont	5.1 c	5.3 c	—	5.6 c	6.0 b	6.1 c	7.82 a	6.66 a	5.16 a	3.87 a	2.69 a	1.18
						2023						
BLP	5.6 c	5.7 d	5.4 d	5.6 d	5.7 d	6.2 e	6.36 b	5.23 b	4.75 bc	2.98	2.20 c	1.78 d
Cowsmo	6.4 b	6.7 b	6.8 b	6.9 b	7.0 b	7.2 c	6.31 b	5.18 b	4.79 bc	3.74	3.91 a	3.19 a
Lab	6.8 a	7.0 a	7.1 a	7.3 a	7.5 a	7.7 a	6.15 b	5.05 b	4.23 c	2.89	2.83 b	1.96 b
Purple	6.4 b	6.5 c	6.7 b	6.9 b	7.1 b	7.4 b	7.55 a	6.50 a	5.82 a	3.73	3.21 ab	1.64 bc
Vermont	5.5 c	5.6 d	5.7 c	6.2 c	6.4 c	6.8 d	7.39 a	6.38 a	5.55 ab	3.13	2.75 bc	1.40 cd

[i] pH and EC measurements collected by performing the pour-through method (Torres et al. 2010) in central data cells of plastic flats containing pepper plants.

[ii] Week 3 pH data were not collected.

[iii] BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA), Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA), Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume, Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA), and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

[iv] Means followed by the same letter within the same column and year are not significantly different ($P \leq 0.05$).

Water-holding capacity. Water-holding capacity differed between growing media. BLP (680%) exhibited the greatest water-holding capacity, whereas Lab (287%) exhibited a lower water-holding capacity compared with BLP and Vermont (Table 2).

Cucumber and pepper emergence and plant count

Cucumbers. In 2022, cucumbers seeded in Cowsmo, Lab, and Vermont showed between 42% and 46% higher emergence in flats than in soil blocks (Table 5). In soil blocks, cucumber emergence was 23% greater in BLP and 32% greater in Purple than in Cowsmo, Lab, and Vermont. In flats, cucumber emergence was similar between media. Cucumber plant count was higher in flats compared with soil blocks with Vermont, Lab, and Cowsmo. No differences were found in cucumber emergence and plant count between treatments in 2023.

Peppers. In 2022, peppers seeded in Lab and Purple showed a 45% and 26% higher emergence in flats than soil blocks, respectively (Table 5). Pepper plant count was similar between flats and soil blocks for all media in 2022, except Lab produced a 38% lower plant count in soil blocks than flats. Across all media in 2023, pepper emergence was 33% higher in flats than in soil blocks, whereas no differences between the media were found. Pepper plant count was similar among all treatments in 2023.

Table 4. Cucumber whole plant nutrient concentrations from five organic growing media in 2022 and 2023.

Media	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
			2022		
BLP[i]	5.1 a[ii]	1.34 a	7.3 b	1.1 c	0.55 c
Cowsmo	1.7 c	0.75 c	5.1 d	0.7 c	0.39 d
Lab	4.2 b	0.83 c	8.4 a	1.0 c	0.49 cd
Purple	5.1 a	0.96 b	5.9 c	2.1 b	1.30 a
Vermont	5.8 a	0.95 b	6.3 c	3.1 a	0.73 d
			2023		
BLP	4.4 b	1.12 a	6.5 ab	1.2 c	0.46 c
Cowsmo	1.6 e	0.62 c	5.3 c	0.7 d	0.41 d
Lab	2.1 d	0.67 c	6.6 a	0.7 d	0.39 d
Purple	3.6 c	0.60 c	6.5 ab	1.4 b	0.62 b
Vermont	4.9 a	0.86 b	6.2 b	2.5 a	0.68 a

[i] BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

[ii] Means followed by the same letter within the same column and year are not different ($P \leq 0.05$).

Table 5. Emergence and plant count of cucumber and pepper transplants grown in different growing media in soil blocks (SB) and flats (F) in 2022 and 2023.[i]

Method	Media	Cucumber		Pepper	
		Emergence	Plant count	Emergence	Plant count
			2022		
F	BLP[ii]	24 a[iii]	24 ab	23 a	23 ab
SB	BLP	20 a	20 abc	21 ab	21 b
F	Cowsmo	25 a	25 a	23 a	24 a
SB	Cowsmo	16 b	17 d	23 a	24 a
F	Lab	25 a	25 a	23 a	24 a
SB	Lab	16 b	18 cd	15 c	17 c
F	Purple	24 a	24 a	23 a	24 a
SB	Purple	22 a	23 ab	18 bc	23 ab
F	Vermont	25 a	24 a	24 a	25 a
SB	Vermont	16 b	19 bcd	22 a	23 a
			2023		
F	BLP	24	24	23 ab	24
SB	BLP	24	25	15 d	23
F	Cowsmo	24	24	22 ab	23
SB	Cowsmo	23	24	17 cd	24
F	Lab	25	25	24 a	24
SB	Lab	23	24	17 cd	24
F	Purple	24	25	23 ab	23
SB	Purple	24	24	19 bc	23
F	Vermont	24	24	22 ab	23
SB	Vermont	21	21	14 d	23

