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Optimization of Soilless Media for Alkaline Irrigation Water

Cody Tramp, Julie Chard, and Bruce Bugbee

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ABSTRACT

High root zone pH reduces nutrient availability and high alkalinity water is strongly buffered around an alkaline pH. Soilless media can be altered to improve nutrient availability. This study was conducted to optimize the composition of soilless media for use with high alkalinity water. Mixes of peat and/or perlite or vermiculite in 50/50 and 33/33/33 volumetric ratios were tested. In some studies, mixes were also amended with up to 2.4 g/L of dolomite limestone to neutralize the initial acidity of the peat. Mixes containing vermiculite settled more, had higher water holding capacity (WHC) and percent plant available water (%PAW), and similar air filled porosity (AFP), compared to mixes containing perlite. Dry mass was measured in corn, peas, tomatoes, and soybeans, and chlorophyll content was measured in corn. The addition of dolomite increased pH and decreased dry mass in corn, soybean, and tomato, but peas were unaffected. Chlorophyll content in corn also declined with increased amounts of dolomite. After a week of daily irrigation, pH 7.8 nutrient solution neutralized the acidity of the peat, without the need for addition of dolomite. Mixes containing vermiculite improved growth and chlorophyll concentration compared to mixes with perlite. The higher cation exchange capacity (CEC) of vermiculite-containing mixes may have improved nutrient availability. A soilless mix of only peat and vermiculite, in approximately equal volumes, resulted in the greatest growth and chlorophyll content when watered with high alkalinity nutrient solution.

INTRODUCTION

Alkalinity is the measure of the ability of water to raise pH (Nelson, 2003). It is measured through the amount of carbonate and bicarbonate present in the water. Water with a high alkalinity value is able to change the pH of soil or other solutions, and to strongly buffer the solution at the alkaline pH, strongly resisting further pH changes.

Cation exchange capacity is the sum of the exchangeable cations that a material can absorb per unit weight, and it plays a major role in making nutrients available to plants. A media's air filled porosity (AFP) is a measure of the percent of wet media volume that is occupied by air; an AFP of 10-13% is considered sufficient for pots at least 15 cm deep (Handreck and Black, 2002). AFP values vary as a function of depth within a media. In this study AFP values were calculated as an average throughout the pot, rather than at a specific depth. The water holding capacity (WHC) is a measurement of the percent of the media volume in a drained pot that is occupied by water. WHC is not the same as the plant available water (PAW), which is the amount of water in the media that is available for use by the plants.

Peat moss drains well, and has a high cation exchange capacity (CEC) and high PAW (Bunt, 1988; Nelson, 2003; Rippy and Nelson, 2007). Perlite is used in soilless media to increase

aeration and to decrease cost (Handreck and Black, 2002). Vermiculite has a high CEC and high PAW, with a lower AFP than peat or perlite (Nelson, 2003). Vermiculite is packaged in several grades, based on particle size. Medium vermiculite consists of particles smaller than 4 mm, and fine vermiculite consists of particles smaller than 2 mm (The Vermiculite Association, 2006). Dolomite is commonly added to media to compensate for the low pH of peat moss (~ 4.5) by providing additional carbonate and bicarbonate and to provide an additional source of calcium and magnesium (Handreck and Black, 2002).

Plant health can be assessed via the dry mass of the plant and the concentration of chlorophyll in the most recently developed leaves. Chlorosis, an indicator of poor plant health often due to iron deficiency, was observed in corn grown in a soilless media containing peat moss, perlite, and dolomite, prompting these studies.

The objectives of these studies were to assess the effects of the media components on fresh mass, dry mass, and chlorophyll content of several crop species watered with high alkalinity nutrient solutions.

MATERIALS AND METHODS

Media Mixes

The soilless media in these studies were composed of combinations of Sunshine® brand Sphagnum Peat Moss, Expanded Perlite manufactured by Hess Pumice, Therm-O-Rock, Inc. fine vermiculite, and Chemical Lime 65 AG Dolomite. Fine vermiculite was used in all of the experiments; medium vermiculite was used only in the comparisons of vermiculite properties. Pots were prepared, depending on the study, using the volumetric ratios of 50/50 peat/perlite, 33/33/33 peat/perlite/vermiculite, or 50/50 peat/vermiculite. Some pots were amended and mixed well with 0.0 g/L, 0.3 g/L, 0.9 g/L, or 2.4 g/L dolomite.

Nutrient Solution

The nutrient solution used in these studies consisted of 5 kg of Peter's 20-10-20 Peat-Lite® Fertilizer and 1 g Fe-EDDHA (iron(III) ethylenediamine-N,N'-bis(2-hydroxyphenyl-acetic acid)) dissolved in 100 L de-ionized water, and diluted 1:100 with tap water by a Dosatron® proportioner. The pure tap water and diluted nutrient solution both had a pH of approximately 7.8. The dilute solution was added to the pots via a dripper-line system. In one experiment pots were watered to excess once every other day. In all other experiments pots were watered for one minute twice a day, at 8 am and 6 pm.

Method of Media Packing

Each pot had a total volume of 4.0 L and a height of 15 cm. Pot volume was determined by blocking all the drainage holes and filling the pot with water. The diameter at the rim was 21.5 cm and diameter did not change for the first 5 cm from the rim, and then decreased constantly to 16 cm at the base. The pots were initially filled above the pot rim with dry media and tapped against the table ten times to allow the media to settle. If the media settled below the rim, additional dry media was then added to bring the volume above the pot rim and media was tapped five more times to settle. If media remained above the rim, it was leveled off, giving each pot exactly 4.0 L of total media volume.

