GROWING SUBSTRATES COMPRISED OF COMPOSTED MATERIALS AND REDUCED PEAT MOSS FOR PRODUCTION OF GREENHOUSE POTTED GERBERA
(*Gerbera jamesonii*)

by

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ABSTRACT

GROWING SUBSTRATES COMPRISED OF COMPOSTED MATERIALS AND REDUCED PEAT MOSS FOR PRODUCTION OF GREENHOUSE POTTED GERBERA (*Gerbera jamesonii*)

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Peat moss is a major component of many plant growing substrates but is quickly becoming a limited resource. To reduce the reliance on peat moss a number of composted products, including pine mulch, manure, yard waste and aged bark - in combination with peat moss and/or coconut coir, were mixed in various combinations as growing substrates for greenhouse potted Gerbera (*Gerbera jamesonii*) production. Four new substrates were developed and compared to a commercial mix, BM6 in greenhouse production trials.

Experiments were conducted to (1) compare the plant growth and quality of potted Gerbera in the newly developed substrates to BM6, (2) determine whether a pre-charge fertilizer was needed for the newly developed substrates, (3) determine appropriate rates of a pre-charge fertilizer for the newly developed substrates, and (4) determine the nitrogen drawdown index over the time of production and determine if there is a relationship between the NDI values and the nitrogen availability measured by pour through values.

Two of the newly developed peat reduced substrates were successful in producing acceptable quality potted Gerbera. One of the substrates contained a low percentage of peat moss and the other contained coir fines. Fertilizer pre-charge rates, and some nutrient and irrigation management protocols were recommended for these two substrates.

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Floriculture Industry

Ontario's floriculture industry has flourished over the past few decades contributing to over half of Canada's greenhouse industry farm gate valu**e** (Brown and Murphy, 2007; Statistics Canada, 2008). The industry has become the third largest agricultural sector in Ontario, next to dairy and swine, with a farm gate value of over $800 million (Brown and Murphy, 2007). With over 880 greenhouses in Ontario making up 4 250 000 square metres of area, the industry is third in flower production in North America next to California and Florida (Brown and Murphy, 2007). Bringing in over $315 million annually, potted flower production has ranked number one in floriculture production in the country contributing to almost 60% of the country's cultivated plants and flowers in 2008 (Statistics Canada, 2010). The large scale of the ornamental crop production industry means an increase in demand for growing substrates to grow these crops. This is a continuous demand annually as most ornamental crops are grown, shipped and sold in the same container meaning growers require a new supply of substrates each year.

Potted gerbera are an example of a very popular ornamental crop that growers produce, ship, and sell all in the same growing substrate. For what once was a minor commodity, potted Gerberas are now an important potted plant within the floriculture industry producing more than 3 200 000 potted gerberas in 2009 (Mailvaganam, 2010). Gerberas are produced from plugs and grown in 4-inch or 6-inch pots, visible in gardens and grocery store shelves all over the world (Beytes et al., 2003). This number of gerbera would require approximately 38, 400 m^3 of growing substrate to produce the potted plants for one year which, in turn, requires a continuous supply of materials from year-to-year for the substrates.

Growing Substrates

Currently, the most commonly used growing substrates contain constituents such as peat moss, perlite and vermiculite (Robertson, 1993; Perlite, 2010). The various combinations of these components have proven to be quite successful in the growing of numerous ornamental plants and growers have developed management practices surrounding the use of these substrates and exploiting their physical properties. Desirable physical properties of a substrate are essential to optimal plant performance and each greenhouse crop may require different physical properties from the substrate along with best management practices to ensure this performance is met (Raviv, 2002). Depending on the components that make up a particular substrate the physical properties, including water holding capacity, porosity, air space and bulk density, can vary greatly. These parameters dictate the plant's ability to uptake water and nutrients, and even a small change in one of these parameters can result in poor plant performance (Fonteno, 2003).

A substrate used for gerbera production would preferably have high water holding capacity, as well as high air space for improved drainage. Drainage is an important factor as gerberas do not like water sitting around their roots or water-logged substrates (Rogers and Tjia, 1990). The pH of the substrate should preferably be between 5.5 and 6.2 as this is optimal for nutrient uptake (Reed, 1996). Quite commonly gerberas are grown in a typical ornamental substrate containing high percentages of peat moss and perlite (Marfa et al., 2002) such as in products like BM6, 78% peat moss to 22% perlite (Berger, 2008). The mixture of these components have been known to produce high quality plants as the peat moss contributes to holding water and the perlite adds the porosity and airspace which improves drainage.

Peat moss is a light material with a relatively low pH, an important factor in nutrient uptake (Reed, 1996), but most importantly it has a high water holding capacity (Bergeron, 1994) which plays an important role in plant growth. Despite its popularity and performance in growing plants, numerous studies and industry professionals have raised concerns about the extensive harvesting of peat and its potentially negative environmental impacts (Robertson, 1993; Barkham, 1993). Peat moss is harvested from natural bogs, marshes and swamps making up about 111, 328, 000 ha in Canada (Bergeron, 1995). Peat lands are natural carbon sinks which include about a third of the global soil carbon (Waddington et al., 2009). The destruction of these areas through harvesting or agricultural practices releases carbon gases to the atmosphere (Keys, 1992; Waddington et al., 2009). Not only does the release of carbon raise environmental concerns, it is also suggested that the harvesting of peat moss leaves the area in a state that is unlikely or difficult to return to a functioning ecosystem (Van Seters et al, 2001). All of these issues as well as the high price, and overall ecological impact are creating concerns as to the long-term availability of peat as the primary component in growing substrates (Raviv, 1998).

Expanded perlite is used in addition to peat moss in growing substrates to increase air space and improve drainage (Perlite Canada, 2010). Perlite is a natural mineral that is expanded with high temperature thus increasing its volume considerably (Perlite Canada, 2010). The heating process of perlite requires the use of fossil fuels, thus rising fuel prices have increased the cost of perlite (Bolen, 2009).

Due to the need for a continuous supply of growing substrates in the container plant production industry, as well as the environmental and economic issues involved with the production, harvest, manufacturing and shipment of both peat moss and perlite the industry has been pushed to adopt alternative, more cost-effective components to incorporate into the substrates. Some of the components being examined include composts, bark, manure, and coconut coir as they are natural waste or byproducts of other activities/processes. These components have been incorporated into ornamental growing substrates cautiously for a number of reasons. Issues surrounding the inconsistencies of the batches, concerns with toxicity due to the presence of heavy metals (Bucher, et al., 2000), as well as the lack of well-tested and successful management practices when it comes to watering and fertilization has caused growers to hesitate when accepting substrates containing composted products. Although there is some hesitation, composted products such as yard waste and bark are becoming more popular as constituents of growing substrates especially in ornamental crop production (Raviv et al., 2002). They have proven to have some advantages for substrate quality that peat moss does not have, including; lower costs, increased air porosity, better drainage, plant nutrients and beneficial microbial activity thus providing disease suppression (Raviv et al., 2002; Carlile, 2008). Another attraction is that composted products such as yard wastes, pine bark and manure are examples of products that are produced in large quantities and have a continuous supply suggesting they may be welcome additions to growing substrates (Moore, 2005).

Previous studies comparing the use of peat and perlite mixes to mixes containing composted products have shown that composted mixes are inferior in terms of plant growth and greenness for certain crops (Frantz et al. 2007; Blok et al. 2009). It has also been suggested that having a bark content of about 20% will produce the best results (Raviv et al. 1998) and that having more than 20% bark in a substrate may cause nutrient deficiency as it can tie up the nitrogen supply (Rogers and Tjia, 1990; Jackson et al. 2009; Sharman et al. 1993) by immobilizing the available inorganic N to organic N (Handreck, 1992). However, solid and liquid N can be added to the substrate throughout the time of production to counteract this immobilization (Rogers and Tjia, 1990; Handrek, 1992). For example, some studies have indicated the growth of plants such as gerbera, chrysanthemum, and anthurium, are equal to commercial mixes when compared to alternative mixes using composted products such as coir, barks, and composts (Blok et al. 2009). The physical properties of the substrates such as porosity, container capacity, and air space, are of great concern in substrate analysis as they are a vital component in plant performance (Frantz et al. 2007; Michel, 2007). This implies that if growing conditions are optimal, good plant growth can be achieved.

Coconut coir is another peat substitute being examined in the horticulture industry for use in growing substrates. Coir comes in different forms, either as coco fiber or coir chunks, which are both byproducts of coconut harvesting. Research has suggested it has similar properties to peat moss and has been successful in plant production (Meerow, 1994; Noguera, 2000). There have been some concerns raised about toxicity in plants due to salinity problems; however, this is dependent on the batch and it is suggested that the salinity be monitored before and throughout production (Meerow, 1994). As with bark, there have also been concerns with N immobilization when using coir as a constituent in growing substrates (Handreck, 1993b). But again, if a proper fertilizer program is used, this issue can be alleviated (Noguera, 2000). The physical properties of coir have proven to be similar to those of peat moss for water adsorption and drainage (Meerow, 1994). Research has also indicated a potential to increase water holding capacity in a growing substrate when coir is incorporated (Hernández-Apaolaza, et al., 2005). There have been concerns with the shipping costs of coir. However, a major advantage to using coir, other than its similarities with peat moss, is the fact that it is a renewable resource by-product with a continuous supply, which has been under-used historically (Hyder et al. 2009; Noguera et al. 2000; Meerow, 1994). Although it is being transported to North America it is a waste product that is being used.

Although there have been studies on the development of new substrates and the performance of ornamental crops, there are very few studies on substrate analyses with the growth of potted gerberas.

Fertilizer

A good fertilizer program is essential to optimal crop production, and the use of products such as composted yard waste and bark products as replacements for peat moss in growing substrates has caused concern for growers as their plant nutrition programs may need to be altered. As mentioned there are problems related to possible nutrient deficiencies and nitrogen immobilization (Caballero, 2009; Hendreck, 1992) depending on what constituent is being used. For both N immobilization and nutrient deficiencies Hendreck (1992) suggested that with the incorporation of a pre-plant slow release fertilizer as well as high N feeding solution throughout production may counteract the effects of the high N immobilization and stabilize the amount of nitrogen present in the substrate.