[i] Emergence data collected 10 d after seeding (DAS) cucumbers and 15 DAS peppers. Plant count data collected at time of first sampling, 22 DAS cucumbers and 36 DAS peppers. All numbers out of 25 total cells or blocks.

[ii] BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

[iii] Means followed by the same letter within the same column and year are not different ($P \leq 0.05$).

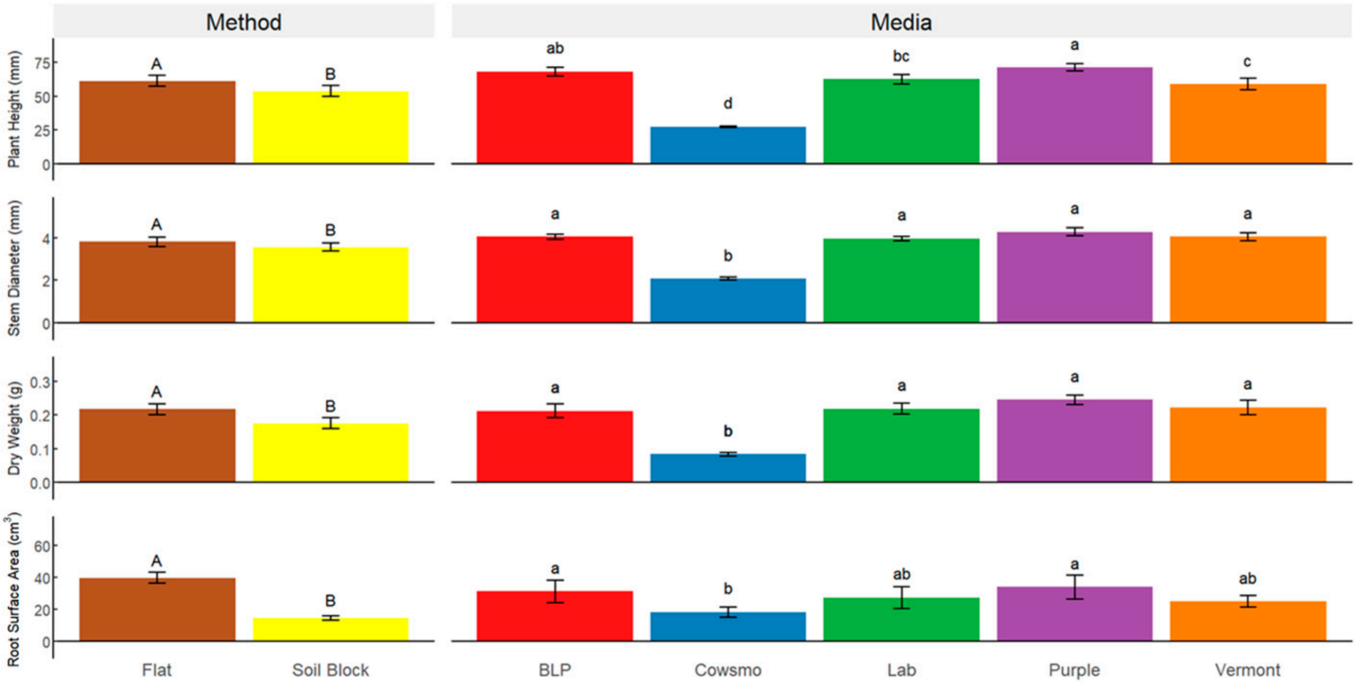

Fig. 1. Cucumber growth parameters when grown in flats, soil blocks, and with five different growing media in the Iowa State University Horticulture greenhouse in Ames, IA, in 2022. Mean separation for whole plot factor, method, represented by capital letters. Mean separation for subplot factor, media, represented by lower case letters ($P \leq 0.05$). BLP represents Beautiful Land Products “Soil Blocking Mix” (Tipton, IA, USA); Cowsmo represents Cowsmo “Green Potting Soil” (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics “Seed Starter Mix” (Middleton, WI, USA); and Vermont represents Vermont Compost Company “Fort Vee” (Montpelier, VT, USA).