Planting

Packed pots were thoroughly soaked with tap water prior to planting. Seeds of corn, soybean, tomato or pea were sown into the soaked media. One week after planting, pots were thinned to a uniform number of plants.

Chlorophyll Readings

Chlorophyll readings were taken on corn plants with an Opti-Sciences CCM-200 Chlorophyll Content Meter on the newest fully-expanded leaf. Twelve measurements were taken per pot, four samples from each of the newest fully-developed leaves on the three plants in each pot, and were averaged together to give an average Chlorophyll Content Index (CCI) for each pot.

Fresh and Dry Mass Measurements

Freshly harvested shoots were weighed and then dried at 80 °C for 72 hours inside a forced air oven. Dry mass was then recorded.

Chelated Iron Treatments

Each 4 L pot was watered with 150 mL of a 2 mM $\text{FeCl}_2 \cdot 6\text{H}_2\text{O}$ + 2mM N-hydroxyethyl-ethylenediaminetriacetic acid (HEEDTA or HEDTA) solution, when specified.

Measurement of pH

The pH of the media was measured by taking a 15 mL sample of the media and mixing it with 40 mL de-ionized water for 1 minute, then taking a reading using a Omega pH electrode. Samples were taken both from under the nutrient solution dripper and from the edge of the pot. After one week of watering with nutrient solution, samples were taken from three separate pots and averaged.

Determination of Water Holding Capacity (WHC)

Water holding capacity was determined by watering the pots to excess and allowing them to drain for 30 minutes. The pots were then weighed, and the weights were adjusted for the dry mass of the media in each pot. The mass of water was divided by the settled volume of the media at the time of measurement to give the water holding capacity expressed as a percentage of settled volume.

Determination of Air-Filled Porosity (AFP)

Air-filled porosity was measured by watering the pots to excess and allowing 30 minutes for draining. The drain holes were plugged to prevent further drainage and water was added slowly to the edge of the pots. This allowed the air pockets to fill with water from the bottom of the pot up, reducing the amount of trapped air during measurement. The amount of water added was assumed to be equivalent to the amount of space available in the media for air. The AFP was divided by the settled volume of the media at time of measurement to give the percentage of the settled volume that was occupied by air in the drained media.

Measurement of Settling

Triplicate pots of each media type were filled and settled as described above. The pot diameter was constant for the first five centimeters of depth. The vertical distance from the rim to the settled media was measured and multiplied by the horizontal surface area of the pot to determine

the volume settled. This volume was then subtracted from the total volume of the pot (4 L), to determine the settled media volume.

Determination of Plant Available Water

The percent (by volume) of plant-available water (% PAW) in peat/perlite and peat/vermiculite mixes was determined using electronic balance connected to a datalogger. Two peat/perlite 50/50 and two peat/vermiculite 50/50 pots were thinned to 10 plants per pot (wheat, cv. Apogee). Pots were soaked and allowed to drain for 30 minutes prior to the start of the dry down period. Each pot was placed on a scale in a growth chamber at 25°C and continuous light. Transpiration rates were calculated from pot weights on 10-minute intervals. As the available water decreased, transpiration rates decreased. When transpiration rates fell to below 50% of their maximum in all four pots, the pots were re-watered to their original weights and allowed to dry down again. The process was repeated to achieve three replicate dry-downs. The volume of water removed from the pots via evapotranspiration was determined for each pot when the transpiration rate was reduced to 80% and 50% of the maximum transpiration rate. The % PAW was calculated by dividing the volume of water removed from the pot by the total volume of the pot (4.0 L). Measurements were repeated using one tomato plant (cv. ‘Early Girl’) per pot, and the overall % PAW were calculated using data from both species.

RESULTS

Physical properties

The pH 7.8 nutrient solution increased the pH of the media from 4.5 to 7.5 in one week (Figure 1). Media not directly exposed to the nutrient solution (edge of pot) showed increased pH with increasing amounts of dolomite. Media directly exposed to nutrient solution (center of pot) had pH similar to nutrient solution across all dolomite levels. The 33/33/33 peat/perlite/vermiculite mix had a pH that was the similar to or more alkaline than the 50/50 peat/perlite mix in both locations, across all dolomite levels.

