VALORIZING INDUSTRIAL BYPRODUCTS - PAPER MILL PULP SLUDGE AND DRYWALL THROUGH THE DEVELOPMENT OF HIGH-QUALITY GROWTH MEDIUM

By

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Abstract

The human population continues to rise and projections suggest there will be nine billion people on earth by 2050. Food consumption patterns continue to indicate there will be a need to significantly increase agricultural production, to meet the rising demand for food. This brings into focus the need to develop novel ways as part of planning for future demands while using the same amount of land and minimizing environmental impacts. With a lens on increasing regional food production; combinations of waste cellulose fiber sludge from Port Hawkesbury paper mill and gypsum from Cabot Gypsum, Nova Scotia, were used to cultivate Little Bing tomato (LBT) (*Solanum lycopersicum*), comparing growth rates and quality against commercially available peat moss. Results demonstrated it is possible to produce LBT in pulp-gypsum blends. This could lead to the diversion of several thousand tons of waste pulp sludge and drywall from landfills each year.

List of Abbreviations and Symbols Used

Al	- aluminum
ANOVA	- analysis of variance
ATG	- average time to germination
ATP	- adenosine triphosphate
B	- boron
BD	- bulk density
BS	- base saturation
C&D	- construction and demolition
Ca	- calcium
CBC	- Canadian Broadcasting Corporation
CBI	- Cape Breton Islands
CEC	- cation exchange capacity
CEO	- chief executive officer
CF	- coconut fibre
CG	- Cabot Gypsum
CK	- cytokinin
Cl	- chlorine
CRD	- completely randomized design
Cu	- copper
EAC	- Ecology Action Center
EC	- electrical conductivity
FAO	- Food and Agriculture Organisation
Fe	- iron
FGD	- Flue gas desulfurization
F_v/F_m	- fluorescence
GHG	- greenhouse gasses
H	- hydrogen
H_a	- alternative hypothesis
H_o	- Null hypothesis
HRM	- Halifax Regional Municipality
ICP/MS	- Inductively coupled plasma mass spectrometry
ICP/OES	- Inductively coupled plasma - optical emission spectrometry
K	- potassium
LBT	- little bing tomato
LSD	- least significant differences
Mg	- magnesium
Mn	- manganese
Mo	- molybdenum
MRM	- most recent mature leaf
N	- nitrate
n	- sample
NS	- Nova Scotia
NSDA	- Nova Scotia Department of Agriculture
NSPI	- Nova Scotia Power Inc.

NSSWRMS	- Nova Scotia Solid Waste Resource Management Strategy
P	- phosphorus
PD	- pore distribution
pH	- potential of Hydrogen
PHP	- Port Hawkesbury paper
PSD	- particle size distribution
p-value	- significance
RBFN	- Réseau BioFuelNet
S	- sulphate
SFA	- substance flow analysis
SME	- saturated media extract
SMEWW	- Standard Methods for the Examination of Water and Wastewater
SRES	- School for Resource and Environmental Studies
TDF	- Technology Development Foundation
TFPC	- Toronto food policy council
TSS	- total soluble solids
UGMP	- Urban Garden Mentors Project
UN	- United Nations
USEPA	- United States Environmental Protection Agency
VCSEE	- Verschuren Centre for Sustainability in Energy and the Environment
WBCSD	- World Business Council for Sustainable Development
WHC	- water holding capacity
Zn	- zinc
α	- alpha

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Chapter 1: Introduction

1.1 Overview of Problem

According to the World Business Council for Sustainable Development (WBCSD) Vision 2050 - The New Agenda for Business, outlines their response to three questions: “What does a sustainable world look like? How can we realize it? What are the roles businesses can play in ensuring more rapid progress toward that world?” (WBSCD, 2010). The WBSCD, (2010) ambitiously declares, “In 2050, around 9 billion people will live well, and within the limits of the planet” (p.6). Nevertheless, the Council recognizes the diminishing of current resources, and that changes in climate will impose limiting factors for 9 billion people to maintain lifestyles built on high resource consumption. Consequently, a twofold increase in agricultural productivity using the current land and water resource consumption is among the seven crucial areas to be focused on (WBDSD, 2010).

The Government of Canada (2017), states that 10% of its greenhouse gasses (GHG’s) are produced by activities related to agriculture and forestry, while another 3% comes from the country’s landfills. To combat these and other occurrences, the Government fostered the establishment of the *Pan-Canadian Framework on Clean Growth and Climate Change* and charged it with the responsibility to ensure the reduction of emissions. Within this portfolio is the goal to foster sustainability through the use of by-products from sectors such as those involving agricultural and forestry activities.

The term *sustainable prosperity* has been officially integrated into the policy language of a number of Canadian provinces. The Ontario government, for example, has moved to develop a strategy specifically focusing on creating a waste-free Ontario by integrating circular economy concepts into their platform (Smart Prosperity Institute, 2017). Meanwhile, Réseau BioFuelNet (RBFN), seeks to bring together key industry partnerships in order to better support research in biofuel development that contribute to the debates relating to food and fuel. To this end, RBFN establishes the vision for Canadian agriculture to double its output by 2050, while generating more biomass for energy production, and moving production to colder regions of Canada (RBFN, 2017).

Within rural Nova Scotia (NS), it is recognized that heavy transportation is needed to sustain food supplies and with this comes increased GHG emissions (Franks & Hadingham, 2012). Against this backdrop is Port Hawkesbury Paper (PHP), an industrial operation within NS with heavy dependence on forest and water resources, it is predisposed to having a relatively high carbon footprint. Cabot Gypsum (CG), the producer of Acadia Drywall is co-located with PHP and generates waste drywall in considerable volumes and is also resource intensive. Such resource intensive operations may have the capacity to drive novel innovations in food production by integrating such operations into agro-ecoindustrial synergies and material exchanges (Gulipac, 2016).

If one takes together, the WBCSD's articulation on population growth by 2050 and the necessity to maintain local business and manufacturing activities to ensure regional resiliency (such as PHP and Cabot Gypsum), it is clear there is a need to dramatically improve contributions that such operations can make to their surrounding communities (WBCSD, 2010). It is against this backdrop that this research is relevant, as the intent was to seek synergistic solutions governed by principles of a circular economy that address the demand for locally produced food while optimizing locally available materials – in this instance waste pulp as a potentially effective growth medium. More specifically, the intent was to investigate the utility of a growth medium formulated from: (a) PHP's waste pulp (cellulose fibre sludge), and (b) gypsum from waste drywall board at CG. The aim is to improve the mills footprint while supporting the production of affordable, locally produced food for Nova Scotian residents by supplying lower cost inputs to food production from locally available material. It should be noted that this research is embedded in a larger project that seeks to integrate this growth medium into greenhouse developments at PHP which will also receive waste heat and [ideally] CO_2 (from PHP) to support plant growth.

To expound further, this research fits into a larger undertaking with broad goals to: a) ensure an economically viable production base within Nova Scotia; b) supply affordable, locally produced, quality produce to Nova Scotia; and c) demonstrate a regional development opportunity that could be transferable to other rural, primary-resource dependent jurisdictions.

1.2 Research Objectives

Working in partnership with the Verschuren Centre for Sustainability in Energy and the Environment (VCSEE) and Dalhousie University's School for Resource and Environmental Studies (SRES), this research undertook activities with the following objectives:

1. Optimize a plant growth medium using paper mill (cellulose-based) pulp sludge and waste gypsum (high mineral fibre board).
2. Carry out plant growth trials for comparative analyses of physical and chemical characteristics of each substrate and biometric parameters using Little Bing tomato as the indicator species.

3. Offer recommendations in relation to the viability or suitability of the growth medium as a whole.

1.3 Hypothesis

It is possible to use combinations of locally sourced drywall board (gypsum) and paper mill pulp sludge (cellulose fibre sludge) to generate a saleable growth medium for use in cold weather greenhouse crop production within Nova Scotia, Canada.

1.4 Outline of Thesis

This thesis is comprised of six chapters. The first chapter introduces the research while highlighting its relevance and providing a theoretical context.