There have been many studies examining the Nitrogen Drawdown Index (NDI) of substrates and relating these values to fertilizer rates (Jackson et al. 2009; Sharman et al. 1993; Handrek, 1992). The NDI is a measurement used to determine the amount of nitrogen that is immobilized in soilless media. The method allows you to distinguish if most of the nitrogen in the substrate is immobilized (value is close to 0) or if little of the nitrogen is immobilized (value is closer to 1) (Hendreck, 1992). This has been a tool used to determine if the substrate will require additional fertilizer or an increase in fertigation throughout plant production. This being said, there is still much to learn about the NDI of substrates throughout the production period on the substrates the plants are growing in and comparing the NDI values to the pre-charge rates throughout production.

Hypothesis

The newly developed substrates, comprised of composted materials reduced or no peat content and no perlite, will perform as well as or better than the current industry standard (BM6) in the production of potted gerbera plants.

Objectives

The objectives of this study were motivated by the challenge to develop an environmentally sustainable plant growth substrate with little or no peat or perlite. New substrates composed of locally available composted materials were developed and tested using potted gerbera as a test species. In addition to reducing or eliminating the peat and perlite content of the substrates, this study aimed to determine optimal pre-charge fertilizer rates; investigate the relationship between pre-charge rates and NDI; and investigate the relationship between the NDI and substrate N content by pour through nutrient analysis.

Chapter 2: Developing Sustainable Growing Substrates for Potted Gerbera (Gerbera jamesonii) Production.

Introduction

Peat moss and expanded perlite comprise the majority of growing substrates in ornamental greenhouse production. Environmental and economic issues involved with the production, harvest, manufacturing and shipment of both peat moss and perlite (U.S. Geological Survey, 2009; Robertson, 1993; Barkham, 1993; Raviv, 1998; Perlite Canada Inc., 2010) have pushed the industry to adopt alternative, more cost effective and environmentally sustainable components in growing media. Composted products such as yard waste and bark are becoming more popular in growing media and have proven to have some positive advantages to substrate quality including increased air porosity, better drainage, plant nutrients and beneficial microbial activity thus providing disease suppression (Carlile, 2008; Moore, 2005). The general goal of this research was to provide the ornamental horticulture industry with a reliable scientific rationale for reducing the amount of peat moss and eliminating perlite in ornamental growing substrates by using locally available, sustainable materials such as compost, bark and manure to create a cost effective alternative. To achieve this goal, new substrates were created using various alternative components and potted gerberas were used in production trials to evaluate the relative performance of the new substrates compared to an industry standard.

Materials and Methods

Four new substrates were developed and tested against one of the commonly used commercial growing substrates, BM6 (Berger, Les Tourbières Berger Ltee, Saint-

Modeste, QC, Canada), for greenhouse potted gerbera production. See Table 1 for composition of the newly developed substrates.

Table 1: Composition (%) of each substrate treatment

Mix	Peat	Coir	Coir Chunks	Composted Yard Waste	Manure Compost	Aged Bark	Aged Bark Chunks	Composted Pine Mulch
Mix 1	30	-	20	10	-	25	-	15
Mix 2	30	-	20	-	10	25	-	15
Mix 3	30	-	20	10	-	-	25	15
Mix 4	-	30	20	10	-	-	25	15
BM6	78				22% Perlite			

The peat moss used was Fafard, Saint-Bonaventure, QC. The compost, and composted pine mulch were both 6 mm in size and were supplied by Gro-Bark, Milton, ON. The coconut coir fines were supplied by Gro-Bark, Milton, ON. The aged bark was 6 mm in size and supplied by Gro-Bark, Georgetown, ON. The composted manure was 6 mm in size and obtained from Dingo Farms Inc., Bradford, ON. The coir chunks were small 6-12 mm coconut coir chunks from Mellenniumsoils Coir, St. Catherines, ON. The manure was supplied by Dingo Farms Inc., Bradford, ON. A commercial product BM6, 22% perlite and 78% peat moss was used as the fifth treatment (Berger, Les Tourbières Berger Ltee, Saint-Modeste, QC, Canada) and was used for comparison.

Plant Culture

Gerbera (*Gerbera jamesonii)* transplants were propagated at a commercial greenhouse in southwestern Ontario, Canada. Seven week old transplants, with an average of seven leaves, were planted in 6 inch diameter pots (1300 mL) containing the different substrates (treatments) and placed in one of the research greenhouses (glass house: 7.62 × 6.10 m) at the University of Guelph Bovey Greenhouse Complex (lat. 43.55 degrees N. and long. 80.25 degree W.). There were five treatments and three replicates (troughs) each containing 20 potted plants. The five treatments included the four new substrates and BM6, a commercially available product used for comparison. Each subirrigation trough (replicate) held 20 potted plants at the start of the experiment and was thinned accordingly as the experiment progressed and plants grew to make the whole greenhouse full of plants to resemble the environmental conditions in commercial greenhouses. Additional gerbera plants of the same size were grown in border troughs to avoid any possible edge effect in the experiments.

All plants were sub-irrigated with a nutrient solution containing, in 40 L solution, 648 g $Ca(NO_3)_2$, 378.73 g KNO_3, 246 g Mg SO_4, 170 g K_2HPO_4, 43.5 g K_2SO_4, 72 g NH_4NO_3, 0.50 g $CuSO_4$, 2.22 g $MnCl_2 \cdot 4H_20$, 3.72 g H_3BO_3, 0.24 g $NaMoO_4 \cdot 2H_20$, 212 g Fe EDTA 13%, and 1.44 g Zn SO_4. This fertilizer composition was used successfully to produce quality potted Gerbera in the study preformed by Zheng et al. (2004). The target pH was 5.6 to 5.8 and EC was 0.500 $dS \cdot m^{-1}$ for weeks two and three after transplanting then increased to an EC of 1.0 $dS \cdot m^{-1}$at four WAT. Five weeks after transplanting the EC was raised to 2.0 $dS \cdot m^{-1}$ and pH was kept at a maximum of 5.5 by using an acid or a base to alter. These conditions were maintained until the end of the production trial.

Two WAT, all treatments were watered whenever the substrate dried to a moisture content of 40 ± 1%. The moisture content was calculated following $Ø = WP – ((MP + P + DS) / V) * 100)$. Where: Ø = % substrate water content, WP = mass of pot with wet substrate, MP = mass of pot, P = mass of plant, DS = mass of dry substrate, V = volume of substrate.

Harvests were conducted every two weeks starting at week six after transplanting (WAT) and continuing to fourteen weeks. At each harvest two plants from each trough were harvested totaling six plants per treatment. Three of the pots were used for aboveground plant analysis and the pots, substrate and roots intact, were used for the measurement of substrate porosity, container capacity, air space and bulk density with the roots included. The aboveground biomass of all of the plants was separated into leaves, crown, buds, shoots, and flowers. Following measurements of fresh weights each plant component was placed in an oven of 70^{o}C and dried to a constant weight. Leaf area of each plant was measured using a leaf area meter (LI-3100;LI-COR Inc. Lincoln, Nebraska USA). The longest shoot length and largest flower width were measured at each harvest. Specific leaf area was also calculated by dividing the leaf dry weight by leaf area of each plant.

Substrate Physical Property Measurement

Prior to planting, each substrate was tested initially for its physical properties including; total porosity, container capacity, air space and bulk density following the North Carolina State University Procedures for Determining Physical Properties of Horticultural Substrates Using the NCSU Porometer (Fonteno, 2003). The three pots from each treatment were used to test the substrates' physical properties as mentioned above throughout the time of production. The methodology was slightly altered to perform the test in the 6-inch pots that the plants had been growing in as well as with the roots intact. Each pot had all but two of the holes on the bottom covered with duct tape. The pots were placed in a large sink which was filled with water to the top of the pots and let sit for 15 minutes to allow the substrate to completely saturate. The remaining two holes of each pot were plugged with putty so the saturated substrate could be taken out of the water and placed on a container. The holes were unplugged and the substrate was allowed to drain for one hour. The drain volume was recorded and the substrates were placed in bags and dried in an oven (105^{o}C) for 48 hours to a constant weight.

Statistical Analysis

Statistical analysis was performed using Prism Graphpad (version 5.03; GraphPad Software Inc; La Jolla, CA, 2010). Multiple means comparison was performed on all growing substrate physical and chemical properties, and plant growth measurement data using ANOVA and Students *t*-test.

Results

Visual Assessment

Plants in the four new substrates started to show signs of yellowing on the young leaves at 5 WAT indicating a potential lack of nutrients. To correct this, the EC of the nutrient solution was increased to 2.0 $dS \cdot m^{-1}$ and the pH was adjusted to 5.5. The chlorosis remained on these leaves for another 4 weeks. Toward the end of production (10 WAT) it was less visible in treatments one and three but still visible in treatments two and four. The overall marketability of the new substrates was less desirable than that of BM6. The plants were not as big, the leaves were not as full and the greenness of the leaves was not as rich as the plants grown in BM6. Throughout the trial the newly formulated substrates never fully saturated the top of the substrate. BM6 on the other hand would always fully saturate. This lack of saturation may in turn be beneficial as fungus gnats breed on the moist surface of a substrate; however, with the top of the new substrates being dry they were limited in breeding grounds.

Plant Growth

The growth of plants in BM6 throughout the whole trial was higher in leaf number, leaf area, aboveground biomass and leaf weight than the other four treatments (Figure 1). Dry root weight of all treatments was consistently similar throughout the first four harvests. At harvest five, Mix 1 (0.032kg±0.005) had higher dry root mass than the other four treatments (0.0171kg±0.0009). There were no differences in specific leaf area (SLA) in any treatments at any harvest interval.

Flower Number

At ten and twelve WAT harvest intervals BM6 had more flowers per plant than the other four new substrates (at 10 WAT: new substrates mean = 0, se= 0, BM6 mean = 1.33, se = 0.49; at 12 WAT: new substrates mean = 0.625, se= 0.23, BM6 mean = 3.17, se = 0.40). By the last harvest, 14 weeks after transplanting there was no difference in flower number per pot (mean= 1.77, se= 0.29).