Transplant growth parameters

Dry weight. Cucumber dry weight was greater in flats than soil blocks by 20% in 2022 (Fig. 1) and 38% in 2023 (Fig. 2). All media produced cucumbers with similar dry weight in 2022, except Cowsmo-grown cucumbers exhibited between 90% and 103% lower dry weight than all other media. In 2023, cucumbers grown with Lab and Cowsmo exhibited a lower dry weight than cucumbers grown with BLP, Purple, and Vermont.

In 2022, pepper dry weight was between 50% and 130% greater in soil blocks than flats for all media, except Cowsmo. Cowsmo-grown peppers had a similar dry weight in both methods in 2022 (Fig. 3), but dry weight was consistently lower than all other treatments in both years. In 2022, Purple in soil blocks (1.22 g) and Vermont in soil blocks (1.18 g) produced the largest pepper dry weights. In 2023, the largest pepper dry weights were found in BLP in soil blocks (0.55 g), Purple in soil blocks (0.59 g), and Vermont in flats (0.58 g) (Fig. 4). In 2023, no differences in dry weight were found between peppers grown in flats and soil blocks.

Plant height. In 2022, cucumber plants were 13% taller in flats than in soil blocks (Fig. 1). In 2023, Cowsmo- and Vermont-grown cucumber plants were 39% and 30% taller in flats than soil blocks, respectively, and all other media produced plants with a similar height in both methods (Fig. 2). Cucumber plants grown in BLP (68 mm) and Purple (71 mm) were the tallest in 2022. In 2023, the tallest cucumber plants were found in BLP in flats (78 mm) and soil blocks (85 mm) and Vermont in flats (90 mm). Cucumber plants in Cowsmo were 48% to 96% shorter than all other media in both years.

In 2022, pepper plants were between 47% and 74% taller in soil blocks than flats in all media, except Cowsmo, which produced peppers with a similar height in both methods (Fig. 3). In 2023, BLP and Purple produced taller peppers in soil blocks than in flats, by 18% and 30%, respectively (Fig. 4). Pepper plants were tallest with Vermont, Purple, and BLP in soil blocks, and, in 2023, Vermont in flats as well. Cowsmo in soil blocks consistently produced peppers that were between 97% and 166% shorter than all other media in either method.

Stem diameter. Cucumber stem diameter was 7% larger in flats than in soil blocks in 2022 (Fig. 1). In 2023, Cowsmo and Vermont produced cucumbers with 20% and 14% larger stem diameters in flats than in soil blocks, respectively, while all other media produced a similar stem diameter in both methods (Fig. 2). In 2023, Vermont in flats displayed a larger cucumber stem diameter than all other treatments. Cowsmo in soil blocks consistently produced cucumbers with a smaller stem diameter than all other media in either method.

In 2022, peppers in soil blocks exhibited a 26% larger stem diameter than in flats (Fig. 3). In 2023, peppers grown with BLP, Lab, and Purple had larger stem diameters in soil blocks than in flats (Fig. 4). The largest pepper stem diameters were found in BLP, Vermont, and Purple in 2022, and with those same media in soil blocks in 2023. Cowsmo in soil blocks consistently produced smaller pepper stem diameter than all other media in either method.

Root surface area. Cucumber root surface area was 92% and 118% larger in flats than in soil blocks in 2022 (Fig. 1) and 2023 (Fig. 2), respectively. Cowsmo in flats and soil blocks produced between 171% and 193% smaller pepper root surface area than all other treatments. Pepper root surface area with Purple produced 52% to 193% larger root surface area than all other treatments (Fig. 3). In 2023, no differences between media were found in cucumber root surface area.

Discussion

Peppers grown in soil blocks tended to have lower emergence at 15 DAS than those in flats, seen across all media in 2023 and with Lab and Purple in 2022 (Table 5). Although pepper plant count between methods was not different at the time of plant count data collection (36 DAS), apart from Lab in 2022, the lack of continued disparity from emergence (15 DAS) to plant count (36 DAS) between methods indicates a delay in pepper emergence in soil blocks, as opposed to a reduction in germination. The seedling environment as determined by the transplant method, specifically the growing medium temperature and bulk density, may help explain the delay in emergence found in peppers in soil blocks.

Flats used were made of black plastic, which conducts heat from artificial lighting and solar radiation into the growing medium.