In chapter two, a review of the literature surrounding the main concepts associated with the pulp sludge and drywall (gypsum) is provided. It was important to develop a relatively good understanding of these material prior to undertaking the actual experiment. Therefore, this chapter served as a basis for developing a working knowledge of both substrates.

Chapter three provides details of the experimental methodology undertaken as well as the equipment used in the execution of the trials.

The results of trials are presented in chapter 4. These depict the outcomes of growth and analysis of data obtained from plant trials while illustrating chemical composition changes of the substrate and plants over the duration of the experiment.

In chapter five, the results of the trials are explained and discussed in the context of relevant literature and related historical work. The intent was to present the analysis of results and provide a rationale for those results which are anomalous with other trends or previous hypotheses.

Arising from the lessons learned from this experiment; conclusions, limitations and recommendations are put forward in chapter 6. This also includes areas to focus on for future research.

1.5 Relevance of Research

One of the goals associated with the approach being taken to manage solid waste in Nova Scotia, Canada is to support research and development linked to waste diversion that considers potential economic opportunities (Nova Scotia Environment, 2009). In response, one of the long-term goals of the collaborative research between Dalhousie University and the VSCEE at Cape Breton University is to tackle challenges relating to enhancing economic and environmental sustainability while implementing economically sustainable innovations and promoting environmental sustainability in Atlantic Canada. Ultimately, these efforts seek to integrate various by-product streams into suitable, incremental industries that can have a positive economic effect on the region by: (a) addressing existing gaps in supply/product availability; (b) reducing GHG emission intensity of companies against is total economic output; (c) creating new, regionally appropriate commercial operations suitable to the local skill set, markets and knowledge base (industrial and academic); and (d) addressing productivity/cost challenges to local industries.

1.5.1 Cellulose-fibre Sludge

Port Hawkesbury Paper produces ~100 tonnes of sludge (predominantly isolated wood fibres) per day, some of which is burned as biomass for thermal generation by Nova Scotia Power Inc (NSPI) in a facility co-located with PHP. The specific volume burned by NSPI is confidential but is known to vary considerably. However, based on general data from PHP it is projected to be less than ~20% of the mill's total output. Another portion is directed to farm application, but this is based on a 'by-request' scenario. The remaining portion is spread across the mill's land. This allows for vegetation re-growth, but no economic return is realized from the utilization of this material. In addition, the current receiving area where the sludge is spread is considerable and reaching capacity. In this context, future end-of-life options may be limited to landfilling in municipal facilities. As ~20% is used by NSPI and ~10% is land-applied on farms, 70% or ~ 70 tonnes of pulp needs to be disposed of each day. Over a one-week period, this represents ~490 tonnes of pulp sludge waste (a dry weight of >25,000 tonnes per year). An alternative option is required.

1.5.2 Construction and Demolition (C&D) Waste

According to both Nova Scotia Environment (2009) and Gardener (2013), up to 30% of waste generated in Nova Scotia is considered construction and demolition (C&D) waste. Seeking opportunities to divert C&D waste from landfill also aligns with the research intent and lead to the decision to investigate the incorporation of waste gypsum into the growth medium as an amendment. Materials from both Cabot Gypsum (CG), located adjacent to PHP, and gypsum waste originating from demolition processes in the Province are included in the experimental activities. CG has ~60 tons of waste wallboard in the back of their plant and expressed an interest in this project. They are seeking alternative end-uses for those materials that cannot be incorporated into their primary production.

The Nova Scotia Solid Waste Resource Management Strategy (NSSWRMS), articulates the need to foster activities that will reduce C&D material entering landfills and the need for research that promotes economic possibilities while identifying preventative methods of waste generation and encouraging diversion from landfills (Nova Scotia Environment, 2009). Further, the NSSWRMS emphasises the need to develop viable strategies to reduce waste and generate greater participation from the broader community, in preventing waste generation (Nova Scotia Environment, 2009). It is important to underscore the potential contribution of this research undertaking to affect these desired outcomes

1.6 Socioeconomic Impacts

Research completed in the province of NS indicated the presence of food insecurity and suggested one of the main contributors to this was income (Williams, 2006). Using the guide as suggested by Houghton (1998) and Kalina (2001), the authors further suggested the need for a system that will cater for urgent needs, strengthening the community and an overall change in the system to the extent that policies are adopted to ensure food security within the province,

Williams (2006) mentioned efforts being made to tackle food insecurity by providing food for those urgently in need. However, these approaches were being considered temporary solutions to the issue (Williams, 2006). Chief among the efforts to build community capacity was the implementation of the Urban Garden Mentors Project

(UGMP) in Halifax by the Ecology Action Center (EAC) in 2005. The over arching goal of the EAC project was to foster the interaction among youth and seniors with experience in crop production.

Perhaps the most critical step towards ensuring food security in NS lay with the need to develop public policies which could result in systemic changes (Williams, 2006). The Toronto Food Policy Council (TFPC) was cited as one example of efforts being made to ensure greater access to food while being good community and environmental stewards (Williams, 2006). According to Ontario Ministry of Agriculture, Food and Rural Affairs (2019) the number of farms present in Nova Scotia in 1996 (4,453) decreased to 3,478 in 2016 while the acreage also went down from a high of 1,055,000 acres in 1996 to 915,000 in 2016.

With the continued insecurity of the food supply-system in Nova Scotia, chief amongst the objectives of the bench scale study is to determine the potential impact the development of a new greenhouse growth medium, including both economic and social impacts. Relevant research is necessary to support the continued growth and sustainable development of the Province as a whole, for example, Halifax Regional Municipality (HRM) has taken decisive steps towards promoting socioeconomic, environmental and community development (Halifax, 2019). To support these areas of development, HRM implemented a plan called HaliFACT 2050 to drive the reduction of emissions, cost savings and the collaborative efforts towards community building. Meanwhile, media reports have continued to reveal that NS has the highest levels of food insecurity in Canada (CBC News, 2015). Environmental responsibility, regional resiliency and food security are all issues that are intertwined and while results of this research may not answer all the questions in relation to the Provincial challenges at these levels; it is anticipated that it should contribute to the existing body of knowledge surrounding possible emissions reduction strategies, socioeconomic strengthening and community building.

It is also evident that there needs to be robust system in place to enhance the security of the 'food-future' for Nova Scotians. The LBT crop trial using pulp sludge from PHP and Waste drywall board from CG is being done with the hope of unearthing the possibility of what could effectively support further development of local food production by reducing input costs of operations – if it proves to be an economically viable means of obtaining potting and growbag medium especially for greenhouse crop production.

1.7 Theoretical Framework – Context

The mid 1980's saw engagements in talks about the rising costs associated with the use of conventional fuels such as natural gas and coal for heat production (Southgate, Taylor, & Uchida, 1986). These arguments drew attention to agriculture as an avenue which could reuse waste heat (Southgate et al., 1986). According to Hadiwijoyo, Purwanto, & Sudharto Hadi, (2013) the impacts of business on the environment was not a topical issue 60 years ago. Given the challenges of implementing the concept of circular economy where the flow of material is managed to ensure energy waste is restricted, Ritzen & Sandstrom (2017) underscored the importance of companies being able to accommodate disruptions in their current operation in order for it to be a success.

This research examines the potential of this approach to environmental sustainability at a regional level via a synergistic agro-industrial park. As early as 1995, researchers experimented with the use of paper mill pulp as a growing medium for grass, trees and crops, assessing the impact it would have on root formation (Coburn & Dolan, 1995). More recently, Jackson and colleagues found that the inclusion of sludge from paper mill and primary pulp which had been composted in acidic soils boosted pine tree production (Jackson, Line, Wilson, & Hetherington, 2000).

1.7.1 Waste Management in Nova Scotia

Early on Nova Scotia positioned itself as a leader in waste management; jurisdictions across the world showed keen interest in the Province's strategies and principles on this front (Friesen, 2002). Friesen (2002) further noted that the most thought out plan in North America to manage solid waste, was developed and implemented here in Nova Scotia, dating back to the year 1995 and has resulted in all residents being able to place the recyclables on the curb side for recycling. In addition to these, Friesen (2002) highlighted the fact that 72% of organics are being retrieved from the curb in residential areas while another 85% is being retrieved from larger industrial entities.