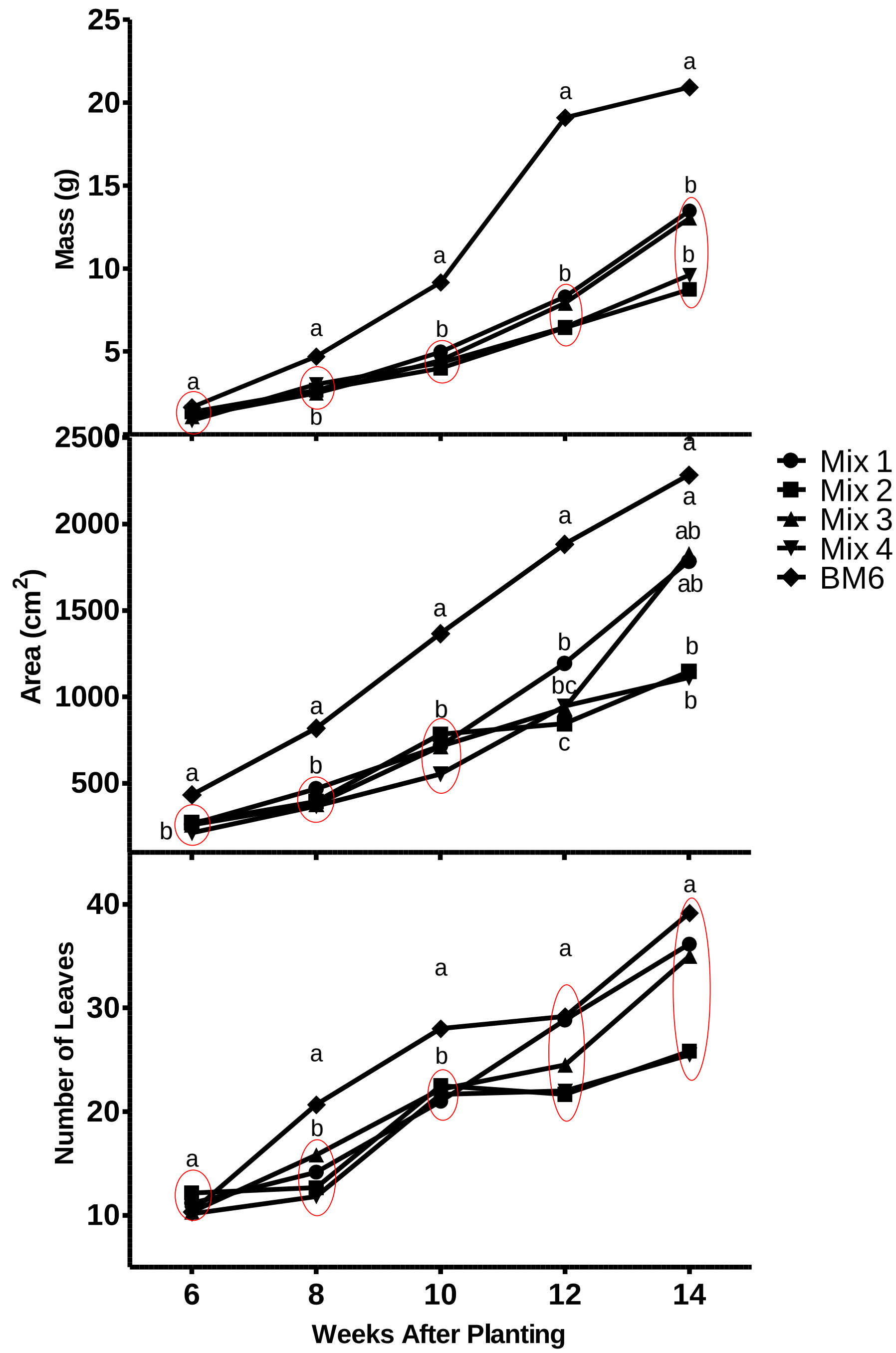

Figure 1: Aboveground dry biomass, leaf area, and leaf number (respectively top to bottom) at each harvest interval. Points followed by the same letter are not significantly different at *p*<0.05 using Tukey's *t*-test. Points contained within an oval showed no differences. Data are a mean of 3 replicates.

Substrate Physical Properties

The initial total porosities of the new substrates showed no differences (89.86%±0.25) but were all higher than BM6 (81.88%±0.24). Mix 2 (68.07%±0.67), and BM6 (69.31%±0.51) had initial container capacities higher than mix 3 (61.83%±1.54) and mix 4 (63.86%±1.30) whereas mix 1 (67.14%±0.67) was only different from mix 3. mixes 3 (0.0015 $g \cdot m^{-3}$), 4 (0.0017±0.00003 $g \bullet cm^{3}$), and BM6 (0.0010 $g \bullet cm^{3}$) all had different initial bulk densities except mixes 1 and 2 (0.16 $g \cdot m^{-3}$). Mix 3 had a higher initial air space percentage (28.49%±0.86) than mixes 1, 2 and 4 (23.41%±0.81). BM6 (12.57%±0.56) was different than the rest of the substrates with the lowest air space percentage. The total porosities of mixes 1 and 3 were higher than that of BM6, and the total porosity of mix 4 was lower than that of BM6 at six weeks after transplanting (WAT)); however, by 14 WAT no differences were measured amongst all the treatments in total porosity (84±0.9%), container capacity (66± 0.7%), and air space (18±0.8%) (Table 2). The bulk density of BM6 (0.0010 0.000013 $g \bullet cm^{3}$) was lower than the four new mixes (0.0016 ± 0.000012 $g \bullet cm^{3}$) at each of the five harvests.

Table 2: Initial and final physical properties of growing substrates

Substrate	6 WAT			14 WAT		
	Total Porosity	Container Capacity	Bulk Density	Total Porosity	Container Capacity	Bulk Density
	%	%	g•cm3	%	%	g•cm3
Mix 1	91.8a	68.2a	0.0018a	86.1a	66.5a	0.0016a
Mix 2	86.9b	66.5ab	0.0018ab	80.7a	63.5a	0.0016a
Mix 3	92.4a	68.1a	0.0017b	87.3a	66.5a	0.0015b
Mix 4	83.2c	64.0b	0.0018a	82.8a	64.1a	0.0016ab
BM6	85.7b	66.7ab	0.0011c	84.1a	69.0a	0.0011c

CPM = Composted Pine Mulch
Data are a mean of 3 replicates.
Values followed by the same letter are not significantly different at $p<0.05$ using Tukey's *t*-test.

pH and EC

There were no differences in initial pH values (5.6±0.04) among any of the five substrate treatments. There were no differences in pH value (6.1±0.05) among all the new substrates; however they were all higher than that of BM6 (5.5±0.07). The initial EC values of the substrates exhibited no differences in treatments (0.357 $dS \cdot m^{-1}$ ±0.0079) except treatment two (0.283 $dS \cdot m^{-1}$ ±0.0087) which was lower than all substrates but BM6 (0.341 $dS \cdot m^{-1}$ ±0.0117).Throughout the trial there were no differences in EC level (1.596 $dS \cdot m^{-1}$±0.06) among all new substrates; however, they were all lower than that of BM6 (2.5 ±0.20 $dS \cdot m^{-1}$) (Figure 2).

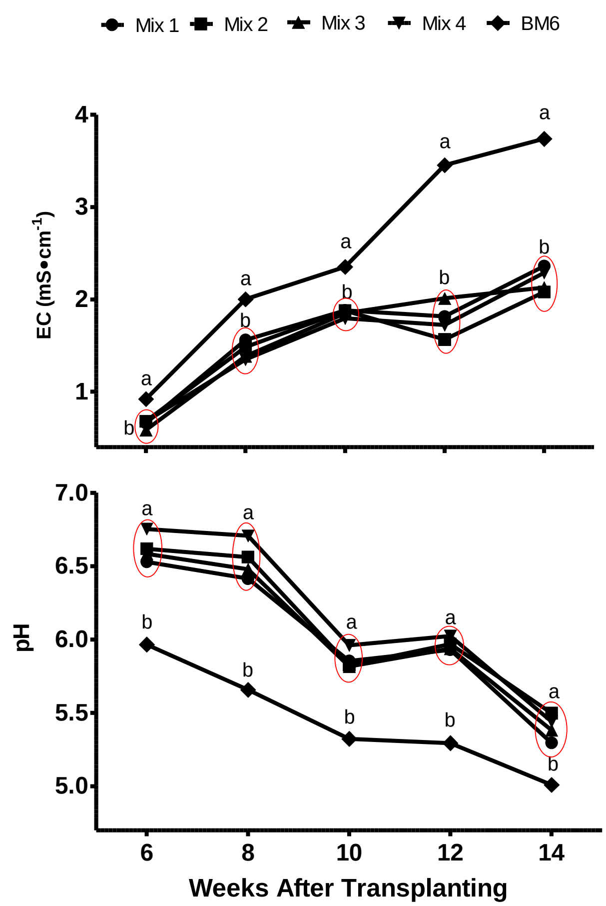

Figure 2: Electrical Conductivity and pH over 5 harvest intervals. Points followed by the same letter are not significantly different at *p*<0.05 using Tukey's *t*-test. Points contained in the circle showed no differences. Data are a mean of 6 replicates.

Discussion

During production BM6 showed more vigorous growth than the four newly formulated substrates. Although the new substrates did not perform as well as BM6 in this study, previous studies have suggested that composted products used in growing substrates can be quite an effective addition to growing media and can result in plant growth similar or better to that of plants grown in conventional peat:perlite mixes (Moore, 2005; Blok et al. 2009). It has also been shown that composted materials can be beneficial to plants by adding to the nutritional content of the substrate (Carlile, 2008; Moore, 2005).

The physical properties of a substrate are a vital component in plant performance (Frantz et al. 2007; Michel, 2007) making it important that the substrates are within the acceptable range for plant production. All treatments showed no differences in physical properties, including, total porosity, air space, and container capacity by the end of plant production including BM6. All new substrates, initial and final physical properties were within the acceptable range (bulk density < 0.004 g•cm^3, porosity >85% volume, air space 20-30% volume, and container capacity 60-100%volume) (Abad et al. 2001; de Boodt et al. 1972) for plant growth indicating this is not a factor in the poor plant performance in the new substrate treatments.