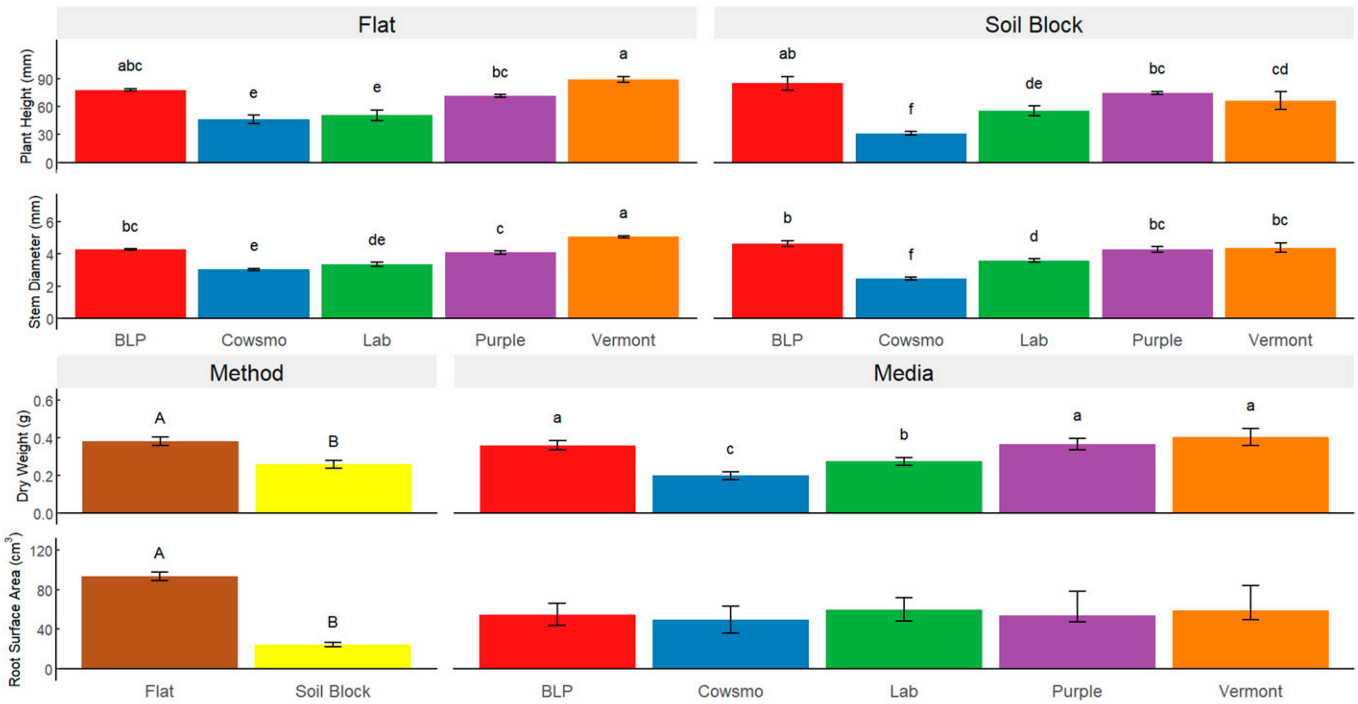

Fig. 2. Cucumber growth parameters when grown in flats, soil blocks, and with five different growing media in the Iowa State University Horticulture greenhouse in Ames, IA, in 2023. Interaction between method and media found for plant height and stem diameter, therefore, mean separation represents method by media effect. No interaction between method and media found for dry weight and root surface area, therefore, mean separation for whole plot factor, method, is represented by capital letters and mean separation for subplot factor, media, is represented by lower case letters ($P \leq 0.05$). BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

The growing media within flats was on average 3 °C higher as compared with soil blocks, 21.3 °C in flats and 18.5 °C in soil blocks. This increase in medium temperature is similar to what is found in containerized production in black pots (Ingram et al. 2003; Markham et al. 2011). An increase in growing medium temperature, without exceeding an ideal range, can lead to more rapid germination and seedling emergence (Cantliffe 1998). Research found 'Dasher II' cucumbers to reach 80% germination 2 DAS at 15 °C, 1.5 DAS at 20 °C, and 0.75 DAS at 25 °C (Jennings and Saltveit 1994). This reduction in hours to germination in temperatures above 20 °C has also been found in hot peppers (*Capsicum baccatum* var. *pendulum*), reaching 50% germination after 10 DAS at 15 °C, 8 DAS at 20 °C, and 7.5 DAS at 25 °C (Silva et al. 2012). Therefore, the faster emergence of peppers in flats as compared with soil blocks may be partly explained by the higher medium temperature with that method.