1.7.2 The Circular Economy - Agro-Industrial Ecology

The concept of a circular economy encapsulates the practice of integrating principles of recycling and reuse into material use and system design, therefore limiting the volume of those elements considered "waste" being directed to a disposal site such as a landfill (Julian, Denise, & Marko, 2017). Currently, experts within the agri-food sector are attempting to present the picture in terms of what future practice would look like if circular economy was integrated as an operational strategy. According to (Kristensen, Kjeldsen, & Thorsøe, 2016), the concept of agri-food futures is now being positioned in relation to the ways we consider the models that will be used in the industry to address future resource input constraints.

The principle of substance flow analysis (SFA) has also been brought into focus, as a means of assessing the similarities and differences among economic factors within industries (Fernandez-Mena, Nesme, & Pellerin, 2016). In support of SFA, industrial symbiosis is becoming an increasingly popular approach to analyse prospects of economically optimizing use of wastes from one industry, as raw material in another (Fernandez-Mena et al., 2016). A recent study in Cuba demonstrated that it is possible to link several agricultural establishments in a network that optimizes use of wastes being generated among them (Concha, Adams, Suárez, & Faxas, 2017).

1.7.3 Industry Examples

The owners of the greenhouse operating under the name Truly Green Farms in Chatham Ontario, Canada, embarked on a major project to inject the waste heat and CO_2 from the neighbouring Greenfield Specialty Ethanol. This is twenty-two-acre greenhouse; expected to produce six million kilograms of tomato within the year (Dodge, 2014). Greg Devries, one of the owners and Chief Executive Officer (CEO) of the farm, projected a 3% increase in production and a decrease in heat production cost by approximately 50%, after the system is fully implemented (Dodge, 2014). According to the CEO Truly Green Farms, he also anticipates supplying Greenfields with corn for their ethanol and feed production; thereby, closing the loop on wastes within their production processes.

While Truly Green Farms embarked on putting together their ideas to implement the novel waste management systems, Technology Development Foundation (TDF) of

Turkey was quite busy operating one of the foremost examples of industrial symbiosis (TDF, 2014). Their system successfully integrated a number of industries to include fruit juice production wastes, feed production, biogas generation, highway construction and cement production. The town of Kalundborg in Denmark is another key example of industrial symbiosis; a fully integrated development initiated in 1972, which has laid the foundation to what has proven to be a successful approach to the concept of a 'circular economy' (Gulipac, 2016). The Kalundborg system incorporates the reuse of: heat, wastewater, industrial plaster, gas and by-products of yeast in a closed system, where all the wastes are reused within the industrial network (Gulipac, 2016). To date the system has been operating close to forty years and remains a resource to those interested in the conceptualization and development models to produce a similar effect (Valentine, 2016).

Chapter 2: Literature Review

2.1 Propagation by Seeds

Davies et. al. (2018), present crop production from seeds as a means of initiating the offspring which can continue to reproduce from seeds, also known as sexual reproduction. They argued that most of our food production is derived from the use of seeds. Importantly, there are features that must be present in order for germination of a seed to take place. These include the seed being alive or viable and exposed to an environment that caters for optimum water, temperature, gases and light (Davies et. al. 2018).

Since water is a limiting factor and helps to determine how well the seed is able to interact with the medium in which it is being germinated; a lack of moisture being induced by poor quality substrate may result in moisture stress and germination of the seed impacted negatively (Davies et al., 2018). Once optimum conditions are present and the seedlings begin to grow, they will use up all the nutrients stored in their cotyledons. When these nutrient reserves are exhausted, the plant will need to interact with the medium in which it is being grown for additional nutrients (Davies et al., 2018).

2.2 Crucial Parameters for Greenhouse Substrate Management

There are growing media and amendments which have been used over many years to successfully produce crops under greenhouse conditions. Several desirable features allowed them to have become the substrates of choice. This section will explore some of these features in the context that they are standards the pulp and gypsum-pulp blends will have to measure up with, in order to compete in the long term. With that said, references will be made to ‘soilless’ medium, however, it must be noted that the pulp and gypsum currently under study are not completely ‘soilless’. This is due to PHP adding 35% clay (King, 2017) to the wood pulp during paper manufacture for a ‘shiny finish’ to the calendar paper they produce. Also, the gypsum being used is a naturally existing mineral ($CaSO_4 \bullet 2H_2O$) that has been mined locally (Cabot Gypsum, 2019), for the purpose of making wall board at Cabot Gypsum.

2.2.1 Nutrient Availability

Tsukagoshi & Shinohara (2016) suggests the main source for the nutrients in soilless crop production is the irrigation solution. Individual growth medium will have features dictating the types of formulations that will be ideal to support the plants being considered for growth (Wang, Gan, & Long, 2013). When using a soilless medium as a substrate material for plant growth, precision in nutrient management becomes important as a means of helping to maximizing the availability of essential elements in the life of the crop (Gorbe & Calatayud, 2010). While provision of the essential elements is critical, both Tsukagoshi & Shinohara (2016), recognize the significance of stable pH between 5.5 and 6.5 for the successful production of most crops.

2.2.2 Acidic or Alkaline Media (pH Range)

According to Tripepi (2011.), pH represents one of the primary areas of focus when it comes to fertility management in greenhouse growth medium. In fact, he argues that pH may be the most crucial area of concern in a growth medium, on the basis that it carries significant implications to the availability and toxicity levels which may be related to nutrients. Nutrients such as aluminum (Al) and Manganese (Mn) have the tendency to become toxic whenever the pH falls between 5 and 5.5, whereas Hydrogen (H) becomes poisonous at pH levels lower than 4 (Havlin, Tisdale, Nelson & Beaton 2013).

Additionally, deficiencies among magnesium (Mg), molybdenum (Mo), nitrate (N), are realized at a pH below 5.5 and phosphorus (P) and potassium (K) symptoms set in at levels below 5.0. Calcium (Ca) deficiency usually manifests at pH levels below 4.8. (Havlin et al., 2013). Other nutrients such as chlorine (Cl), Boron (B) Iron (Fe), Zinc (Zn) and Copper (Cu) are needed in very small quantities and become deficient at pH below five (Tripepi 2011).

Both Darryl & Dean, (1983) and Tripepi (2011) underscored the significance of ensuring the pH of the soilless media stays within the 5.6-5.8 pH range. This is because the pH of the water used in greenhouses are generally alkaline or above a pH 7. Hence, when this water is added to the growth medium, the pH may move close to being alkaline. Keeping in mind, if the baseline pH was high, adding water could raise it to levels beyond which the plants could efficiently grow and reproduce (Darryl & Dean, 1983, Tripepi 2011). Appendix 1 provides an overview of how nutrient availability varies with changes in pH. The thicker portions of the horizontal lines indicate that nutrient is readily available at the corresponding pH.

2.2.3 Electrical Conductivity (EC)

Tomato plants can tolerate EC values up to 2.5 mmho (Havlin et. al. 2013). The concept of EC is synonymous with the measure of the salt concentration of the growth medium, which ultimately has a relationship with osmotic pressure in the roots of the plant (Food and Agriculture Organization of the United Nations, 2013). An excess of these results in the substrate leads to reduced uptake in plants because the substances in the plants will tend to move out to the nutrient solution in the medium as it attempts to achieve a balance with concentrations. (Food and Agriculture Organization of the United Nations 2013).

Ideal EC in a given growth medium will be dependent on the crop at the various stages of growth and the climatic conditions (Lee, Enthoven & Kaarsemaker, 2016). According to Pardossi, et al., (2011), whenever the EC is higher than the established threshold for the crop, this is may be treated by irrigation leaching. This, allows an oversupply of nutrient-free water to flow through the rootzone of the plant and thereby remove the excess salts or nutrients by leaching. In a study conducted by Samarakoon (2006), it was confirmed that lettuce yields decreased while the EC of the solution was increased in a soilless growth medium.