Gerbera require a pH range of 5.8 to 6.2 (Beytes, 2003; Reed, 1996). The pH of the substrate is very important in nutrient uptake by the plant (Caballero et al., 2007). The pH of BM6 was more favorable for gerbera growth than that of the four newly formulated substrates. Studies indicate that high pH and low electrical conductivity (EC) values can lead to nutrient deficiencies which were evident in the visual assessments of the plants as well as decreased dry matter of the plants (Caballero et al. 2009). Initially the plants were fertigated with a nutrient solution with EC of 0.5 dS·m^{-1} and two weeks later the solution was raised to 1.0 dS·m^{-1} following the recommendation of Zheng et al. (2004). This resulted in the pH of the new substrates to be too high and EC to be too low. In the study by Zheng et al. (2004) BM6 was the only substrate used indicating that approach may only be effective for substrates similar to BM6. Composted materials however are different and normally have a higher pH than peats (Corti, 1998) as observed in our study. Also, the new substrates used in this study had lower initial EC than BM6 due the absence of initial fertilizer charge. The higher pH and low EC nutrient solution, and the lack of initial fertilizer charge in the substrates in this study may have contributed to the slow growth of the plants in the newly formulated substrates at the beginning of the trial which resulted in lower overall growth than BM6.

Conclusions

The newly formulated substrates differed in performance compared to BM6 but not to each other. The physical properties of all five substrate treatments were similar and in an optimal range for plant growth indicating this may not have been the cause of poor plant growth. pH and EC, however, were not within the optimal range for gerbera production (pH between 5.8 to 6.2) and these are important variables in plant growth and performance indicating they may be the limiting factor in optimum growth of the plants in the new substrate treatments.

Two of the substrates indicated promising growth results and may have performed better if they had the proper nutrients. This suggested that further research should be conducted to investigate whether a pre-charge fertilizer and increased nutrient solution quality could be used to further improve the performance of two of the newly developed substrates. These modifications to the experimental objectives will form the basis to Chapter 3.

Chapter 3: Use of Pre-charge Slow-release Fertilizer in Newly Developed Growing Substrates for Potted Gerbera *(Gerbera jamesonii)*.

Introduction

There are about 20 elements, including micro- and macro- nutrients that are defined as essential nutrients for successful plant growth. If one or more of these elements is lacking, plant growth can be hindered. To ensure the plants are properly fed, a pre-charge slow release fertilizer or sufficient feeding solution is required for production. The substrates currently used by the ornamental industry come prepared with an adjusted pH and slow release pre-charge fertilizer by the substrate companies. Slow release fertilizers can often provide plants with the required nutrients from the start of production and then throughout the production time (Segura et al. 2005). In addition to providing the plants with the essential nutrients the pH is also a vital factor to ensure the plant is able to uptake the nutrients from the substrate. Many crops grown in soilless media, including potted Gerbera, perform best when pH is between 5.8 and 6.2 (Reed, 1996). In addition to using a pre-charge fertilizer it is important to ensure there is supplemental feeding and that the pH is maintained throughout the time of production as it is the limiting factor in nutrient uptake by the plant (Caballero et al. 2009).

The results from the first trial (Chapter 2) strongly suggested that nutrients were lacking in the new substrates tested. Commercial products, such as BM6, are pre-charged with fertilizer implying any new substrate should as well. The results from the first trial illustrated this importance as the substrates that did not contain any pre-charge fertilizer did not perform as well as the commercial product and showed signs of nutrient deficiencies. Since the physical properties of the substrates were comparable to the commercial product it suggested that the problem was chemical. After examining the pH and EC it was clear that these values were not within the range for optimal plant growth. This led to the development of this trial. The objective was 1) to compare the growth of gerbera (*Gerbera jamesonii*) in two substrates, each with and without a pre-charge slow release fertilizer, as well as to the commercial product BM6.

Materials and Methods

<u>Plant Culture</u>

Four substrates were formulated and tested in this trial (Table 1).

Table 3: Composition (%) of each substrate treatment

Mix	Peat	Coir	Coir Chunks	Compost Yard Waste	Aged Bark	Composted Pine Mulch	6-3-6 Pre-Charge Fertilizer
Mix 1	30	-	20	10	25	15	
Mix 2	30	-	20	10	25	15	3.92 g•L
Mix 3	-	30	20	10	25	15	
Mix 4	-	30	20	10	25	15	3.92 g•L
BM6	78			22% Perlite			

*3.92 g•L is an industry standard rate converted from kg/cubic yard.

The peat moss used was Fafard, Saint-Bonaventure, QC. The compost, and composted pine mulch were both 6 mm in size and were supplied by Gro-Bark, Milton, ON. The coconut coir fines were supplied by Gro-Bark, Milton, ON. The aged bark was 6 mm in size and supplied by Gro-Bark, Georgetown, ON. The coir chunks were small 6.4-12.7 mm coconut coir chunks from Mellenniumsoils Coir, St. Catherines, ON. The pre-charge fertilizer used was an organic 6-3-6 fertilizer used at a rate of 3.92 g·L and is a product provided by Sylvite Agri Services, Norwich, ON. A commercial product BM6, 22% perlite and 78% peat moss was used as the fifth treatment (Berger, Les Tourbières Berger Ltee, Saint-Modeste, QC, Canada) and was used for comparison.

Gerbera (*Gerbera jamesonii)* transplants were propagated at a commercial greenhouse in southwestern Ontario, Canada. Five week old transplants, with an average of 5 leaves, were planted into 6 inch pots (1300 mL) containing the different substrates (treatments) on Wednesday August 4, 2010. Plants were placed in a glass research greenhouse (7.62 × 6.10 m) at the University of Guelph Bovey Greenhouse Complex (lat. 43.55 degrees N. and long. 80.25 degree W.). The experiment was an incomplete random design with five treatments and three replicates (troughs) for each treatment. Each subirrigation trough (replicate) was 4.57 m long and with 20 plants in each trough. Plants were thinned accordingly as the experiment progressed to resemble the environmental conditions in commercial greenhouses. Same size gerbera plants in border troughs were used as protection plants to mitigate edge effects.

The average day and night time temperatures were 22 to 24^0C and 18 to 20^0C respectively. Pots were saturated after planting and overhead watered for the first week. After one week all plants were watered via sub-irrigation with a gerbera nutrient solution containing: 648 g $Ca(NO_3)_2$, 378.73 g $KNO_{3,}$ 246 g Mg SO_4, 170 g K_2HPO_4, 43.5 g K_2SO_4, 72 g NH_4NO_3, 0.50 g $CuSO_4$, 2.22 g $MnCl_2$ • $4H_20$, 3.72 g H_3BO_3, 0.24 g $NaMoO_4$ • $2H_20$, 212 g Fe EDTA 13%, and 1.44 g Zn SO_4 per 40L of solution. Growing substrate water content was frequently monitored by weighing randomly selected pots from each trough. The moisture content was calculated following Ø = WP – ((MP + P + DS) / V) * 100). Where: Ø = % substrate water content, WP = mass of pot with wet substrate, MP = mass of pot, P = mass of plant, DS = mass of dry substrate, V = volume of substrate. Plants were fertigated whenever the substrate water content reached 40%±1%. The fertigation solution was monitored and adjusted to maintain a pH of 5.5

and an electrical conductivity (EC) of 2.0 $dS\bullet m^{-1}$using a pH and EC meter (OAKTRON Instruments, Vernon Hills, IL, USA). Substrate pH and EC was measured weekly via the pour through method (Reed, 1996) in attempts to maintain a substrate pH of 5.8 to 6.2.

The first harvest for growth measurements were conducted 5 weeks after transplanting (5 WAT) on September 8, 2010. Six plants per treatment were harvested, two from each treatment trough. All plants aboveground biomass was used for analysis where as only three pots were used for root analysis and three for the substrates physical properties. All plants were separated into roots, leaves, crown, buds, shoots, and flowers. After fresh weights were measured, each component was placed in an oven at 70^{o}C to dry to a stable weight. Leaf area of each plant was measured using a leaf area meter (LI-3100, LI-COR Inc. Lincoln, Nebraska, USA). The longest shoot length and largest flower width were measured at each harvest. Specific leaf area was also calculated by dividing the leaf fresh weight by leaf area of each plant. The same procedure was completed at the last harvest 8 WAT on September 29, 2010; however, instead of 2 plants per trough being sampled 3 plants per trough and a total of 18 plants per treatment were sampled.

Substrate Physical Property Measurement

Three pots per treatment at each harvest were used to test the substrate physical properties throughout the trial following the North Carolina State University Porometers methodology (Fonteno and Harden, 2003) with modifications. Each pot was placed in a metal trough where water was slowly added until it reached the top of the pots. Pots were left in the water for 15 minutes to saturate. The saturated pots were transferred one by one to sit on a collection container to drain for one hour to determine the air space (AS). The drain volume was recorded and each pot was weighed and dried at 70^{o}C for one week to determine the bulk density (BD). The container capacity (CC) was calculated as the wet weight – dry weight / pot volume * 100. Total porosity was calculated by adding the AS and CC.

Statistical Analysis

Statistical analysis was performed using Prism Graphpad (version 5.03**;** GraphPad Software Inc; La Jolla, CA, 2010). Multiple means comparison was performed on all growing substrate physical and chemical properties, and plant growth measurement data using ANOVA and Students *t*-test.

Results

Visual Assessment

At 4 WAT the plants grown in mixes 3 and 4 showed signs of yellowing on the new leaves that had been fully expanded. The chlorophyll content of the new leaves at the final harvest interval was the lowest in mixes 3 and 4 but there were no differences in the other treatments (Table 1). This trend continued until the end of plant production at 8 WAT thus resulting in the overall marketability of mixes 3 and 4, especially mix 3 with no pre-charge fertilizer, to be worse than that of the other treatments. Overall the marketability, plant density – the overall fullness of the plant, greenness of the leaves and overall look, of the peat treatment with a pre-charge fertilizer was comparable to that of the plants grown in BM6.