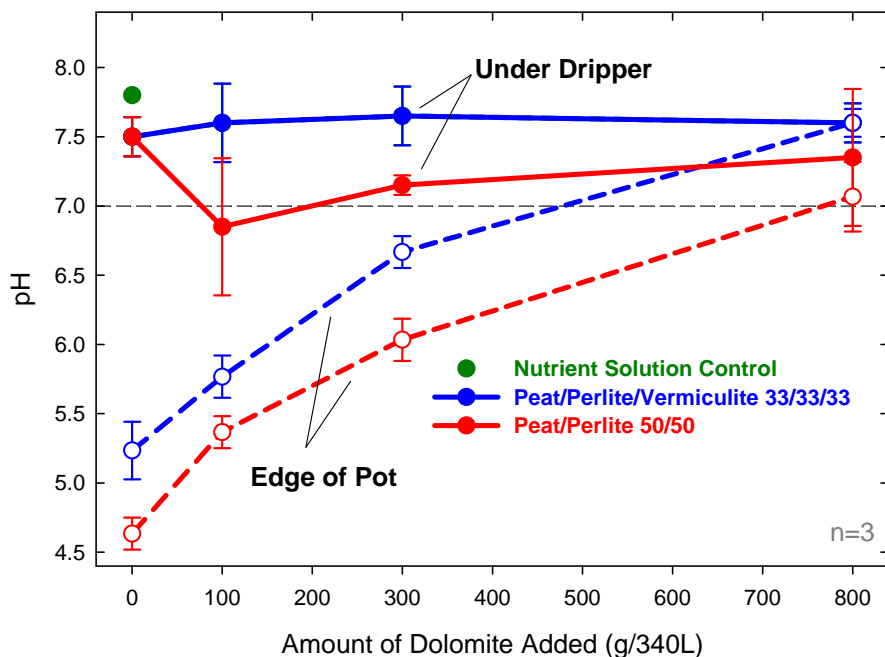


Figure 1. pH values after seven days of watering in unplanted pots. Solid lines were measured directly under the nutrient solution dripper (center of pot) and dashed lines were from media not directly exposed to nutrient solution (edge of pot). Each data point represents the average of three pots. Error bars represent ± 1 standard deviation. Nutrient solution was pH 7.8.

Differences in physical properties between fine vermiculite (particle size < 2 mm) and medium vermiculite (particle size < 4 mm) were examined (Table 1). After one week, the fine vermiculite settled to 93.8% of its original size, and the medium settled to 95.7%. The WHC of fine and medium vermiculite was 56.2% and 53.8% of the settled volume, respectively. The AFP of the fine and medium vermiculite was 34.5% and 32.1%, of the settled volume, respectively.

Table 1. Comparison of properties of fine and medium vermiculite. WHC and AFP values were adjusted to represent percent of settled volume composed of water and air, respectively. Values are the average of 3 replicate pots, and are shown \pm 1 standard deviation. Data was collected after seven days on the irrigation system.

Vermiculite Size	Percent of Original Volume (%)	Adjusted Water Holding Capacity (%)	Adjusted Air Filled Porosity (%)
Fine Vermiculite	93.8 \pm 0.8	56.2 \pm 2.1	34.5 \pm 2.2
Medium Vermiculite	95.7 \pm 0.5	53.8 \pm 1.0	32.1 \pm 0.8

The mixes gradually settled over a period of five weeks of watering with the dripper system. The majority of settling occurred during the first two weeks, but some mixes took longer to completely settle. The 100% peat settled to approximately 73% of its original volume, and the 100% perlite settled to 96% of its original volume. The 100% vermiculite and the other mixes settled to 85-90% of their original volumes (Figure 2). The AFP and WHC values were calculated per unit media volume using the settled volume of the media at the time of their measurement.

The WHC for all media increased during the first three weeks, and then stabilized (Figure 3). The 100% peat held approximately 80% of its volume in water, and the 100% perlite held approximately 50% of its volume in water. The 100% vermiculite and the other mixes had WHC values between 55% and 70% of their settled volumes.

The AFP of all media declined during the first three weeks, and then stabilized (Figure 4). At the end of the five week study, the 100% perlite and 100% vermiculite each averaged approximately 34% air by volume, and the 100% peat contained approximately 15% air by volume. The other mixes averaged between 20% and 25% air by volume. Values are the average value throughout the entire pot, and were not calculated at specific depths.