2.2.4 Cation Exchange Capacity (CEC)

Méndez, Paz-Ferreiro, Gil, & Gascó (2015) suggest that CEC involves an assessment of the plant substrates to bind nutrients to its surface and thereby make them unavailable to plants and not leachable. Measurements of the CEC were carried on recycled paper mill sludge sourced from six (6) different processing plants in Malaysia and the results showed an average of 14.43 cmol (+) kg^{-1}. (Abdullah, Ishak, Kadir, & Bakar, 2015). The CEC of a growth medium is highly dependent on its general physical characteristics, as smaller particle sizes are associated with high CEC (Shirani, Mohammadi-Ghehsareh & Manoukyan 2013). The principle of smaller particle yielding higher CE was confirmed in relation to soil particles having more surface area for interacting with nutrients and the roots of plants (de Campos, & Baptista, 1979). The presence of Ca and Mg in soils in different quantities has been associated with reduced CEC capacity (Rato Nunes, Cabral, & López-Piñeiro, 2008).

The foregoing understanding of the relationship between pH and CEC supports the arguments that some nutrients may become deficient or toxic, at different pH within the medium (Havlin et al., 2013). However, despite this general understanding of CEC, (Rehm, 2009) challenged the validity of understanding CEC in the context of fertilizer and suggested the only basis on which CEC should be of concern, is to determine soil texture. While there is some controversy around its importance, CEC remains a much-desired feature in reducing the incidence of leaching (Méndez, Paz-Ferreiro, Gil, & Gascó, 2015), therefore, careful thought should be given to how this feature informs water management at the root zone. This is because if the pulp is retaining high amounts of nutrients and the water supply is poor, the chance of damaging the root system of the plants, due to high salinity, is significantly increased (Ingram, Henley, & Yeager 1993).

2.2.5 Microbial Community Within Growing Medium

Literature review revealed that there is a paucity of data to support the knowledge base contributing to the understanding of the biological communities that inhabit soilless medium. However, the paper from Grunet et al., (2016) outlined a study using mineral and organic based soilless medium in an attempt to understand the features which contribute to the communities within the soilless horticultural systems. The finding from this study provided some insight to the diversity that exists in these communities while hinting on their capacity to guide approaches taken to improve crop production (Grunet, et al., 2016).

Nevertheless, arguments have been put forth suggesting that inconsistencies in plant growth and production may be aligned with the uneven distribution of microorganisms in soilless media and there needs to be further research (Bukovská, Püschel, Hršelová, Jansa, & Gryndler, 2016). While the literature on the roles of microorganisms in soilless culture particularly in relation to nutrient management seems limited, there were suggestions that if these organisms are better understood, they could play a role in the application of less fungicidal treatments and more biological control of pests (Koohakan et al., 2004). Some substrates have been subjected to the process of pasteurization before their use; in order to avoid destroying beneficial organisms during these processes, temperature not exceeding 60 ^{0}C over a thirty-minute period has been recommended (Davies, et al., 2018).

2.2.6 Physical Parameters of Growth Medium

The features associated with the physical nature of the soilless medium are of key concern, as compared to naturally existing soils (Martínez, Oliveira, Calvete, & Palencia, 2017). Kuisma, Palonen, & Yli-Halla (2014) argue that "A growing medium should primarily have a balanced and stable porosity to provide enough air and water to the roots and physically support the crop. Adequate water uptake of crop requires high water holding capacity (WHC) in the medium" (p. 218). Kuisma et al., (2014) went on to highlight that porosity is a critical feature which determines the amount of air and water which the soilless medium is able to retain.

Other important physical features of the soilless medium include the bulk density (BD), particle size distribution (PSD) and pore distribution (PD) (Wallach, 2008); who argues that BD is based on the idea of deciding on the weight of the material after moistening, compressing to remove the water and allowed to dry completely. There is a relationship between BD and the capacity of the plant to absorb nutrients. For example, Guan (1997) was able to demonstrate that where there was high BD, nutrient uptake was greater.

Importantly, PSD is significant in the context of helping to maintain a relatively good balance between the interaction and movement of water within the growth medium (Zhang, Sun, Tian, & Gong, 2013). There is a close relationship between pore space, porosity and ultimately the PD of the substrate is important in the context of the fraction of the medium which can accommodate the water or nutrient solution being added (Abad et al., 2005).

2.3 Leading Greenhouse Plant Substrates: Peat Moss and Coco Peat (Coir).

2.3.1 Peat Moss

Peat is the result of vegetation decomposing over the course of hundreds of years in wetlands (Peat and Peatlands, 2019). Canada's northern landscape undergoes changes in its glacial formations, resulting in temperature, moisture and aeration that promote formation of peat (Peat and Peatlands, 2019). According to U.S. Department of Agriculture, Forest Service Agriculture Handbook 732, (2014), the use of peat moss leads the way in North America. As a product of the temperate regions, mainly in North America and Europe, its color ranges from light to dark and is an indication of its state of decomposition. Dark peat is highly decomposed. Peat is acidic in nature and although it is not a hydrophilic material, it retains high amounts of moisture when used with other hydrophilic materials (Owen & Lopez, 2015).

The predominant features which have given rise to the success of peat moss are many. When added to soils, the physical structure is improved, and moisture retention increases while cutting the rate at which leaching takes place due to its excellent CEC.

Although peat is able to absorb water to a measure of ~ 20 times its own weight, it manages to positively influence the movement of air in clayey soils. It has a high tolerance for alterations in pH and is typically free from weeds and pollutants (Peat and Peatlands, 2019).

2.3.2 Coconut Fibre (Coir)

Coconut fibre (CF), goes by several names to include coir pith, coir meal, coir dust or coco peat (Arenas, Vavrina, Cornell, Hanlon & Hochmuth, 2002) and it is derived as a by-product of coconut processing. Coir is a foremost organic medium which supports plant growth throughout the agriculture industry. The wettability of coir was studied and the results show significant changes in size between its wet and dry fibres (Thomas, Woh, Wang, & Goh, 2017). According to Wang, Gabriel, Legard & Sjulin, (2016), their research with 100% coir revealed it is a viable open-field option for growing strawberries. While providing a brief historical overview of coco peat (coir) Meerow, (1997) referenced reports of its fibres remaining undecomposed for over a century and resembling the traditional peat moss. Further research by Meerow demonstrated that coco peat aerated and retained water in a manner that remained constant over time. Additionally, the electrical conductivity was low and the plants grown in the coco peat had roots that were larger than those grown in 1:1 mix of perlite and sphagnum (Meerow, 1997).

2.3.3 Other Greenhouse Substrates

While greenhouse enthusiasts and horticulturists favor the use of peat and coir, there are composts from pine bark and fibre available as growth media (Owen & Lopez, 2015). Other growth media include rice hull and sawdust (U.S. Department of

Agriculture, Forest Service Agriculture Handbook 732, 2014). Material such as perlite, vermiculite, pumice, vermiculite, growstones, clay aggregates have been successfully used individually and in tandem with peat (Owen & Lopez, 2015). As a whole, some of these materials require additives in order to optimize their functionality. For instance, peat often requires a wetting agent in order to retain sufficient moisture. Other additions include limestone as a means of managing pH and fertilizers as a source of nutrients for plants to grow effectively (Owen & Lopez, 2015).

2.4 Pulp from Port Hawkesbury Paper Mill and Gypsum from Cabot Gypsum

2.4.1 Paper Mill Pulp (cellulose fibre sludge)

Appeals for affordable and environmentally sound ways to manage the pulp sludge being produced by paper mill factories date back several years (Evanylo & Daniels, 1999). Evanlyo & Daniels (1999), composted paper mill sludge and used it in growth trials. They concluded it was most suitable for use as an organic amendment which could supply some nutrients in potting media, and proceeded to conduct tests that examined the impacts of pulp waste on plant germination; Tebenkova, Lukina, Vorobyev, Orlova, & Gagarin, (2015) revealed that the nitrogen (N) content of the soil increased significantly and carbon (C) content was slightly reduced when compared.

Additionally, the test by Tebenkova, et al. (2015) showed promising increases in phosphorus (P) and potassium (K) quantities, along with the increased presence of worms associated with composting the biomass. Paper sludge was also successfully utilized in the revegetation of an unspecified area of land; this success was attributed to the high percentage of N, P and K found in it (Beauchamp, Camire, & Chalifour, 2006). While some researchers found good nutrient content in primary sludge, there are those with inhibitions about its capacity to supply adequate quantities, especially when mixed with sand or soil (Fierro, Norrie, Gosselin, & Beauchamp, 1997). Further tests were carried out on three grass types in different combinations, and the results were favorable with only normal addition of supplemental N, P and K (Fierro et al., 1997).