Table 4: Leaf Chlorophyll Content Index of newest fully expanded leaf at the initial and final harvest

Substrate	5 WAT	8 WAT
	Chlorophyll Content Index	Chlorophyll Content Index
	CCI Units	CCI Units
Mix 1	47.7ab	38.0a
Mix 2	57.6a	48.6b
Mix 3	26.2c	31.1a
Mix 4	53.4ab	34.5a
BM6	42.4b	39.8ab

Data are a mean of 6 replicates.
Values followed by the same letter are not significantly different at $p<0.05$ using Tukey's *t*-test.

Plant Growth

At the final harvest, 8 WAT, the plants grown in Mix 3 were comparable in all harvest parameters to that of the plants grown in BM6 including: chlorophyll content index of new leaves, flower number, leaf number, and aboveground biomass. Mix 2 had both higher leaf area and leaf fresh weights than BM6. Gerbera plants grown in Mix 3 were lower in leaf area, leaf weight, and aboveground biomass than the other four treatments (Figure 1) throughout the whole trial. At the final harvest the dry root weight of Mix 1 was higher than BM6. The root weights of Mixes 2, 3 and 4 were comparable to the root weight of BM6.

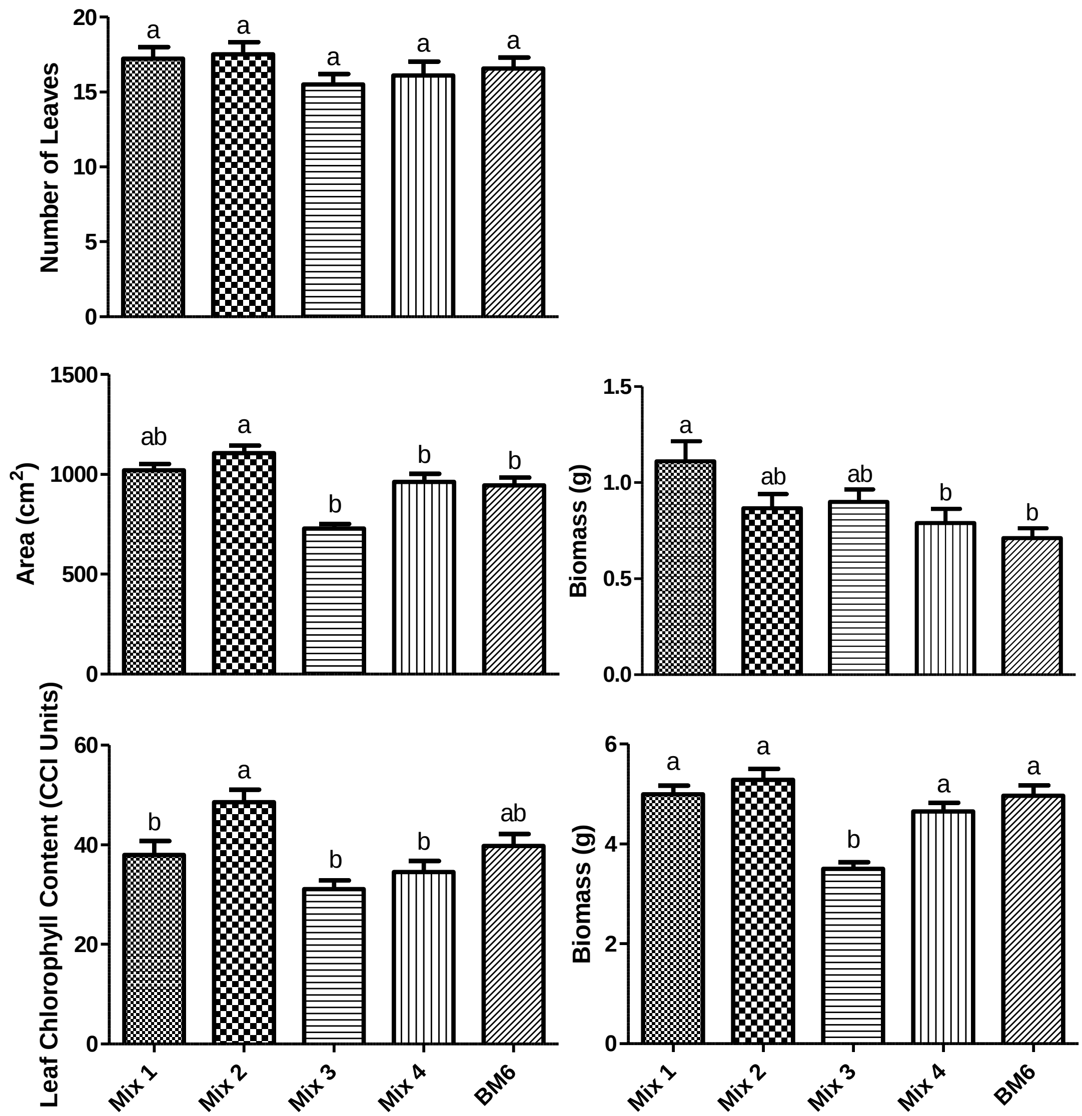

Figure 3: Number of leaves, leaf area, leaf chlorophyll content, root dry biomass and aboveground dry biomass (respectively top to bottom and left to right) at the final harvest. Data are a mean of 6 replicates. Points followed by the same letter are not significantly different at *p*<0.05 using Tukey's *t*-test.

Flower Number

At the final harvest, there was no difference in flower number per plant between Mixes 1, 2 and 4 and BM6. BM6 did have more flowers per plant than Mix 3 (Figure 2). There was no difference in bud number per plant in any of the treatments (Figure 2).

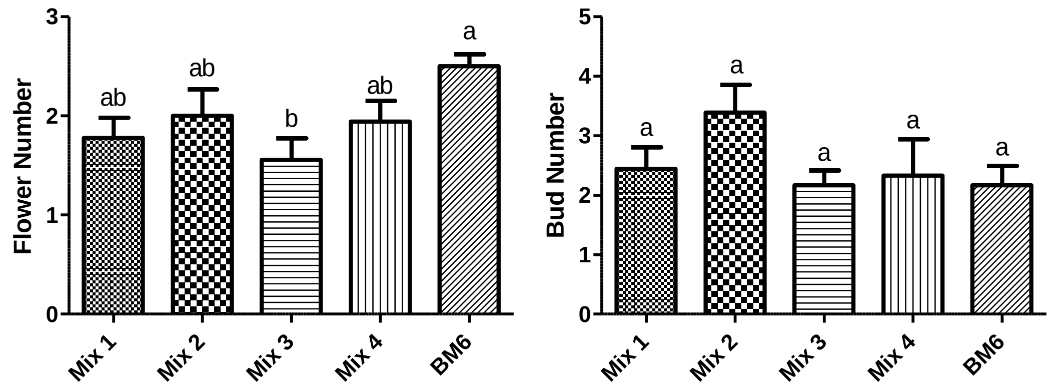

Figure 4: Flower and bud number (respectively left to right) at the final harvest. Data are a mean of 6 replicates. Points followed by the same letter are not significantly different at *p*<0.05 using Tukey's *t*-test.

<u>Substrate Physical Properties</u>

At the first harvest, 5 WAT, the substrates showed no differences in container capacity and air space (container capacity mean = 79.29%, se = 0.62%, air space mean = 9.65%, se = 0.56%). The total porosity was higher in Mix 4 than Mix 2 (Mix 4 mean = 91.78%, se = 0.86%, Mix 2 mean = 86.96%, se = 1.10%). There were no differences in Mixes 1, 3 and BM6 at this harvest (mean 88.65%, se = 0.50%) (Table 2).

Table 5: Growing substrates initial and final physical properties

Substrate	5 WAT			8 WAT		
	Total Porosity	Container Capacity	Bulk Density	Total Porosity	Container Capacity	Bulk Density
	%	%	g•cm3	%	%	g•cm3
Mix 1	89.47ab	81.31a	0.223ab	84.19a	74.23a	0.213ab
Mix 2	86.96b	79.51a	0.230a	87.61a	75.68a	0.224c
Mix 3	88.01ab	77.56a	0.213b	84.49a	76.19a	0.209a
Mix 4	91.78a	79.94a	0.227ab	88.78a	77.20a	0.220bc
BM6	88.46ab	78.11a	0.113c	87.01a	76.39a	0.114d

Data are a mean of 3 replicates.
Values followed by the same letter are not significantly different at $p<0.05$ using Tukey's *t*-test.

pH and EC

Mix 4, coconut coir plus the pre-charge, had a higher pH throughout the whole trial (6.68±0.16) Mix 1 (6.06±0.13) and BM6 (5.89±0.12). Mix 2, peat moss plus the pre-charge (6.44±0.15) and Mix 3, coconut coir with no pre-charge (6.33±0.20) showed no difference from any of the treatments in the average pH throughout the trial. There was a jump in the pH for all treatments at week two which may have resulted in the averages being slightly higher for the pH. There was only a difference in average EC values throughout the trial which was between Mix 2 (1.96±0.07 $dS•m^{-1}$) and BM6 (2.14±0.05 $dS•m^{-1}$). Mixes 1, 3 and 4 showed no differences in average EC values throughout the trial (2.30±0.05 $dS•m^{-1}$) (Figure 3).