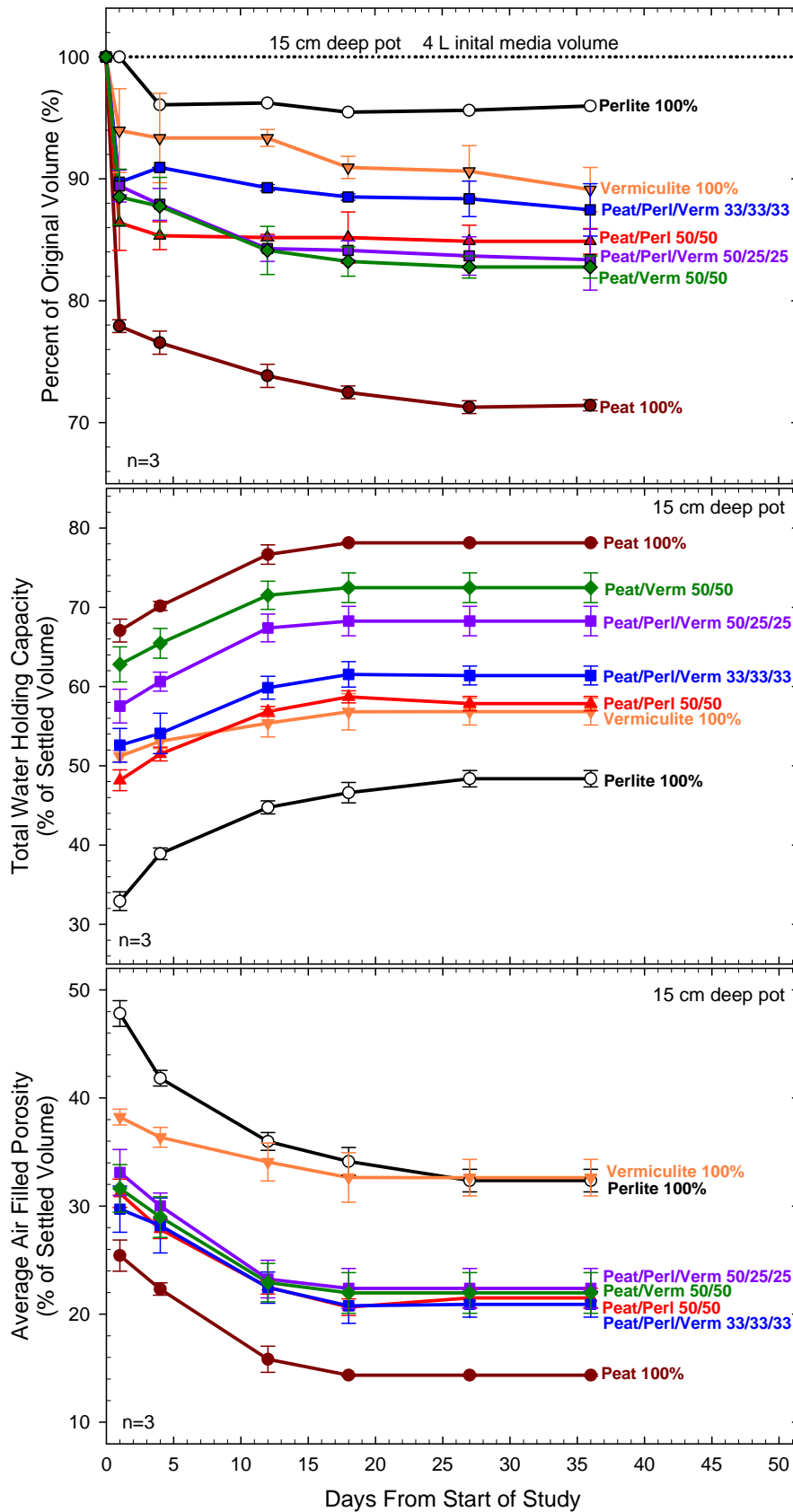


Figure 2. Settling of seven media over five weeks of watering. Each data point represents the average of three pots. Error bars represent ± 1 standard deviation. Error bars that are not visible are smaller than the width of the symbol.

Figure 3. Media water holding capacities over five weeks of watering. Each data point represents the average of three pots. Error bars represent ± 1 standard deviation. Error bars that are not visible are smaller than the width of the symbol.

Figure 4. Media air-filled porosities over five weeks of watering. Each data point represents the average of three pots. Error bars represent ± 1 standard deviation. Error bars that are not visible are smaller than the width of the symbol. Percents are the average value throughout the entire pot, and were not calculated at specific depths.

Determination of Plant Available Water

When plants removed a volume of water equal to 31% (peat/perlite) or 50% (peat/vermiculite) of the media volume, transpiration rates dropped to 80% of their maximum daily value. When plants removed water equal to 35% (peat/perlite) or 54% (peat/vermiculite) of the media volume, transpiration rates dropped to 50% of their maximum value (Table 2).

Table 2. Comparison of percent plant available water. Values are shown ± 1 standard deviation. Peat/perlite 50/50 had 3 replicate pots with tomato and 2 replicate pots with wheat. Peat/vermiculite 50/50 had 2 replicate pots with each species.

Media	%PAW (v/v) at 80% of Max Rate			%PAW (v/v) at 50% of Max Rate		
	Tomato	Wheat	Overall	Tomato	Wheat	Overall
Peat/Perlite 50/50	33 \pm 3	30 \pm 1	31 \pm 3	36 \pm 1	34 \pm 1	35 \pm 1
Peat/Vermiculite 50/50	50 \pm 1	50 \pm 5	50 \pm 4	52 \pm 2	55 \pm 2	54 \pm 2

Growth Characteristics

After three weeks of growth in either 33/33/33 peat/perlite/vermiculite or 50/50 peat/perlite with varying levels of dolomite, corn plants differed in size and color. Corn plants grown in 33/33/33 peat/perlite/vermiculite were visibly larger and greener than those grown in 50/50 peat/perlite. The corn leaves, in general, had more chlorosis (were less green) as the amount of added dolomite increased (Figure 5).

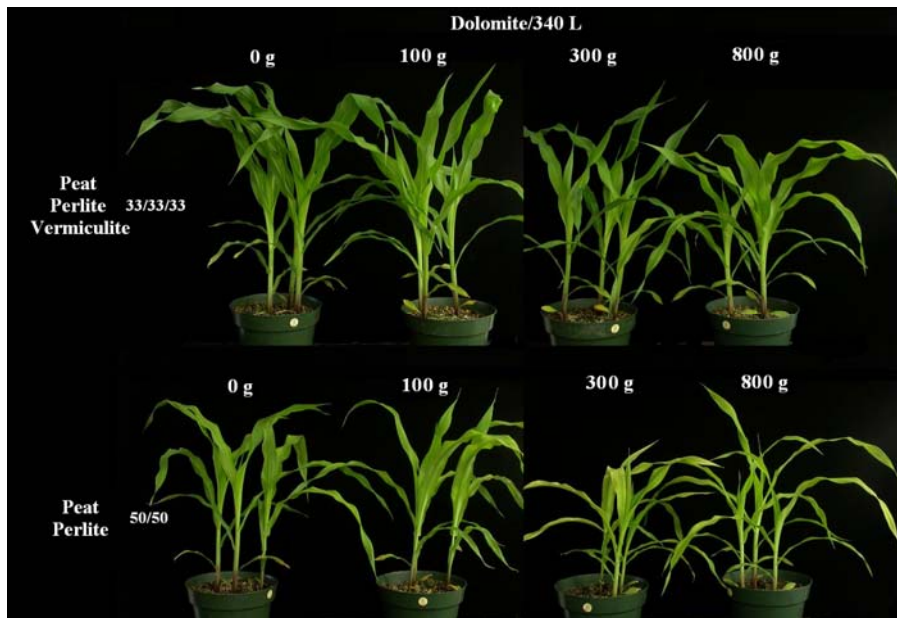


Figure 5. Field corn plants (cv. DK641) photographed 22 days after planting. The top row was grown in peat/perlite/vermiculite 33/33/33, and the bottom row was grown in 50/50 peat/perlite. From left to right the pots contain 0 g, 100 g, 300 g, and 800 g dolomite per 340 L media preparation.