2.4.2 Gypsum

For well over 250 years gypsum has be used in parts of the United States of America as fertilizer, primarily for calcium (Ca) and sulphate (S) and its potential usefulness specifically for horticultural activities has also been recognised (Chen & Dick, 2011). Soils composed of gypsum accounts for approximately 100 million ha of earth and there have been studies conducted to better understand its usefulness to agriculture and its classification (Verheye & Boyadgiev, 1997). The plants which originate from an environment that is gypsum-based are referred to as gypsophiles or gypsovages (Palacio et al., 2007).

An early study revealed that the main constituent of the flue gas desulfurization product was CaSO4´2H20 (gypsum) and this contributed to reducing the availability of toxic elements (Al, Mn, Cd, Cr, and Pb), increasing solubility of some essential mineral nutrients (P, Zn, Cu, and Mo), and promoting root growth (Clark, Ritchey, & Baligar, 2001). In this research, the gypsum is locally sourced from regional quarries and gypsum recycling facilities that make use of mined gypsum (not synthetic). Predominantly, gypsum has been used on soils which have become sodic in nature and to supply Ca and S, however, there seem to be emerging knowledge to suggest it may be beneficial when strategically used on acidic soils (Chen & Dick, 2011).The presence of gypsum in ecosystems has been found to be the main constituent of salt encrustation as a result of water loss through evaporation (Rufaut & Craw, 2010).

Gypsum has been effectively used with peat moss, perlite and other soil amendments to reduce water loss after irrigation in greenhouse production (Newby, 2013). However, within a greenhouse setting Ca^{2+} and SO_4^{2-} have been shown to produce gypsum, which eventually caused emitters needed for water supply to become blocked (Bar-Yosef, 2008), and this may have implications for drainage from substrate containers over time. While the chemical and physiological features of gypsum have been established as beneficial to agricultural practices (Chen and Dick, 2011), the knowledge base surrounding the behaviour of plants being grown in it, is still limited (Zoca, & Penn, 2017).

Chapter 3: Materials and Methods

3.1 Overview

The stated objectives of this research encapsulate the idea of examining the potential for utilizing a combination of waste pulp sludge from the PHP and waste drywall board (gypsum) from CG as a growth medium within typical North American greenhouse crop production.

Materials were obtained directly from PHP (sludge) and CG (waste gypsum); however, neither material was suitable for experimental use in their original state - section 3.3 describes the material at their sources. The methods of preparation were established according to the way in which each material would be specifically used; this will be further discussed below.

A greenhouse that typifies the conditions under which plants are grown in Eastern Canada was selected as the test site; this was the experimental greenhouse within the Life Science's Department at Dalhousie University. Other materials, such as fertilizer, seeds, commercial growth medium (to be used both as a control and for comparative purposes against the experimental mixtures), water and nutrient supply application were sourced from a local farm store and kept in a room designed for storing planting material. The experimental plant growth trial began on February 15, 2019 and the final destructive sampling was done on July 23, 2019. The experiment involved using pulp only, peat moss only (Promix), 5, 10 and 20% blends of gypsum and pulp.

3.2 Research Approach

The experiment was undertaken using completely randomized design (CRD) method. This method was chosen as it was specifically designed for agricultural experiments such as this, involving crop trials in a greenhouse setting (Salkind, 2010). Given the 'bench-scale' nature of this experiment and the space limitations, a total of 50 plants were deemed suitable with 10 plants in each substrate. The substrates included pulp only, 5% gypsum-pulp, 10% gypsum-pulp, 20% gypsum pulp and a peat moss only blend. The primary control was the pulp only substrate. The overall goal of the experiment was to examine the response of the tomato plants to different blends of the growth media under uniform greenhouse conditions, and assess the possibility of the materials being used in the formation of a locally sourced substitute for traditional greenhouse substrates.

Where applicable, results from the trial were subjected to one-way analysis of variance (ANOVA) between and among means, using the Minitab 18 statistical software to establish significance of differences. A significance level of 0.05 (α=0.05) was established and the null hypothesis *(H_0)* was set as "All means are equal". On the other hand, the alternative hypothesis (H_a) was set as "Not all means are equal". Consequently, resulting p-values > 0.05 were deemed insignificant which meant the analysis "failed to reject the *(H_0)* "that all means are equal". P-values < 0.05 were deemed significant and in these cases the (H_a) which suggests "Not all means are equal" were accepted while the *(H_0)* was rejected (Minitab Blog Editor, 2014 and Minitab Blog Editor, 2015).

The means were also subjected to "Fisher Pairwise Comparisons Grouping Information Using the Fisher LSD method and 95% Confidence" where LSD represents the least significant differences. In this context, letters were assigned to individual means and the understanding that means which vary have different letters assigned to them by the software (Minitab 18, 2019a). Outcomes of significance are presented in the results section of this report. Standard deviation was determined in Microsoft Excel from Microsoft Office 2016 software kit.

Plant and substrate samples were submitted to the Nova Scotia Department of Agriculture Soils Laboratory (NSDA) and the Dartmouth-based AGAT Laboratory for analyses. The heavy metals and e. coli content of the substrates were analysed by AGAT while nutrient content of plant tissue and substrate were conducted by NSDA. AGAT laboratory is accredited and certified to carry out these tests and used incubator and ICP/MS analytical techniques for microbial and heavy metals, respectively. NSDA is owned and operated by the province of Nova Scotia and applied SMEWW 3120B and ICP-OES analytical techniques for major ions and trace metals, respectively. Further, NSDA determined the conductivity by SMEWW 2510B; pH values 4500-H+B; alkalinity USEPA 310.2; chloride USEPA 325.2 and nitrate + nitrite-N USEPA 353.4.

3.3 The Substrates – Pulp Sludge, Gypsum and Peat

The pulp being used to cap the land at the PHP is blended in such a way that it was difficult to determine its exact age. Therefore, fresh material was collected before it was transported to the landfill and older material was also collected from the landfill. This was done to create a relative balance in terms of what could be expected if the material were to be processed into a growth medium in the future. The relative balance was obtained by mixing the old and new pulp waste on a 1:1 basis. No chlorine bleaching is done to the pulp which is generated thermo-mechanically. The pulp waste is expelled to the outside the mill, loaded onto trucks with a frontend loader and transported to an open field for spreading by a bulldozer.

Waste drywall from Cabot Gypsum is stacked in their waste holding area, of which approximately 4% is from construction and demolition and contains wall board from other manufacturers (Cabot Gypsum Board, 2014). The waste drywall material existed in a comingled state with portions ranging from intact pieces to finely crushed particles. This led to the choice of the CF198 Hammermill driven by alternating current for use in breaking down the material to a usable form. It is worthy to note that, at the time of collection, the drywall in the holding area were considered too damp to be crushed to a consistency that would allow for adequate blending with the pulp. This was in the height of winter 2018 therefore, using sunlight as a means of drying was not an option and would therefore require a commercial sized oven to sufficiently dry the material.

As an alternative, moisture-free drywall produced at Cabot Gypsum was purchased from a local distributor and put through the hammermill for crushing. The dry wall was milled with its paper covering and included in the blend. This was allowed due to the fact that a) paper is organic in nature, b) threats to a successful crop trial may be limited and c) it was difficult to remove it from the gyproc and its removal would be adding cost and time to the actual preparation of the material. The hammermill is equipped with a vacuum line expelling dust and a funnel-shaped dispenser with zip-lock cloth bag attached to the end for collecting the milled material.

Peat moss is a well-known greenhouse substrate and was used as the baseline medium for these trials for the purpose of providing a comparison for the results involving the use of pulp and gypsum. Pulp was used by itself as the experimental control, while the gypsum was added to the pulp at different ratios to complete the blends. The blend ratios can be found in Table 1 below:

Table 1: Substrates used in the LBT growth trial.