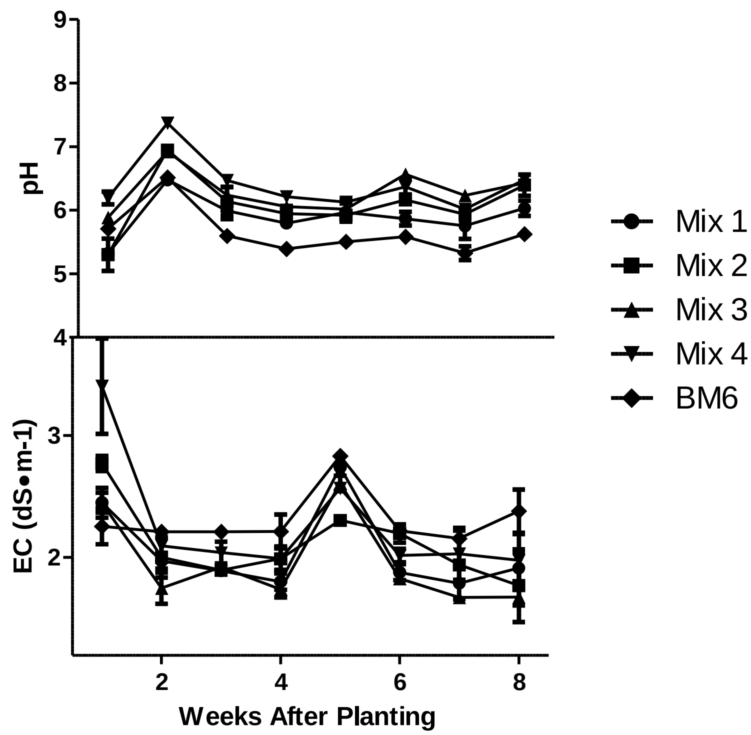

Figure 5: pH and EC average values (respectively top to bottom) weekly throughout production. Data are a mean of 6 replicates.

Discussion

The peat substrate with a pre-charge fertilizer included had the best plant performance of all the treatments. The treatments with the best plant performance were grown in the substrates containing a pre-charge fertilizer, including BM6, in comparison to the substrates with no pre-charge fertilizer (Figure 1). These results coincide with others who have noted that Gerbera specifically have the best response when the use of a slow release fertilizer, including N, is used (Rogers, 1990). The physical properties of all of the substrates were comparable to BM6 in all parameters except the bulk density (Table 2) which suggests that the lack of growth in the treatments with worse plant performance is related to chemical issues rather than the physical properties of the substrate. The pH and EC were well maintained throughout the trial at a range that is optimal for the growth of Gerbera (Reed, 1996; and Rogers, 1990). Beyond these observations, it was evident that Mixes 3 and 4, the two treatments containing coconut coir, did not produce plants that were comparable to the other treatments in terms of leaf area, leaf number and dry aboveground biomass (Figure 1). Coconut coir, as well as other composted substrate components, have posed some problems in the past in relation to nutrient availability or toxicity due to nitrogen drawdown or problems with salinity which has resulted in poor plant performance (Meerow, 2007; Caballero, 2009; Prasad, 1997; Raviv, 2002; and Jackson, 2009). To support this further, the plants in these same treatments had lower chlorophyll content measurements (Table 1) than the plants grown in the substrates that contained peat moss. This has also been found by others who have studied coir containing substrates (Arenas, 2002). It has been suggested by some that when substrate alternatives are used that cause nutrient deficiencies a proper fertilization program is essential for optimal plant growth and with this comparable plant growth is achievable (Hendreck, 1992 and 1993).

Conclusions

The peat substrate with the pre-charge fertilizer included produced the best quality plants of all of the substrate treatments. Overall the substrates that included a pre charge fertilizer, including BM6, differed in performance from those where no pre charge fertilizer was included. There was also a difference between the substrates containing coconut coir fines compared to the ones using peat moss or to BM6. The physical properties of the substrates were similar to each other as well as within the optimal range for greenhouse potted gerbera production (Raviv, 2002). The pH and EC of the substrates were kept within the optimal range for gerbera growth (pH between 5.8 and 6.2); however, it was more challenging to keep the substrates containing coconut coir fines at a lower pH. This may have resulted in these treatments not performing as well as the other treatments. The coconut coir and composted aged bark may have caused problems with nutrient deficiencies due to nitrogen immobilization which may have also contributed to the poorer plant growth.

This research allows others to understand the importance of the incorporation of a pre charge slow release fertilizer in a growing substrate for optimal plant growth. Both of the newly developed substrates that included the pre charge fertilizer illustrated that with proper management practices and fertilizer rates they produce plants equal or greater plants in terms of marketability to those grown in a commercial mix such as BM6. Although quality plants are being produced in these substrates further research on nitrogen immobilization and evaluating specific fertilizer pre charge rates on the newly developed substrates may be needed to further enhance the overall quality of the gerbera.

Chapter 4: Assessing Slow-release Fertilizer Rates for Peat Alternative Substrates

Introduction

Pre-charge or slow release fertilizers play an important role in plant production as they provide plants with an initial supply of nutrients at the start of production (Cadahia, 1993). This was evident in the previous experiment (Ch 3) where the results illustrated the newly developed substrates including a pre-charge fertilizer produced plants comparable to the commercial product while the ones without the pre-charge did not. That experiment also illustrated the importance of fertilizer management by both including a pre-charge fertilizer in the growing substrate as well as continuing to supply the plants with nutrients throughout the growth period. Although comparable plants were produced in the new substrates there are still questions that remain to see if better plant performance can be achieved in the new substrates. When supplying the plants with nutrients via pre-charge fertilizer and feeding solution via fertigation, it is important for growers to know which rate produces the best plants. Furthermore examining the components of the substrates is also important to ensure there are no restrictions in nutrient uptake due to certain substrate constituents. It has been suggested that the use of organic constituents, such as composted products including bark, can cause N-immobilization in the substrate if not fully composted, thus reducing the amount of nitrogen that is available for plant uptake (Hendreck, 1992; Caballero, 2009; Raviv, 2002).

Currently, no research has been conducted on gerberas examining the best pre-charge rate for optimal plant performance. Different studies using gerbera have used different pre-charge fertilizers and have looked into different feeding solutions, all of which have produced marketable products (Kaewruang, et al. 1989; Caballero et al. 2009; Segura, et al. 2005; Zheng et al. 2004); however, there has been no study that examines specific rates of pre-charge fertilizer in relation to the growth of potted gerbera. There has also been minimal work done on the analysis of N-immobilization on substrates with multiple composted alternatives which have caused concern with nutrient deficiencies and nitrogen immobilization (Caballero, 2009; Hendreck, 1992). Finally there has yet to be any work done on the Nitrogen Drawdown Index (NDI) on the actual substrates in which the plants are grown throughout production.

The objectives of the research were to: 1) determine the optimum pre-charge rate in two newly developed growing substrates; 2) investigate the relationship between pre-charge rates and NDI; 3) and investigate the relationship between the NDI and substrate N content by pour through nutrient analysis.

Materials and Methods

Two substrates were formulated for this trial each with five different pre-charge fertilizer rates.

Table 6: Composition of each substrate treatment

Mix	6-3-6 Pre-Charge Fertilizer	Peat	Coir	Coir Chunks	Composted Yard Waste	Aged Bark	Composted Pine Mulch
Mix 1	2.0 g•L	30	-	20	10	25	15
Mix 2	3.0 g•L	30	-	20	10	25	15
Mix 3	3.92* g•L	30	-	20	10	25	15
Mix 4	5.0 g•L	30	-	20	10	25	15
Mix 5	7.0 g•L	30	-	20	10	25	15
Mix 6	3.0 g•L	-	30	20	10	25	15

Mix 7	3.92 g•L	-	30	20	10	25	15
Mix 8	5.0 g•L	-	30	20	10	25	15
Mix 9	7.0 g•L	-	30	20	10	25	15
Mix 10	9.0 g•L	-	30	20	10	25	15

*3.92 g•L is an industry standard rate converted from kg/cubic yard.

The peat moss used was Fafard, Saint-Bonaventure, QC. The compost, and composted pine mulch were both 6 mm in size and were supplied by Gro-Bark, Milton, ON. The coconut coir fines were supplied by Gro-Bark, Milton, ON. The aged bark was 6 mm in size and supplied by Gro-Bark, Georgetown, ON. The coir chunks were small 6-12 mm coconut coir chunks from Mellenniumsoils Coir, St. Catherines, ON. The pre-charge fertilizer used was an organic 6-3-6 fertilizer and is a product provided by Sylvite Agri Services, Norwich, ON.

To determine the pre-charge fertilizer rates to be used in the study, an initial NDI test was performed on both the peat moss and coir substrates following the method developed by Hendreck (1992). This was to determine how much nitrogen was immobilized in the substrate alone. From these results, along with the results from the second trial fertilizer rates, five different rates were selected for each substrate treatment. Since the peat moss substrate performed better than the coir substrate in the previous experiment it was decided to have two rates lower than the original as well as two rates higher. As for the coir substrate it was decided to only have one rate lower than the original and three higher. These rates were also based on the initial NDI results of the substrates. The coir substrate had a lower NDI value than the peat meaning more nitrogen was immobilized; therefore, it was decided to have higher rates for the coir substrate than the peat.

The fertilizer was weighed separately for each treatment and individual pot. Pots were then filled with the desired substrate treatment, dumped into a bowl and the pre measured pre-charge fertilizer was mixed in with the substrate. The mix was then put back in the pot and placed on the trough.