In general, average chlorophyll content (CCI) in corn decreased as the amount of dolomite increased (Figure 6). The pots containing the 33/33/33 Peat/Perlite/Vermiculite mix had higher CCI than the 50/50 Peat/Perlite mix at all dolomite levels tested. In general, the average dry mass of corn plants decreased with increased amounts of dolomite. At all levels of dolomite, the 33/33/33 Peat/Perlite/Vermiculite mix had an average of 1.0 to 1.5 g more dry mass than the 50/50 Peat/Perlite (Figure 7).

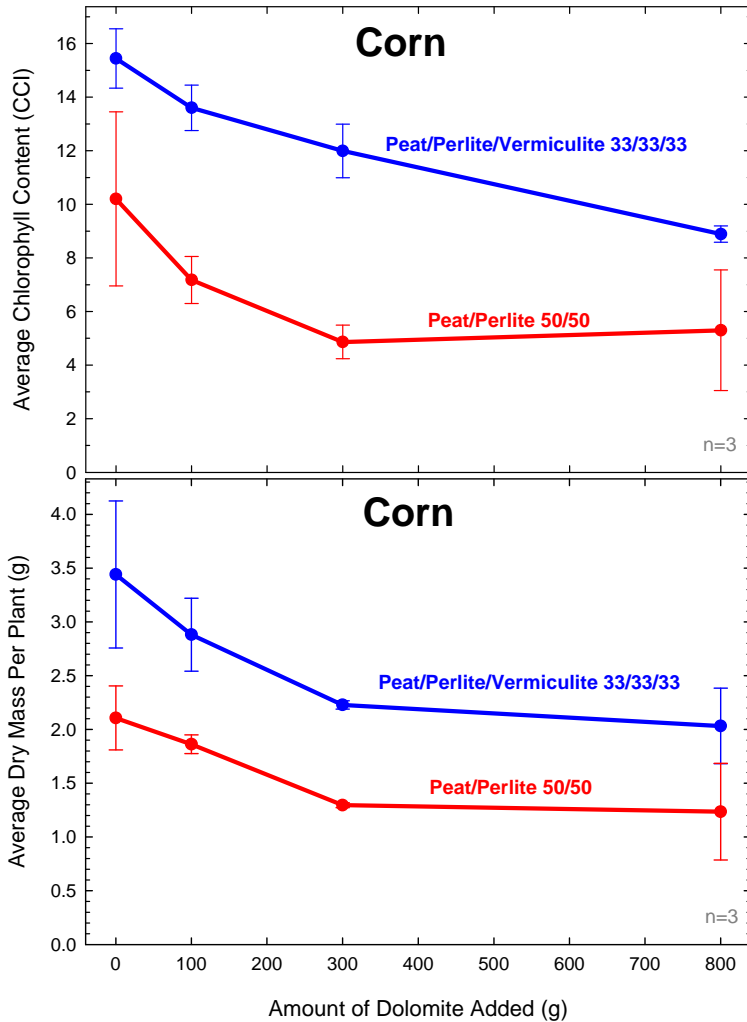


Figure 6. Average chlorophyll content of field corn plants (cv. DK641) measured 21 days after planting. Four readings were taken on the newest fully-developed leaf on each of the three plants in each pot. The twelve readings were then averaged, and the average of the four replicate pots was plotted. Error bars represent ± 1 standard deviation.

Figure 7. Average dry mass of field corn plants (cv. DK641) harvested 22 days after planting. Each point represents the average of three replicate pots. Each pot was weighed and the total mass was divided by the number of plants in the pot. Error bars represent ± 1 standard deviation. Error bars that are not visible are less than the height of the symbol.

In a separate experiment without dolomite, corn had a significantly higher chlorophyll content when grown in 50/50 peat/vermiculite (7.0 CCI) compared to mixes containing perlite (4.0-4.5 CCI) (Figure 8). The chlorophyll content of plants grown in peat/perlite/vermiculite 33/33/33 was nearly identical to that of those grown in peat/perlite 50/50. The three media had a similar dry mass per plant (Figure 9). Differences in the amount of side lighting may have contributed to the growth difference between trials (Figures 7 and 9). Additional studies are warranted to determine the effect of media composition on corn growth.