Substrate Blends	**Hereafter called**
Peat moss only (control)	Peat moss (control)
Pulp only (control)	Pulp only (control)
5% gypsum: 95% pulp	5% gyp
10% gypsum: 90% pulp	10% gyp
20% gypsum: 80% pulp	20% gyp

3.3.1 Physical Features

The pulp from PHP contains 35% clay (King, 2017), it is plant-based biomass and for the purpose of the experiment, gyprock blended with the paper liner was added to it. Therefore, the physical features of the gypsum-pulp blends were assessed. Applying the basic principles as outlined in (Thien & Graveel, 2000), the bulk and particle density were calculated followed by the porosity of the materials. Particle density has been calculated using the standard 2.65 g/cm^3, (Thien & Graveel, 2000), however, this is based on the typical range for mineral based soils. The blends in this experiment are predominantly biomass with added minerals. Therefore, particle densities were calculated specifically for each of the pulp-gypsum blends and the results used to determine the porosity.

It must be noted that the pulp and gypsum blends were allowed to air-dry instead of being oven-dried (Thien & Graveel, 2000). This was done as a fire safety precaution based on the fact that the drywall board was blended with its paper lining and the level of volatile organic compounds were unknow. Calculations were done for both compacted and uncompacted versions of the blends based on (Thien & Graveel, 2000). The ability of the substrates to retain water was tested using the simple infiltration and drainage method as demonstrated by (FAO, Rome [Italy] Land and Water Division, 2017).

3.3.2 Media pH

The baseline acidity and alkalinity of the substrates were established at the NSDA and further tests were conducted at the level of the greenhouse during cultivation of the crop. For the in-house sampling, the pH measurements were take using the saturated media extract (SME) in a 1:2 mix of substrate to deionized water and samples were taken from below the first inch in the substrate material so that measurements would cover areas in the immediate root-zone (Bailey, Fonteno & Nelson, 2000). Measurements were taken using Hanna pH and EC Waterproof HI 98130 meter.

3.3.3 The EC of the Media

The EC was measured with a view to determine whether the soil needed to be conditioned before seeds were sown. The measurements ranged from 1 mmhos/cm^{-1} to 4.36 mmhos/cm^{-1} (Figure 3). As a result, all except the peat moss was flushed with tap water in an attempt to obtain EC readings (Pardossi, et al., 2011; Haj-amor, Ibrahimi, Feki, Lhomme, & Bouri. 2016), prior to sowing the seeds. The intention was to achieve an EC significantly less than the threshold 2.5 mmhos/cm^{-1} suggested for tomatoes, by Havlin et al., (2013). This was achieved as recorded in Figure 4.

The initial EC measurements at the level of the greenhouse were taken using Hanna Primo 5 9964BE in a SME with a 1:2 mix of substrate to deionized water.

Samples were taken from below the first inch in the substrate material so that measurements would cover areas to be occupied by the root-zone (Bailey, et al., 2000.). Seeds were subsequently sown in the various substrates.

Given the relatively high initial EC measurements of the pulp and gypsum-based substrates, monitoring was done at critical points during the life of the LBT plant. Seedling were transplanted at exactly 5 weeks. However, on the day and before seedlings were planted into the 2-gallon pots with the various blends, the pulp and gyp blended substrates were subjected to extended hand watering while in the pots with a hose having a retrofitted misting head (Haj-amor et al., 2016). This was done to the extent that EC's were again brought to within the 0-2.5 mmhos/cm^{-1} EC limit for tomatoes (Havlin et.al.) 2013). EC measurements were taken using Hanna pH and EC Waterproof HI 98130, meter.

3.3.4 Nutrient Content

After the substrates were prepared for the growth trial, samples were submitted to the NSDA for analysis as a greenhouse soil before any form of locally available nutrients were added. This means the samples were analysed similarly to those submitted by farmers throughout the province of Nova Scotia. Hence, the results were considered a reliable account of the basic chemical properties within each sample. The results were used as a basic guide before seeds were sown and before seedlings were moved to the 2-gallon pots for grow-out.

Subsequent to the findings as reported by the NSDA, a locally available nutrient solution (Schultz Liquid Plant Food) containing 10-15-10 NPK, chelated Fe - 0.10%, Mn

- 0.05%, and 0.05% Zn was used during the seedling stage. This represents the most suitable over-the-counter nutrient for the bench scale trial.

After the seedlings were transplanted, a soluble Miracle Gro fertilizer blend with guaranteed analysis of: N-18%, P-18%, K-21%, Mg-0.50%, Cu-0.05%, Fe-0.10%, Mn-0.05% and Zn-0.05% was applied. This water-soluble fertilizer was developed specifically for tomatoes and was mixed at a rate of ½ tsp per gallon of water. This was applied directly to the root zones using a watering can at 7-day intervals, as directed.

3.3.5 Autoclaving

The possibility of E. coli and coliform being present in the sludge, required that sterilization of material be made a high priority. The method of sterilization involved using the AMSCO Eagle Series 3021 Gravity Autoclave oven in one of the laboratories within the Department of Microbiology and Immunology at Dalhousie University. The pulp sludge was placed in autoclave bags and sterilized at the pre-set temperature of 250 °F for 30 minutes. It was then transported in sealed bags to the greenhouse where it was allowed to sit and cool prior to its use in germination trials.

Following the process of autoclaving the first batch of pulp sludge, the appearance of orange-coloured algae occurred within seven (7) days. These were disposed of and fresh batch done as replacement. Two successive germination trials were attempted using the autoclaved cellulose fibre sludge. However, the results were undesirable. Subsequently, trials were conducted with non-autoclaved (unsterilized) material. The germination trials were done using pulp only, peat moss, 5, 10 and 20% gypsum-pulp blends.

3.4 Growth Trial
3.4.1 Crop Choice

Preliminary germination trial with PHP's pulp sludge was undertaken between February and April 2018. This involved the use of wheat, lettuce, sweet pepper, tomato and basil seeds. Each crop was represented by 10 seeds in the pulp sludge and there was 100% germination in all the crops. For this trial no nutrients were added; only daily watering was done. The seedlings grew for 35 days. Using the physical appearance of the seedlings as the basis for choosing the crop for this research; the 10 tomato seedlings visibly expressed highly desirable growth and developmental features when compared to the other crops in the trial. On this basis, tomato was chosen to be used in this more in-depth study.

Little Bing tomatoes – LBT (*Solanum lycopersicum*) was the variety chosen for this trial. It is a compact determinate' crop that grows 18-24 inches (45-60 cm) in height, bearing small fruits with its characteristic medium round appearance (PanAmerican Seeds, 2019). The ripe fruits are red in colour. It requires no pruning and staking is the only vertical support that may be needed as the plants mature. LBT is most suitable for growth in pots and has a relatively short maturation period of 60-65 days from transplanting (PanAmerican Seeds, 2019).

3.4.2 The Greenhouse

The greenhouse used for this trial is located on the roof (8th floor) of the Life Sciences building on the Studley Campus at Dalhousie University. It is operated by the Department of Biology and is specifically designed for research-based activities. Temperature control is automated; there are sensors, fans, windows and heaters strategically placed to accommodate the changes across the seasons. The average temperature over the life of the experiment was 23 °C and the pH of the water supply from the greenhouse remained at 7 for the duration of the growth trials.

3.4.3 Germination

For this experiment, the LBT seeds were combined in a single container and randomly selected for sowing in each of the 72-cell seedling trays being used for germination. These depths were achieved by first, filling the trays to a level that would allow for a minimum of 1 cm from the top, after which, the seeds we covered. All substrates had 20 seeds sown except peat moss which had 52 seeds. Additional seeds were sown in the peat moss for the purpose of covering any shortfall in germination among the non-traditional blends of pulp only,5, 10 and 20% gyp.

After germination, nutrients were supplied in solution, every other day, during watering. This was done throughout the seedling stage, until the last seven (7) days before transplanting, when watering was done every other day as a means of hardening the seedlings before transplanting Davies et al., (2018).

At the point of transplanting (5 weeks), the tallest seedling among the 10 surviving in the pulp only blend was 5 cm. This led to the seedlings in the pulp only substrate being substituted by extra seedlings which were sown and germinated in the peat moss substrate. This was due to the fact that seedlings in the peat moss were at least 15 cm and they were planted as a contingency. They were transplanted into 2-gallon pots for grow out. Following the transplant on day 35, the seedlings were given only water for the first two (2) days and the first nutrient application administered in solution on the third day after transplanting.