An additional factor that may have affected pepper emergence rates was the difference in growing medium bulk density between methods. The bulk density of the growing media was between 137% and 237% higher in soil blocks as compared with the same medium in flats. The compression of moistened growing media into the blocker tool, required to make soil blocks, helps explain the higher bulk density. A higher bulk density imparts an increase in overall compaction and a reduction in available oxygen, as pore space is reduced, and medium solids make up a higher proportion of the block after compression (Gruda et al. 2013; Hanks and Thorp 1956; Sabahy et al. 2015). Without adequate pore space for air and water, root respiration and root metabolic activity are reduced, and overall root growth is inhibited (Green 1976). Furthermore, research has shown pepper seedling emergence to be slowed by 3 to 5 d in field plots with higher compaction (Fawusi 1978). Research has also shown an oxygen-reduced environment, as found with a higher bulk density, increased the number of days required to reach 50% germination in Brassicaceae, Apiaceae, Asteraceae, and Amaranthaceae seeds (Yasin and Andreasen 2016), as most seeds require an aerobic environment to germinate (Cantliffe 1998). The greater bulk density in soil blocks, with a proportionate decrease in the available air and water pore space, may have contributed to a slower emergence of peppers in soil blocks as compared with flats.

As research on soil blocks is limited, bulk density comparison between this study and others is not possible. Further, soil block making is highly variable, using a hand tool and varying levels of compression. Considering the importance of bulk density for root growth and seed germination, an evaluation of appropriate block-making technique and ideal block bulk density has the potential to optimize soil blocks for transplant production. Future research should compare transplants grown in flats and soil blocks with the same bulk density to better elucidate differences found in transplant performance and seedling emergence.

Although peppers grown in soil blocks experienced a delay in emergence, at 50 DAS peppers grown in soil blocks often outperformed peppers grown with the same media in flats. In 2022, soil block–grown peppers with BLP, Lab, Purple, and Vermont displayed a greater plant height, stem diameter, and dry weight than in flats with the same media (Fig. 3). And, in 2023, peppers in soil blocks displayed a greater plant height (BLP and Purple), dry weight (Purple), and stem diameter (BLP, Lab, and Purple) than those grown in flats (Fig. 4).

In contrast to what was found in peppers, cucumbers showed no difference in emergence between methods in 2023 (Table 5). In addition, cucumbers grown in flats had a larger dry weight than those in soil blocks (Fig. 2). An emergence delay, resulting in a slower growth rate and final dry weight, may have occurred in cucumbers in soil blocks, but not be represented in the data. Cucumber emergence data were collected at 10 DAS, although cucumbers are known to germinate and emerge in 2 DAS (Jennings and Saltveit 1994). Collecting emergence data at 10 DAS may not have accurately captured a delay. Therefore, it is possible that a reduction in growing medium temperature and increased bulk density in soil blocks may have resulted in a slower cucumber growth rate that could not be overcome before destructive sampling at 22 DAS.

The overall study findings showed peppers performing better in soil blocks and cucumbers performing better in flats. This may