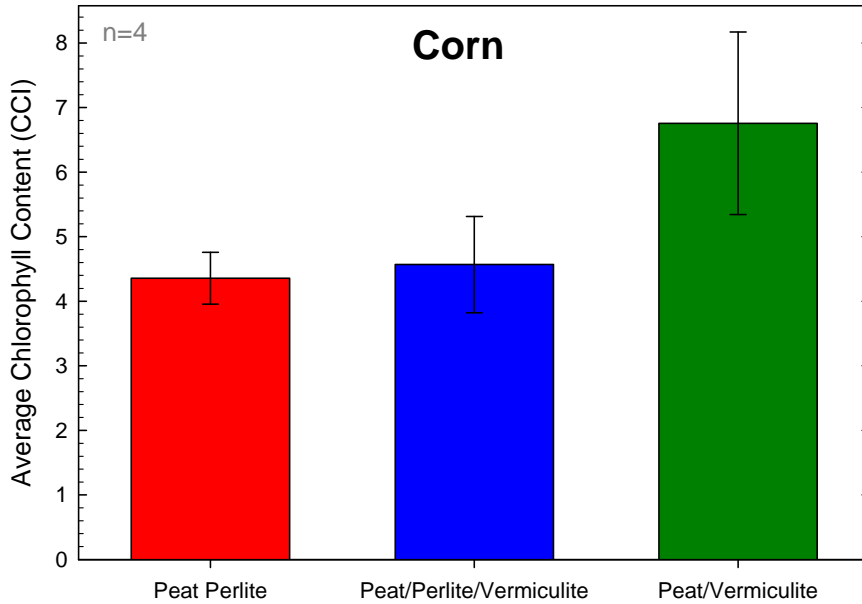


Figure 8. Average chlorophyll content of corn (cv. DK641) measured 26 days after planting. Four readings were taken on the newest fully-developed leaf on each of the three plants in each pot. The twelve readings were then averaged, and the average of the four replicate pots is plotted. Error bars represent ± 1 standard deviation. None of the media contained dolomite.

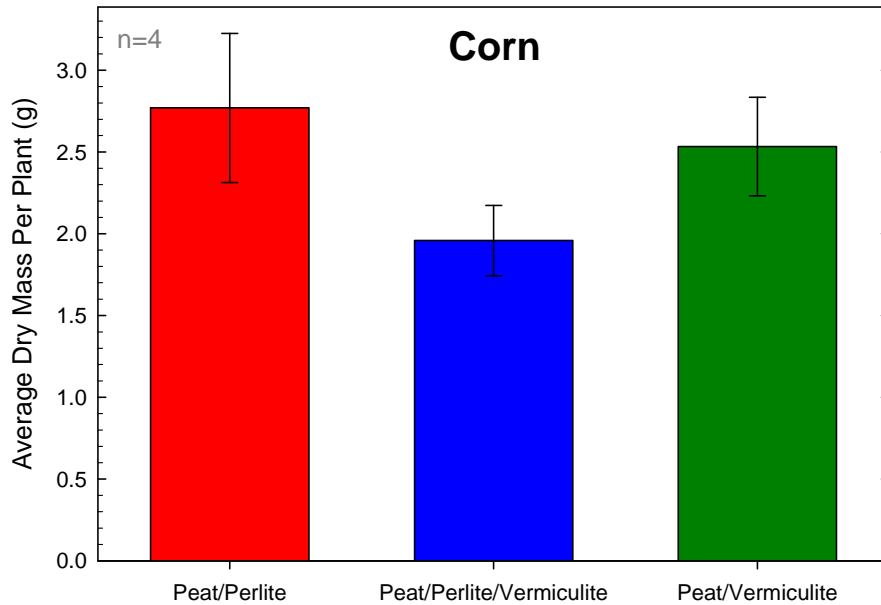


Figure 9. Average dry mass of corn (cv. DK641) harvested 27 days after planting. Each point represents the average of four replicate pots. Each pot was weighed and the total mass was divided by the number of plants in the pot. Error bars represent ± 1 standard deviation. None of the media contained dolomite.

Dry mass decreased as dolomite concentrations increased in soybean (Figure 10) and tomato (Figure 11), and showed no change in peas (Figure 12). In tomatoes, no visual differences in color were observed between levels of dolomite.