3.4.4 Stem Diameter at 4 and 21 Weeks of Age

Random samples (n=5) of LBT were selected across all the substrates at 4 and 21 weeks old for the purpose of obtaining the diameter of their stems (Figure 8). These measurements were taken using the Empire 6-inch Stainless Steel Digital Caliper 2789. Where possible measurements were taken at ~5 cm from the root collar.

3.4.5 Plant Height

Differences in the height of LBT plants were captured in the 4th and 20th week of life. The starting point for this measure was established at the first true leaf of the 5 randomly selected plants (n=5). A standard 12-inch ruler was used to measure the seedlings at 4 weeks old, while a meter rule was used to capture the heights at 20 weeks old. As mentioned before, the plants measured at 4 weeks in the pulp only substrate, were replaced by seedlings from the peat moss substrate. Heights were taken using the first true leaf for starting and the apex as the end point.

3.4.6 Leaf Count

Four weeks after sowing the seeds in the pulp only, peat moss, 5%, 10% and 20% gyp, five seedlings (n=5) were randomly selected and the number of leaflets on the first true leaves counted. Two weeks after transplanting the seedlings into the 2-gallon pots, five plants were again randomly selected (n=5) in each substrate category. The newest forming leaf at the apex on each of the randomly selected plants was tagged and labeled for the purpose of obtaining a final leaflet count on the day the samples were destroyed.

3.4.7 Growth Rate of Little Bing Tomato Plants

The leaves which were tagged for the purpose of counting the leaflets were also used to track the growth rate of the plants across the substrates. The leaves of the samples (n=5) in each category were measured at 3-day intervals, from petiole attachment to the stem to the tip of the leaf, using a standard 12-inch ruler. A total of 10 measurements were done over a 30-day period for each of the 5 leaves in each substrate category. These measurements were taken until at least 2 consecutive readings showed no changes in the length of the leaves. Once the 'no change' readings were obtained, the final measurements were used as the maximum length of the leaves.

3.5 Little Bing Tomato Fruit Harvest

3.5.1 Fresh and Dry Root Weights

In the 21st week of life 3 plants were randomly selected (n=3) for destructive sampling. This was done to obtain the root system of the plant, which include the section from the collar down wards. Once the samples were selected, they were watered and allowed a full 24-hour period without regular watering. This was done to aid the ease with which the substrate would be removed from the roots without significant damage or losses. This is because when the substrate is dry it will more readily fall from the roots of the plants and thereby reduce the extent to which they would have to be handled. Subsequent to this, the root systems were placed in a sieve and a moderate stream of water was allowed to flow over each as they are moderately agitated to ensure the maximum removal of substrates while minimizing root loss.

Following this process, the roots were allowed to drip-dry for ~ 30 minutes and thereafter, their fresh weights taken using the Taylor 3851-149 Digital Kitchen Scale. The roots were packaged in brown paper bags and dried in the Honeywell Milner Dryer Electro Med Equipment BMD-15208 at 65 ºC over a 72-hour period at The Dalhousie Agricultural Campus.

3.5.2 Fresh and Dry Stem Weights

Following the removal and processing of the root system, the separated shoot systems were also processed. All remaining fruits were harvested, the fresh weights of three (3) randomly selected plants (n=3) in each substrate were taken using a digital scale Taylor 3851-149 Digital Kitchen Scale (Figure 14). Like the root systems, the shoots were placed in brown paper bag and oven dried at 65 ºC over a 72-hour period in the Honeywell Milner Dryer Electro Med Equipment BMD-15208 located on the Dalhousie Agricultural campus.

3.5.3 Ripe and Green

The weights of the ripe and green LBT fruits were obtained using Taylor 3851-49 Digital Kitchen Scale. Harvesting of ripe fruits began in the 14th week after sowing seeds and the final harvest which included both ripe and green fruits was done in the 21st week.

3.5.4 Fruit Size

The LBT fruits started ripening at 14 weeks old on plants in the peat moss substrate. However, the opportunity for a one-time harvest that would allow all 50 plants to be sampled came in the 17th week of the growth trial. The fruits from the plants in each substrate were all placed in one container. From each of the combined harvests, 20 fruits (n=20) were randomly selected for measurement. A digital caliper, EMPIRE 6-inch Stainless Steel Digital Caliper 2789 was used to obtain measurements. The stem and blossom end were used as the standard points between which the measurements were taken.

3.6 Chemical Analyses of Plants

3.6.1 Tissue Analyses

In order to develop a basic awareness of the nutrient composition within the seedlings, samples (n=5) grown in each substrate were submitted to NSDA for tissue analyses. The results (Table 10) were assessed against nutrient guidelines for tomatoes at the 5-leaf stage or most recent mature leaf (MRM) as suggested by Hochmuth, Maynard, Vavrina, Hanlon, & Simonne, (2004).

3.6.2 Fluorescence (Stress Levels - F_V/F_M) within the LBT Plants

LBT plants were assessed to determine the level of stress being experienced at three (3) intervals namely: 4 weeks (1^{st} stress test) after sowing which was a few days before transplanting, in the midst of the first mass fruit ripening (14 weeks/2^{nd} stress test) and finally at peak harvest (week 17/3^{rd} stress test) (Figure 18). The MRM leaf was chosen on the randomly selected plants for these assessments. This process was done using the $OS3p_+$ Chlorophyll Fluorometer where n=5. This device gives a measure of the maximum quantum efficiency that may affect photosynthesis II in plants. It is represented as follows:

$(F_{\text{Maximum fluorescence}} - F_{O(\text{minimum fluorescence})}) / F_{\text{maximum fluorescence}}$ or F_V/F_M.

3.6.3 Chlorophyll Content

Chlorophyll content was measured using Minolta Chlorophyll Meter SPAD-502. The leaves (n=5) assessed for fluorescence content were also used to determine chlorophyll content (Figure 19).

3.6.4 Anthocyanin Content of Tomato Plant Leaves

The anthocyanin content of the most recently matured leaf on tomato plants in all substrates was tested - (n=5). Testing was done using Hoskin Scientific Anthocyanin content meter ACM2000 Plus 3244 (Figure 20). This was strategically done in the 4th week after germination, in the midst of the large numbers off fruits present on each plant (14th week) and in the 17th week of life.

3.6.5 LBT Juice Analyses

Fifteen fully ripe (red) LBT fruits were randomly selected from the harvest of each substrate. This was the harvest of week 17 and represented the larger of the two (2) major harvests at that point. The juice from 15 randomly selected tomato fruits were extracted through a strainer into beaker rinsed with distilled water. Immediately following agitation, the pH, salinity and EC were taken using Hanna pH and EC Waterproof HI 98130, meter. Finally, total soluble solids (TSS) also known as the sugar or Brix % was measured using ATAGO® Pocket NFC Refractometer V114941 (Figure 21).

Chapter 4: Results
4.1 Substrate Analyses

4.1.1 Metals Content of the Pulp and Gypsum

The standard for heavy metals in Nova Scotia soils being used for agricultural activities are listed in Table 1 (Nova Scotia Environment, 2019). Also present are the separate heavy metals contents of the pulp and gypsum material being used as substrates. One can see that the heavy metals content pulp and gypsum; are well within the limits set by the province.

Table 2: Heavy metals in pulp, gypsum and Standard for NS agricultural soil.

Metals	**NS Standard for Agriculture Soil (mg/kg)** (Nova Scotia Environment, 2019)	**Pulp (mg/kg)** (AGAT)	**Gypsum (mg/kg)** (AGAT)
Aluminum	15,400	631	515
Antimony	7.5	<1	<1
Arsenic	31	2	4
Barium	10,000	41	13
Beryllium	38	<2	<2
Boron	4,300	6	173
Cadmium	1.4	<0.3	<0.3
Chromium	220	3	<2
Cobalt	22	<1	<1
Copper	1,100	3	<2
Iron	11,000	95	812
Lead	140	2.2	2.7
Lithium	-	<5	<5
Manganese	-	407	53
Molybdenum	110	<2	<2

Metals	NS Standard for Agriculture Soil (mg/kg) (Nova Scotia Environment, 2019)	Pulp (mg/kg) (AGAT)	Gypsum (mg/kg) (AGAT)
Nickel	330	<2	7
Selenium	80	<1	<1
Silver	77	<0.5	<0.5
Strontium	9,400	8	681
Thallium	1	<0.1	<0.1
Tin	9,400	7	3
Uranium	23	0.4	0.4
Vanadium	39	4	6
Zinc	5,600	7	8

4.1.2 Baseline pH of Substrates

The results from having submitted the substrate samples to the NSDA soil's laboratory for initial pH reading are represented in Figure 1 below.