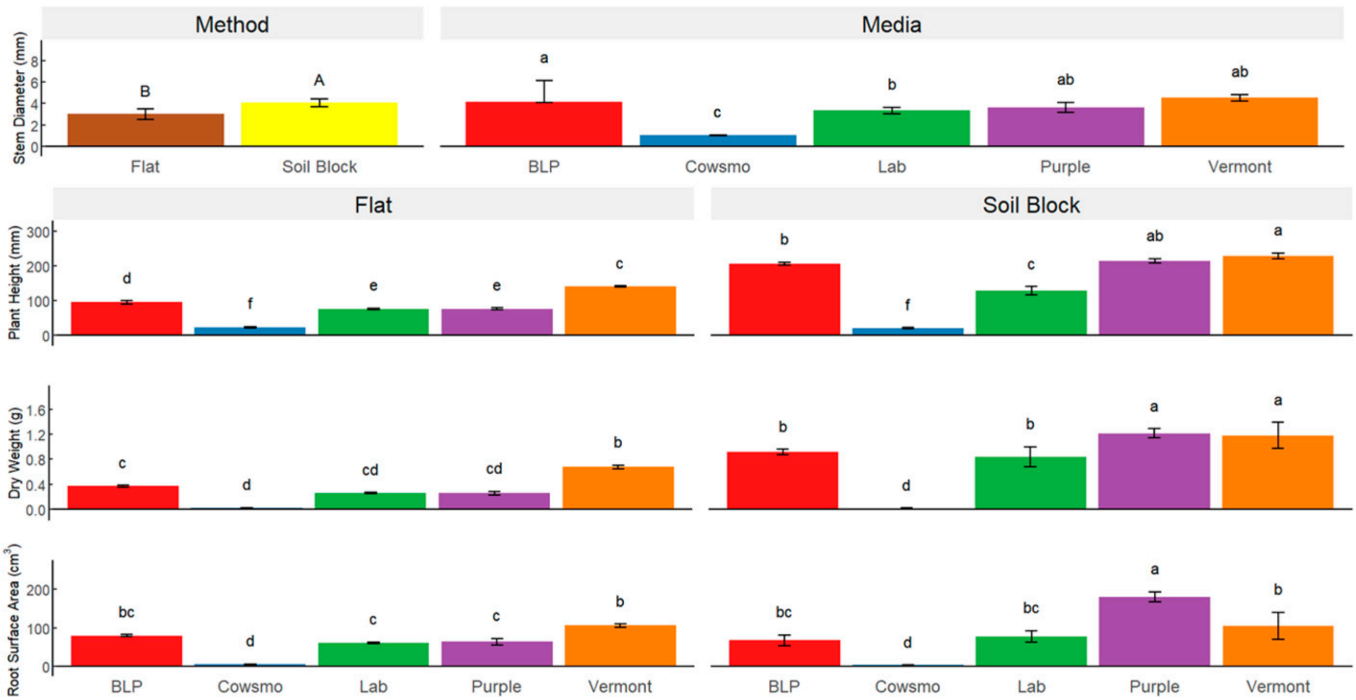

Fig. 3. Pepper growth parameters when grown in flats, soil blocks, and with five different growing media in the Iowa State University Horticulture greenhouse in Ames, IA in 2022. Interaction between method and media found for plant height, dry weight, and root surface area, therefore, mean separation represents method by media effect. No interaction between method and media found for stem diameter, therefore, mean separation for whole plot factor, method, is represented by capital letters and mean separation for subplot factor, media, represented by lower case letters ($P \leq 0.05$). BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

be partly explained by a delay in emergence in soil blocks, which peppers were able to overcome with a longer transplant growth period, and cucumbers were not. The research available on soil blocks in vegetable production is mostly limited to evaluations of the in-field performance and yield from soil block and flat grown transplants. Therefore, we are unable to compare our results with other work.

The second aim of this study was to evaluate the suitability of four commercially