<u>Plant Culture</u>

Gerbera (*Gerbera jamesonii)* transplants were propagated at a commercial greenhouse in southwestern Ontario, Canada. Five week old transplants, with an average of 6 leaves, were planted into 6 inch pots (1300 mL) containing the different substrates (treatments) on Tuesday March 1, 2011. Plants were placed in a glass research greenhouse (7.62 × 6.10 m) at the University of Guelph Bovey Greenhouse Complex (lat. 43.55 degrees N. and long. 80.25 degree W.). The experiment was an incomplete random design with ten treatments and three replicates (troughs) for each treatment with each replicate having two sub samples. Each sub-irrigation trough (replicate) was 4.57 m long and with 20 plants in each trough, ten of one treatment and ten of another with similar fertilizer rates. Plants were thinned accordingly as the experiment progressed to resemble the environmental conditions in commercial greenhouses. Same size gerbera plants in border troughs were used to mitigate possible edge effects. The average day and night time temperatures were 22 to 24^0C and 18 to 20^0C respectively. Pots were saturated after planting and overhead watered for the first week. After one week all plants were watered via sub-irrigation with a gerbera nutrient solution containing: 648 g $Ca(NO_3)_2$, 378.73 g KNO_3, 246 g Mg SO_4, 170 g K_2HPO_4, 43.5 g K_2SO_4, 72 g NH_4NO_3, 0.50 g $CuSO_4$, 2.22 g $MnCl_2 \cdot 4H_20$, 3.72 g H_3BO_3, 0.24 g $NaMoO_4 \cdot 2H_20$, 212 g Fe EDTA 13%, and 1.44 g Zn SO_4 per 40 L of solution. The watering solution was monitored at every watering to maintain a pH of 5.5 and an electrical conductivity (EC) of 2.0 mS cm^{-1} using a pH and EC meter (OAKTRON Instruments, Vernon Hills, IL, USA). Substrate pH and EC was measured weekly via the pour through method to maintain an appropriate substrate pH of 5.8 to 6.2. On April 7, 2011, 5 weeks after transplanting (WAT) the first harvest was conducted. Six plants per treatment were harvested. All plants were separated into roots, leaves, crown and buds, shoots, and flowers. Fresh weights were measured then each component was placed in an oven of 70^{o}C to dry to a constant dry weight. Leaf area of each plant was measured using a leaf area meter (LI-3100), LI-COR Inc. Lincoln, Nebraska USA). The visual assessments were taken at each harvest using a conventional rating scale designed to reflect consumer preferences. The factors rated included plants overall visual appearance, plant greenness, the fullness of the plants, flower quality and size. The final harvest was conducted on May 16, 2011, 11 WAT. Before harvesting the plants at each harvest interval a pour through analysis was conducted and N-NO_3 concentration was analyzed.

Nitrogen drawdown index

To determine the NDI of the substrates each sample pot was dumped into a container and the roots were removed. The substrate was then mixed and 2 samples were taken to fill graduated cones (100 mL). Each cone was filled separately, tapped on the counter 5 times and filled to the top with substrate. Each cone was labeled and placed in a plastic holder which was set over a grate to drain. 100 mL of deionized water was slowly poured over each cone. The samples were left to wait 30 minutes. 100 mL of potassium nitrate solution (prepared by adding 0.54 g potassium nitrate per 1 L of water) was then poured slowly over each cone and left to wait another 30 minutes. Again, another 100 mL of potassium nitrate solution was slowly poured over each cone and left to drain for 15 minutes. Each cone was given a sharp vertical shake to ensure any excess water on the bottom was removed. Cones were left to sit for another 5 minutes. The contents of one of the samples were put into a container where 100 mL of deionized water was added. The water and substrate were mixed into a slurry and left to stand for 5 minutes. The liquid from the slurry was poured into a funnel made of filter paper to collect minimum 10 mL of solution in a collection tube. The remaining cones were put into an incubator (temperature $21^{o}C$) for four days. After incubation the contents in the remaining cones were put into a container with 100 mL of deionized water to make a slurry so the solution could be sampled after 4 days. To obtain a NDI value the $N\text{-}NO_3$ concentration in the solution was analyzed at day 1 and day 4 and the concentration of day 4 was divided by that of day 1 to get a value between 0 and 1. The closer the value was to 0 the more nitrogen was immobilized and the closer the value was to 1 the less nitrogen was immobilized by the substrate. All samples were labeled and frozen in a -$80^{o}C$ freezer until the final harvest (at 11 WAT) was completed and the samples were sent to the Laboratory Services Division, Agriculture and Food Laboratory, University of Guelph, Guelph, Ontario, CA, for analysis of $N\text{-}NO_3$. The $N\text{-}NO_3$ concentration was measured spectrophotometrically at 520 nm, using the Seal AQ2 automated discrete analyzer (Seal Analitical, Mequan, WI, USA).

Statistical Analysis

Statistical analysis was performed using SAS (version 9.1; SAS Institute Inc. Cary, NC, USA, 2011). Multiple means comparison was performed on all growing substrate chemical properties, and plant growth measurement data using ANOVA and Tukey-Kramer's *t*-test. All data was tested for normality using Shapiro-Wilk. Correlation and regression analysis was performed.

Results

Nitrogen Drawdown Index and Pour Through Analysis

The initial nitrogen drawdown index before planting showed that the peat moss had a higher NDI than the coir substrate (Peat = 0.71±0.03; n=3; Coir = 0.36±0.04; n=3).

The NDI results at the first harvest illustrated that overall the values of the peat substrates were higher than the coir substrates (Peat = 0.89±0.02; n=3; Coir = 0.61±0.02; n=3). Among the coir substrates the treatment containing 7 g/L (0.79±0.06) of fertilizer had a higher value than the treatments with 3 g/L (0.46±0.06). There were no differences in NDI values among the different fertilizer rates in the peat substrates.

At the final harvest, the NDI results changed showing the peat substrates to have a lower NDI value that the coir substrates (Peat mean = 1.01±0.25; Coir mean = 1.37±0.36). Among the peat treatments the substrates containing 3 g/L, 5 g/L and 7 g/L had a lower NDI values (1.12±0.96, 0.96±0.11 , 0.97±0.11 respectively) than the treatments containing 3.92 g/L of fertilizer (1.71±0.11). With the coir treatments the substrate containing 3.92 g/L of fertilizer had a lower NDI value (0.84±0.11) than the treatment with 7 g/L of fertilizer (1.41±0.11).

The N-NO3 concentration results showed no trend in terms of whether the substrate contained peat moss or coir. At the first harvest, the peat substrate with 5 g/L of fertilizer had the highest concentration of N-NO3 concentration (115±10.2ppm) and the coir substrate with 9 g/L of fertilizer had the highest concentration (95.2±10.2ppm).

At the final harvest the peat substrate with the fertilizer rate of 7 g/L had the highest N-NO3 concentration of 234.3±21.8ppm. The coir substrate with a fertilizer rate of 3.92 g/L had a higher concentration of N-NO3 than the rest of the coir treatments at 113.9.2±21.8ppm.

The correlation between the N-NO3 concentration results from the pour through analysis and the NDI values obtained at the first harvest was significant (p=0.003). However, this relationship was considered weak with R^2 = 0.28 and at the final harvest the correlation disappeared completely (p=0.97, R^2 = 0.00).

pH and EC

The average pH and EC of the peat and coir treatments at the first harvest were pH = 6.25±0.03, EC = 1.82±0.07 dS/cm; n=3 and pH = 6.42±0.03, EC = 1.37±0.08 dS/cm; n=3 respectively. The average pH and EC of the peat and coir treatments at the final harvest were pH = 6.24±0.04, EC = 1.89±0.07 dS/cm; n=3 and pH = 6.44±0.03, EC = 1.37±0.08 dS/cm; n=3 respectively.

Visual Assessment

There were no differences in chlorophyll content in any of the treatments at the final harvest 61.7±6.3 CCI Units. Seven WAT the substrates containing coir with a pre-charge fertilizer rate of 5 g/L or more showed rust spots on the older leaves. This was consistent throughout the whole greenhouse in each of the coconut coir treatments containing the higher pre-charge fertilizer rates. This trend continued to the end of the production time and was only found in the coconut coir treatments.

Plant performance ratings were assessed at each harvest and at the final harvest the general consensus was that the peat substrate with the lowest pre-charge rate of 2 g/L and the coir treatment with the second lowest pre-charge rate of 3.92 g/L were the most desirable on a scale of 1 to 5 for overall visual appearance (including plant greenness, the fullness of the plants, flower quality and size) of the plant.

Plant Growth

Overall the plants grown in the substrates containing peat moss were better in the parameters of leaf area, aboveground biomass, and leaf number than the plants grown in the substrates containing coir. At the final harvest the plants with the pre-charge fertilizer rate of 2.0 g/L in the peat substrate performed the best compared to the other substrate pre-charge fertilizer treatments (Figure 1).

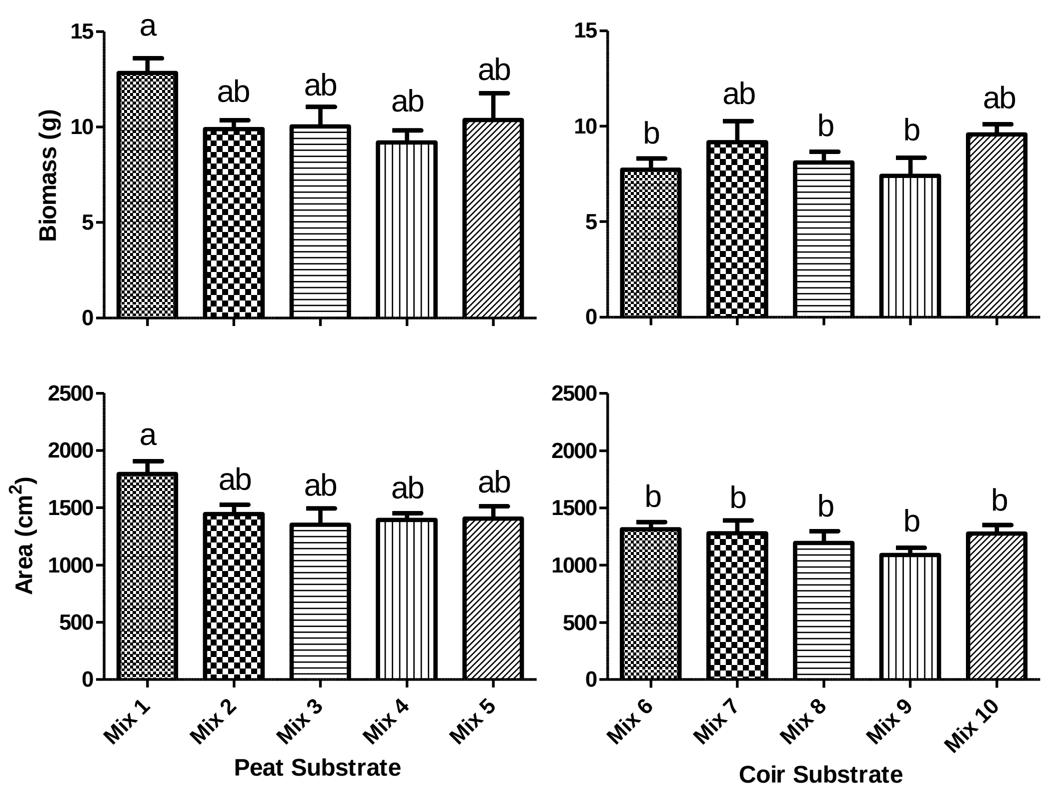

Figure 6: Aboveground dry biomass and leaf area for each of the peat and coconut coir substrates. Data are a mean of three replicates with each replicate having two subsamples.