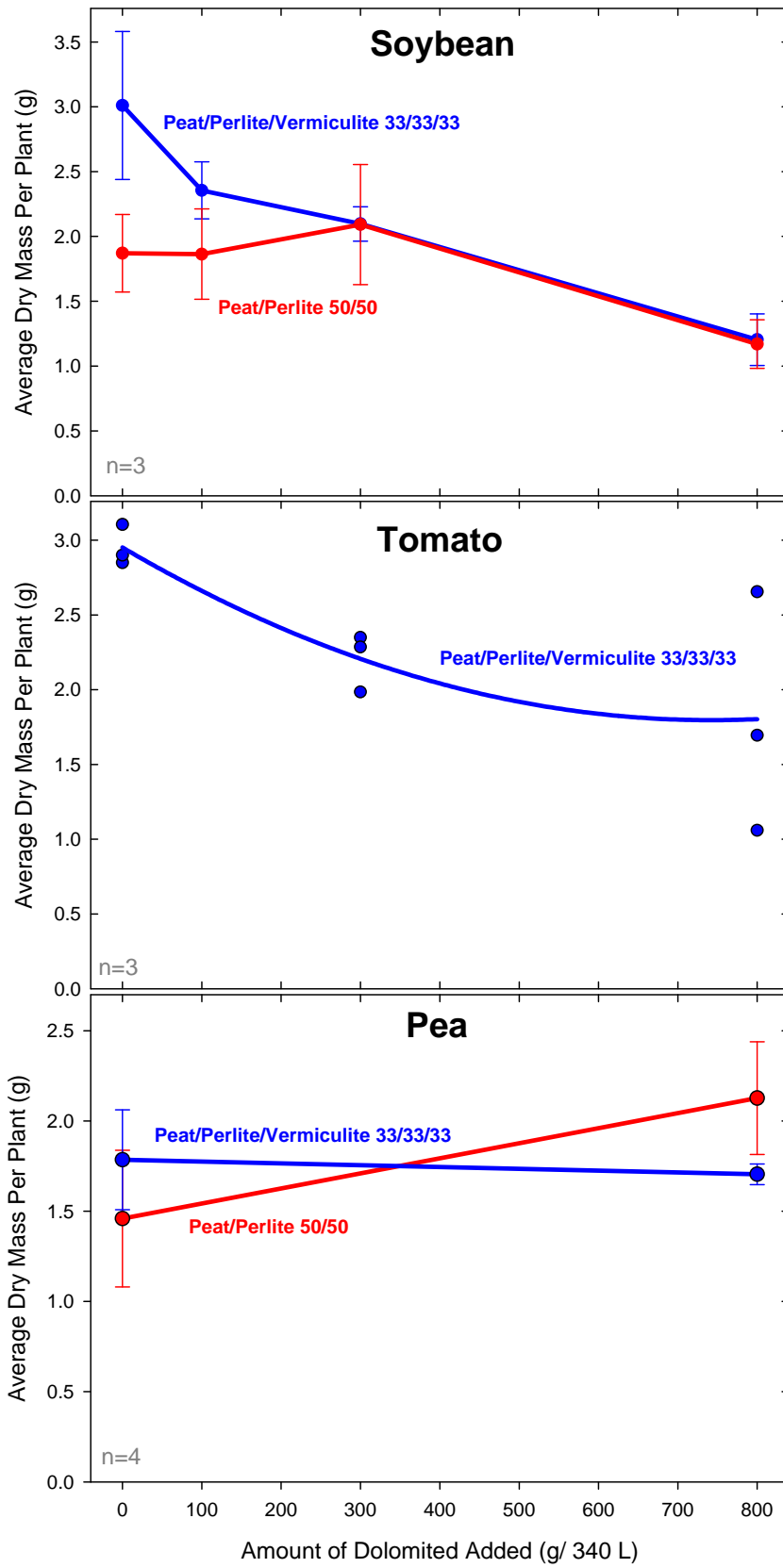


Figure 10. Average dry mass of soybean plants (cv. Hoyt) harvested 32 days after planting. Each point represents the average of three replicate pots. Each pot was weighed and the total mass was divided by the number of plants in the pot. Error bars represent ± 1 standard deviation.

Figure 11. Dry mass of tomato plants (cv. Beefsteak) harvested 38 days after planting. Three replicate pots each with three plants per pot. Each data point represents the average mass of the three plants in that pot.

Figure 12. Average dry mass of pea plants (cv. Earligreen) harvested 30 days after planting. Each point represents the average of four replicate pots. Each pot was weighed and the total mass was divided by the number of plants in the pot. Error bars represent ± 1 standard deviation.

Four weeks after planting, the dry masses of pea plants (cv. Earligreen) grown without dolomite in peat/perlite 50/50 and peat/vermiculite 50/50 averaged approximately 2.75 grams (Figure 13). For tomatoes (cv. Beefsteak), the peat/perlite 50/50 mix had an average of approximately 2.15 grams dry mass, and the peat/vermiculite 50/50 had an average of approximately 2.60 grams.

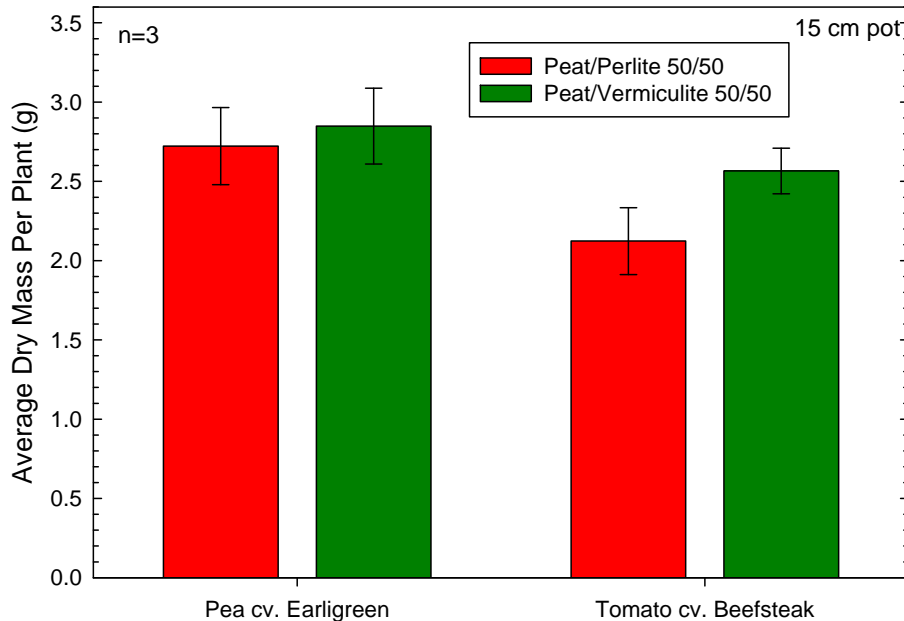


Figure 13. Dry mass of pea plants (cv. Earligreen) and tomato plants (cv. Beefsteak) harvested 28 days after planting. Each bar represents the average of three replicate pots, each containing three plants. Error bars represent ± 1 standard deviation.

A statistically significant difference between the media was observed in corn (cv. DK641) in response to the addition of iron treatments. Watering in this study occurred only once every two days for two minutes via dripper irrigation. On day 26, plants in both media exhibited strong signs of chlorosis, and were given three treatments of iron to compensate for the low concentration of iron in the watering solution (Figure 14). After 11 days from the start of treatments, the chlorophyll content of the corn plants showed a statistically significant divergence, with the peat/vermiculite increasing its CCI from 8 to 20 and the peat/perlite increasing from 6 to 11.5.