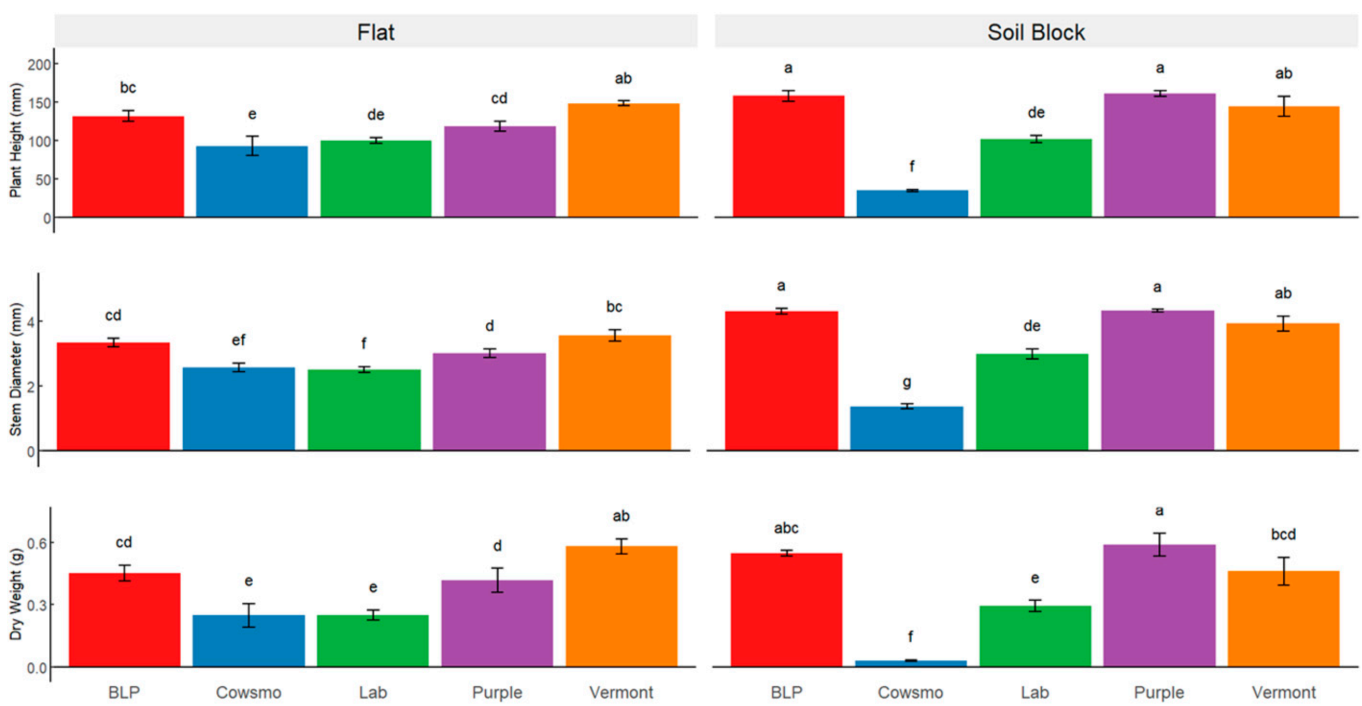

Fig. 4. Pepper growth parameters when grown in flats, soil blocks, and with five different growing media in the Iowa State University Horticulture greenhouse in Ames, IA, in 2023. Interaction between method and media found for all variables. Mean separation represents method by media effect ($P \leq 0.05$). BLP represents Beautiful Land Products "Soil Blocking Mix" (Tipton, IA, USA); Cowsmo represents Cowsmo "Green Potting Soil" (Cochrane, WI, USA); Lab represents a custom laboratory mixture of 50% peat, 25% compost, 12.5% perlite, and 12.5% vermiculite by volume; Purple represents Purple Cow Organics "Seed Starter Mix" (Middleton, WI, USA); and Vermont represents Vermont Compost Company "Fort Vee" (Montpelier, VT, USA).

available certified organic growing media. Many differences were found between growing medium nutrient concentrations and physical properties. The results of this investigation show that BLP and Purple performed similarly to Vermont, whereas Cowsmo stunted cucumber and pepper plant growth, and Lab performed better only than Cowsmo.

BLP displayed the lowest bulk density when used in both flats and soil blocks (Table 2), but still increased by 250% in soil blocks compared with in flats. In addition, BLP exhibited the highest water-holding capacity out of the media evaluated (680%). The companies that developed the products evaluated in this study list medium ingredients without proportions. BLP was the only medium that did not contain compost and appeared to have a higher proportion of peat than the other mixes. Peat is highly porous, with a low bulk density and a high water-holding capacity (Kubota et al. 2013). When comparing soilless medium mixes, studies have found that an increase in the proportion of compost in the mix correlates with an increase in bulk density (Chrysargyris et al. 2019; Wilson et al. 2002). In addition, higher proportions of compost in relation to peat in a mix can lower the water-holding capacity of the medium (Papafotiou et al. 2005). Our study supports the previous findings. Yet, properties are variable by type of compost used and, more specifically, particle size (Carlile et al. 2019). Growing medium for the soil block method is most often recommended to possess a high water-holding capacity and fibrous materials, such as peat, to help hold the block form together (Coleman 1995; Kasten 2019). BLP meets this criterion. The other media evaluated also held together well in block form, although longevity of block cohesion was not within the parameters of this study.

The EC of all the growing media was far above the general guideline of 2 $mS \cdot cm^{-1}$ for optimum plant growth (Ozores-Hampton et al. 1998), and often above 4 $mS \cdot cm^{-1}$, which can limit plant growth (Ozores-Hampton et al. 1998; Willumsen 1997). One of the challenges with soilless medium mixes containing compost is the risk of high EC, but great variability exists depending on the components and process used to make the compost (Balliu 2017). The EC of all the growing media reduced each week of sampling, as irrigation leached excess salts and the growing plants took up nutrients. Even though most of the growing media had an EC outside the optimum range (<4.0 $mS \cdot cm^{-1}$) in the first 2 to 3 weeks of pepper growth, peppers exhibited healthy growth and no signs of salinity stress. This finding may help inform growers and researchers that guidelines should be revisited for EC limits to plant health in soilless mixes.

Cowsmo performed poorly, with transplants displaying lower plant height, stem diameter, and dry weight in both cucumbers and peppers compared with almost all other media with either method. Visible stunting occurred in cucumbers and peppers grown in Cowsmo. Despite similar bulk density and water-holding capacity with the other growing media, Cowsmo displayed 177% to 193% lower total plant available nitrogen (nitrate-N and ammonium-N) concentration than the other media in 2022 and 63% to 177% lower in 2023 (Table 1). Nitrogen is one of the most essential elements for plant growth, contributing to photosynthesis, protein formation, and overall growth. Symptoms of nitrogen deficiency in seedlings include stunting and chlorosis (Uchida 2000). Tissue analysis confirmed a lower amount of plant available nitrogen in Cowsmo, with cucumber plant tissue containing up to 105% lower percentage of nitrogen when grown in Cowsmo than in all other media (Table 4).