At the first harvest there were no differences in bud or leaf number per plant (1.45±0.15 and 12.9±0.18 respectively) in either fertilizer treatment or substrate. At the final harvest there were no differences in flower and leaf numbers (1.5±0.10 and

24.4±0.56 respectively) in either fertilizer treatments or substrates. Mix 1 did have a higher number of buds per plant than mixes 2 and 3 (5.76±0.57, 1.65±0.57 and 2.59±0.57 respectively). There were no differences in buds per plant among the other treatments.

Discussion

The treatments exhibiting the best plant performance were the peat moss with 2 g/L of N pre-charge fertilizer and the coconut coir with 3.92 g/L of N pre-charge fertilizer. Although the coir treatment with a pre-charge rate 9 g/L of N had an aboveground biomass weight similar to that of the 3.92 g/L of N it also showed signs of toxicity on the leaves and the overall look of the plant was less desirable. It was expected that the coir containing substrates would require a higher pre-charge fertilizer rate as the initial substrate NDI analysis indicated that more nitrogen was immobilized in the coconut coir containing substrates than in the ones containing peat moss.

Including aged bark in the substrates was initially a concern due to previous studies suggesting there may be an increase in N immobilization if high percentages of bark are used in a substrate (Caballero, 2009; Hendreck, 1992; Rogers, 1990; Raviv. 2002). This however was not the case with these substrates, which may be attributed to the type of bark used as it is highly composted. Also, following the recommendations of Hendreck (1992) supplemental feeding was used throughout the trial to ensure enough nutrients were being supplied to the plants which may have contributed to the optimal plant growth.

Jackson et al. (2009) has suggested that at low fertilizer rates there may be an increase in nitrogen immobilization in bark-containing substrates. This however was not the case in this study as all substrates contained the same percentage of bark and the immobilization rates were not at a high level. Even with bark included at a higher percentage than suggested none of the treatments, low pre-charge rates included, exhibited excessive immobilization based on the NDI results at any harvest interval.

The results showed that the coconut coir-containing substrates had a greater increase in NDI values from the first harvest interval to the second than the peat moss-containing substrates. Other than peat and coir content the only difference in the substrates was the pre-charge fertilizer rates of the highest and lowest rates. Both the substrates containing the aged bark, coir and peat moss had NDI values close to 1 which meant little to no nitrogen was being immobilized. This agrees with the results found by Kanamori et al. (1979) where it was found that peat moss and barks tended not to change the availability of nitrogen over time. Since the substrates did not immobilize nitrogen, the nitrogen present in the substrate was available for plant uptake so a higher pre-charge fertilizer rate was not necessarily required. This was evident in the trial as there were signs of toxicity in the coir treatments containing high rates of pre-charge fertilizer. This either suggests the pre-charge fertilizer rate was too high or that the feeding solution was too strong. Zheng et al. (2004) found that using a low rate feeding solution with a substrate containing a pre-charge fertilizer produced the best plants in gerbera production. This leads to questioning whether using a high rate pre-charge fertilizer and a low rate feeding solution may be better than a low rate pre-charge fertilizer and high rate feeding solution.

Conclusions

The substrates containing peat moss performed better than the substrates containing coir in overall plant performance. In analyzing the NDI of the substrates prior to planting this made sense as the peat substrate had a higher NDI than the coir substrate. This indicated there was less nitrogen immobilized in the substrates containing peat moss than the ones containing coconut coir at the time of planting. Throughout the production and based on the overall plant growth parameters of leaf area, leaf number, chlorophyll content, aboveground dry biomass and the visual assessment it was clear that the peat substrate with the lowest pre-charge fertilizer rate of 2 g/L of nitrogen and the coconut coir substrate with the second lowest rate of 3.92 g/L of nitrogen performed the best. It was evident that a pre-charge fertilizer is required for optimal plant growth but discovering the optimal amount was the goal of this study. With the signs of nutrient toxicity in the higher rates for the coir treatments as well as the results that showed the lower rates were superior. Results suggest that fertigating with an EC of 2.0 dS•m throughout the time of production with a low rate of pre-charge fertilizer of 2 g/L in peat moss and 3.92 g/L in coir is the best option for optimal plant growth of potted gerbera.

Using the NDI method of analyzing N – immobilization provided a good indication of how much nitrogen was immobilized and thus could allow a grower to decide if more or less pre-charge fertilizer is needed in the substrate. Further research may look into assessing different pre-charge fertilizer rates along with different feeding solution rates to assess plant growth.

Chapter 5: General Discussion and Conclusion

The overall goal of this research project was to develop growing substrates that could be considered environmentally viable while at the same time being able to produce potted Gerbera plants of top quality for the market place. The first step in trying to achieve this goal was with the development of four new substrates (Chapter 2). These new substrates contained a significantly reduced amount of peat moss and perlite was eliminated completely. In order to compensate for these characteristics in the substrates, by-products from coconut harvesting along with locally available composted materials such as yard waste, pine bark, and manure were used.

The first trial (Chapter 2) showed that the physical properties of all four of the new substrates were comparable to the commercial product being tested, BM6. The physical properties tested, which included the total porosity, container water holding capacity, air space and bulk density, were all within the optimal range for potted plant production. This indicated that the plants should have similar growth patterns to that of the commercial product. The experiment described in Chapter 2 showed that the growth of the plants in the new substrates was not comparable to those grown in the commercial product. The results suggested that the problem may be with the chemical properties. Upon investigation it was found that the pH and EC of the new substrates were not within the optimal range. The pH was too high and the EC was too low which potentially resulted in nutrient deficiencies in the plants grown in the new substrates from the beginning of production. In addition to the pH and EC not being within an optimal range, the newly developed substrates did not come prepared with a pre-charge slow-release fertilizer whereas the commercial product did. The lack of pre-charge fertilizer in the new substrate mixes may have hindered plant growth as the plants in the new substrates had less nutrient supply at the start of production than the ones grown in BM6. Two of the new substrates indicated promising growth results and may have performed better if they had the proper nutrients. My second trial was then developed, which examined the addition of a pre-charge fertilizer and an increase in nutrient solution concentration.

The second trial (Chapter 3) examined the use of a pre-charge fertilizer in two of the newly developed substrates from the first trial. The two substrates only differed in their content of either peat moss or coir fines. The trial included both substrates with the inclusion of a pre-charge slow-release fertilizer and without. The substrates including the fertilizer performed better than those without and the peat moss substrate performed better than coir. The physical properties of the substrates, including total porosity, container capacity, air space and bulk density, were tested and were comparable to that of the commercial product BM6. The bulk densities were higher in the new substrates; however, this was expected as they contained less peat moss and heavier constituents such as composted products. The substrates containing coir fines did not produce plants that were comparable in quality to those produced in the peat moss containing substrates. This may have been a result of the pH of these treatments as it was more difficult to maintain a lower pH in these substrates. An additional concern in substrates containing composts or aged bark is the potential for nitrogen deficiency due to nitrogen immobilization (Hendreck, 1992; Meerow, 2007). A third experimental trial was then designed to investigate the nitrogen drawdown index (NDI) of the substrates and the effect of various pre-charge rates for slow release fertilizer applications.

The third trial (Chapter 4) involved the analysis of nitrogen drawdown in each of the two peat reduced substrates, the relationship between the NDI and pour through analysis of nutrients, as well as assessing what pre-charge fertilizer rate resulted in the best plant performance. The results showed the substrates containing peat moss out-performed the substrates containing coir in overall plant performance. When assessing the overall growth and marketability of the plants, those grown in the substrates containing peat moss with the lowest pre-charge fertilizer rate and those in the coconut coir substrate with the second lowest pre-charge fertilizer rate exhibited the best overall performance. This made sense as when analyzing the nitrogen drawdown index on the substrates before planting there was more nitrogen immobilized in the substrates containing coconut coir than in the peat moss substrates which indicated more nutrients would be needed. The plants with the highest pre-charge fertilizer rates in the coir substrates also showed signs of salt toxicity on the leaves indicating an increase in the rate of pre-charged fertilizer may not always be the best solution. Overall the NDI method of analyzing N – immobilization provided reliable results and has the potential to assist people when developing new substrates to understand if nitrogen is immobilized or to help determine pre-charge fertilizer rates.

When developing new substrates for the production of any crop it is essential that both physical and chemical properties are monitored and managed to best suit the crop being produced. This study clearly showed that the substrates developed, containing no perlite, reduced peat moss, higher percentages of bark and coconut coir, are a viable alternative for growers in the production of potted gerbera *(Gerbera jamesonii).* Also, reducing the peat content (or replacing it entirely with composted products such as yard waste) and eliminating the perlite content in favour of composted aged bark, will greatly reduce the environmental impact of such products. It is vital to understand the importance of the substrates physical properties, the management of the pH and EC throughout production and the use of a slow-release pre-charge fertilizer. Specifically, I would recommend using the peat mix with a pre-charge fertilizer rate of 2.0 g•L or the coir mix with 3.92 g•L with a high nutrient feeding solution of 2.0 mS cm^{-1} as a competitive alternative to the commercial standard BM6 for the growth of potted gerbera. These substrate alternatives have proven to produce plants of the same quality or better than those produced in BM6. In addition to providing environmental sustainability the new substrates provided a savings of ~15% per cubic metre compared to the commercial product when purchased in bulk.

Suggestions for future research include; the analysis of using a lower strength feeding solution with the use of a pre-charge fertilizer included in the substrates or testing the growth of other popular ornamentals in these same substrates in comparison to a commercial mix. Recommendations for others who are formulating substrates that are environmentally sustainable for gerbera production is to thoroughly examine the requirements of the crops' needs in a substrate, both physically and chemically. It is also important to understand where the products used for the substrate are coming from and to ensure the process of which they are manufactured is reliable and fairly consistent.

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