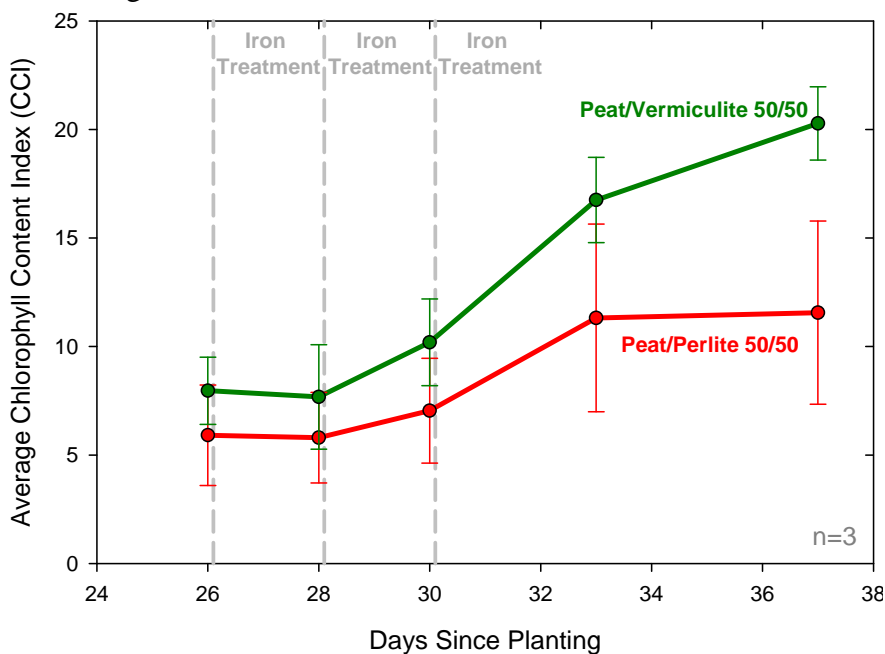


Figure 14. Response of corn (cv. DK641) to chelated iron treatments. Watering occurred only once, for two minutes, every second day in this study. Each data point represents the average of three pots. Error bars represent ± 1 standard deviation.

DISCUSSION

The pH of a soilless media is determined mainly by the pH of the water source. Dolomite is used to offset the low pH of the peat (pH 4.0 to 4.5), but our studies demonstrated that it is unnecessary in areas with high pH water, as the media's pH reached that of the nutrient solution within one week, regardless of dolomite concentration. The addition of dolomite negatively affected the growth and chlorophyll concentration of corn. The dolomite-amended media showed noticeably more chlorosis than media without the amendment. This negative impact was also seen in the experiments done on soybean and tomato, but peas were unaffected by the amendment. Due to the lack of benefits and potential for harm to plants resulting from its use, our findings suggest that areas with high pH water sources should not amend media with dolomite.

Vermiculite is packaged in a variety of different grades, which are visually distinct from each other. But for the physical properties measured and the limited variety of grades tested in these studies, there did not appear to be any significant difference between the grades. The two varieties tested were close to each other in particle size, however, and differences may be greater when comparing more dissimilar grades.

The ratios and types of components in each media affected its physical properties. Perlite media settled very little, vermiculite media settled slightly more than perlite, and peat media settled significantly more than either of the other media. Settling of media made from a combination of these components was intermediate, depending on the ratios of the three components. Media with more peat or vermiculite tended to settle more than media with large proportions of perlite. Settling reduces the total volume of water and air that the media can hold, as well as the amount of root zone it can support, and thus should be considered in media design.

The water holding capacities (WHC) of the media varied quite broadly. Pure peat held nearly 80% of its settled volume in water, while perlite held less than 50%, and vermiculite held around 55%. Media with combinations of these materials had WHC related to the proportions of their components. The 50/50 peat/vermiculite media had the greatest WHC of the mixes, at approximately 72% of settled volume. The 50/50 peat/perlite media WHC was significantly lower, at 56% of its settled volume. A larger WHC allows the plants growing in the media to withstand longer periods between watering events, and reduces the effects of drought due to failure of the watering system. Larger WHC may also provide a larger reservoir of dissolved nutrients, but this was not tested in this study.

The air filled porosities (AFP) of the media seemed to vary very little with media composition. While pure peat had 16% AFP and vermiculite and perlite both had around 35%, all of the mixes of these components, regardless of the proportions of their components, had approximately 23% AFP. As this is well above the 10-13% suggested by Handreck and Black (2002), the media chosen for use does not need to consider AFP as a factor.

The 50/50 peat/vermiculite media had approximately 19% more of its overall volume occupied by plant available water (PAW) than the 50/50 peat/perlite media at both of the transpiration rate levels measured. It should be noted that this difference in %PAW is approximately equal to the

difference in WHC in the two mixes, suggesting that nearly all of the extra water held by the 50/50 peat/vermiculite mix is available for use by the plants.

Across the variety of species and mixes tested, it appeared that mixes containing vermiculite performed at least as well as mixes with perlite, if not significantly better. Increasing the proportion of vermiculite in a mix visually reduced chlorosis, and generally gave higher dry masses and chlorophyll readings. It is not clear why the corn grown in the 33/33/33 peat/perlite/vermiculite mix underperformed the 50/50 peat/perlite and 50/50 peat/vermiculite mixes in one study measuring dry mass (Figure 9) and outperformed the 50/50 peat/perlite in another study (Figure 7). When perlite was eliminated from the mix altogether, the chlorophyll content of corn significantly increased, as did the dry mass of tomatoes. The 50/50 peat/vermiculite mix had results either equal to or greater than the 50/50 peat/perlite mix in all the studies done.

Due to the performance of peat/vermiculite media in producing plants of equal or greater size, with a greater WHC and %PAW and similar AFP compared to other mixes, our studies indicate that a 50/50 volumetric mix of peat and vermiculite is the best choice for use in areas with high pH water sources.

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