The media did not perform consistently in flats and soil blocks, resulting in a significant method by media interaction for most pepper growth parameters. Although peppers grown with BLP, Purple, and Lab in soil blocks performed better than in flats across most metrics in both years, Vermont performed better in flats than in soil blocks across some metrics. In addition, Purple performed well in soil blocks, with the greatest plant height, stem diameter, and dry weight in 2023 (Fig. 4). But, in flats, peppers grown with Purple had the smallest plant height, stem diameter, and dry weight in both years and smallest root surface area in 2022, excluding Lab and Cowsmo. These inconsistencies in pepper performance, depending on both medium and method, led to an inability to parse out a clear method or media affect. As such, the data are presented for each method by media variable when an interaction was found, in contrast to the whole plot and subplot factor presented independently in other parameters.

BLP, Purple, and Vermont can all be considered suitable for growing certified organic vegetable transplants in both soil blocks and flats, whereas Cowsmo should undergo further investigation before continued usage. Our results are contrary to what was found in an on-farm trial, which found Cowsmo-grown broccoli and tomato transplants compared similarly or better to Vermont and a different growing media from Beautiful Land Products (Liddle et al. 2021). Unfortunately, no information regarding growing media analysis from the trial is available to compare with the products used in this study. Although new media was purchased each year during this experiment, variability has been reported within retail potting mix brands and many commercially available products (Wiberg et al. 2006).

The claims surrounding soil block–grown transplants assert that there is an increase in the vegetable transplant root system, due to increased lateral root growth and a lack of root circling (Coleman 1995; Pill and Stubbolo 1986; Tresemer 1983). Our findings do not support these claims, as we did not see a general increase in root surface area in transplants grown with the soil block method. Instead, root growth of peppers and cucumbers correlated with shoot growth, irrespective of method. Cucumbers had a greater root surface area in flats in both years, corresponding with a greater plant height, stem diameter, and dry weight in flats. In addition, in 2022, pepper root surface area did not show differences between methods, except for Purple, which showed a greater root surface area in soil blocks as compared with flats. Further research should look specifically at the architecture of the root system to further understand the impact the soil block method has on vegetable transplant root development.

The lack of physical barriers between soil blocks is claimed to reduce root circling by allowing for air pruning (Coleman 1995; Pill and Stubbolo 1986; Tresemer 1983). We did not witness air pruning, as the air separating blocks became filled with surrounding media during watering. If underwatering was used, instead of the traditional overhead watering that we performed, the air gaps between blocks may be preserved and allow for air pruning. The presence of air gaps may also limit the tendency of transplants to grow into neighboring soil blocks. If this occurs, separating the blocks for transplanting would result in a large amount of root damage, leading to reduction in yields. Others have indicated this tendency as a challenge with soil blocks (Greer and Adam 2005). To prevent this from occurring, establishing the correct size of block and time to transplant is essential. Many favor transplanting relatively young transplants (Balliu 2017), which may be encouraged by the need to stop transplant growth before roots outgrow their individual block.

A natural progression of this work is to analyze the performance of soil block–grown vegetable transplants in the field. Our research was limited to the greenhouse phase and data on in-field performance would be revelatory, allowing for an investigation of the claims of a reduction in transplant shock and increased yields when using this method.

Making soil blocks is a time-consuming and labor-intensive process, especially when compared with the relative ease of filling a flat. The benefit of on-farm plastic reduction can be a significant driver for many growers looking for alternatives to flats (FAO 2021), but the labor cost of using soil blocks on a commercial scale should be investigated further. In addition, by compressing growing media when soil blocks are made, more growing media is used per block than per cell. This additional cost and resource use should be considered, especially as peat continues to be a major component of most growing media. Peat is a non-renewable resource under threat of overexploitation (Nesse et al. 2019); therefore, any reduction in the amount of media used can result in resource conservation and environment benefit.

Conclusion

Our work demonstrated that pepper transplants performed better in soil blocks, whereas cucumber transplants performed better in flats. A significant advantage to the root system of transplants grown in soil blocks was not found, although future research should examine the differences in root system morphology produced between flat and soil block–grown transplants. More work needs to be done to examine the in-field performance of soil block–grown vegetable transplants and assess transplant shock. Cowsmo stunted pepper and cucumber growth, whereas BLP, Purple, and Vermont produced healthy and vigorous transplants. Our findings are relevant for certified organic vegetable transplant producers in the midwestern United States looking to use regionally produced growing media, potentially limiting shipping costs and carbon footprint. Very limited research is available regarding the soil block method, even as it maintains popularity among small and medium-sized growers. More information and continued research on soil blocks would be of great value, establishing optimal bulk density parameters and improving understanding of the impact this method has on vegetable transplant performance.

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