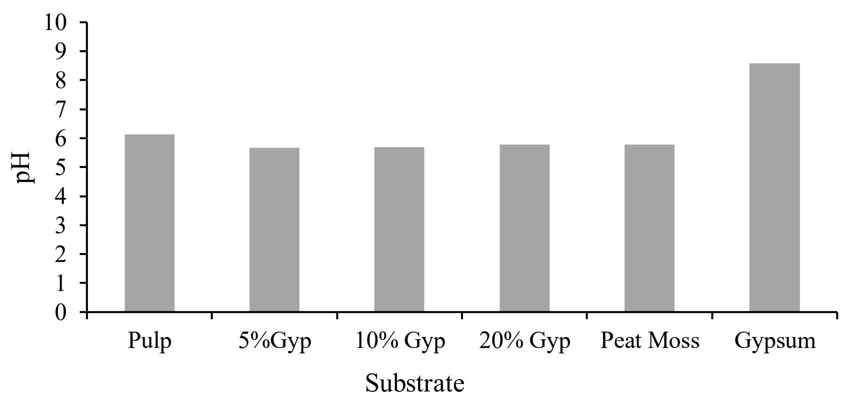

Figure 1: Baseline pH of blended and individual substrates as reported by (NSDA).

4.1.3 Substrate pH Measurements During Cultivation of LBT.

The pH for all substrates were slightly higher than 6, at week 5. However, by week 14, the pH of pulp only, 5% and 10% gyp were all below 5, with 4.94, 4.78 and 4.8 respectively. The pH of 20% gyp and peat moss also fell below 6 in week 14 but were slightly higher than the others, with 5.22 and 5.58 respectively. By week 17, pulp only, 5, 10 and 20% gyp were again on the rise with pH readings of 5.58, 5.26, 5.16 and 5.34 respectively. However, the pH of peat moss revealed a slight decrease from 5.58 to 5.50 in week 17. Differences among pH in weeks 5 and 14 were statistically significant (p = 0.000) in both instances, but not week 17 (p = 0.256).

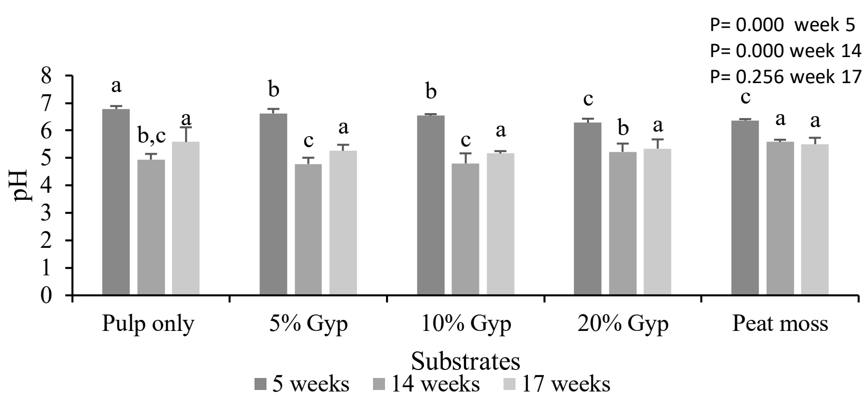

Figure 2: Substrate pH readings and SD at 5, 14 and 17 weeks old (n=5).

4.1.4 Baseline EC of Substrates

The 5% and 20% gyp yielded 1 mmhos/cm^{-1} and 4.36 mmhos/cm^{-1}, respectively, while pulp only EC was 1.91 mmhos/cm^{-1}, 10%gyp = 3.65 mmhos/cm^{-1} and gypsum by itself was 3.35 mmhos/cm^{-1} (NSDA) (Figure 3).

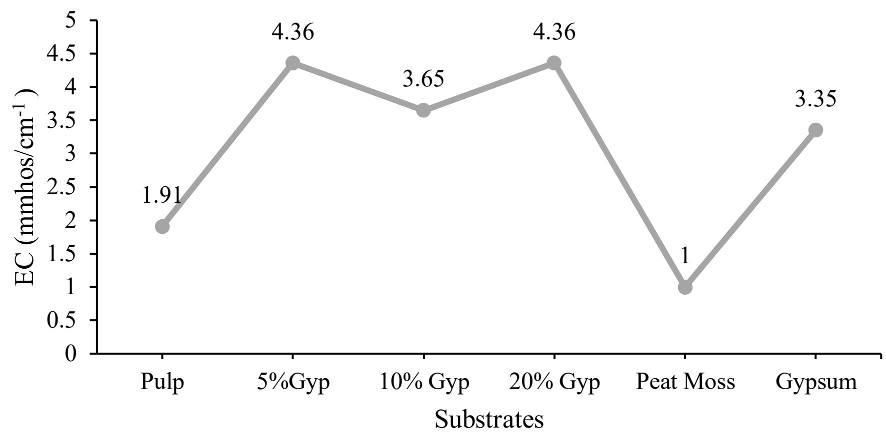

Figure 3: Baseline EC of pulp, gypsum, peat and gyp substrates (NSDA).

4.1.5 Adjusted EC of Substrates

After flushing the substrates with water this resulted in starting EC's of: 1.25 mmhos/cm^{-1}, 1.59 mmhos/cm^{-1}, 1.62 mmhos/cm^{-1} and 1.46 mmhos/cm^{-1} for pulp only, 5%, 10% and 20% gyp, respectively (Figure 4). Peat moss was not treated because its EC was 1 mmhos/cm^{-1}.

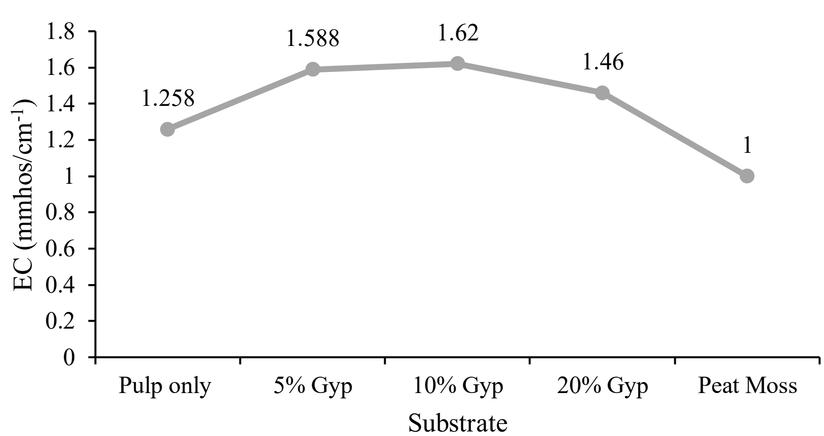

Figure 4: Adjusted EC of substrates, before LBT seeds were sown.

4.1.6 EC Measurements at 5, 14 and 17 Weeks into Production (n=5)

The results show that for the 5-week transplanting exercise, pulp, 5% gyp, and 10% gyp had a mean EC below 1 mmhos/cm^{-1} (Figure 5). However, the EC for 20% gyp remained at 1.08 mmhos/cm^{-1}. Peat moss yielded relatively flat EC readings, however, for the measurements in weeks 14 and 17, an increasing trend was observed. With the exception of peat moss whose EC remained flat, mean readings for week 14 ranged from a low of 0.40 mmhos/cm^{-1} in pulp only to a high of 2.12 mmhos/cm^{-1} in 20% gyp. Week 17's reading ranged from 0.17 mmhos/cm^{-1}in pulp only to 2.34 mmhos/cm^{-1} in 20% gyp (Figure 5). Differences in EC between week 5 and 17 were statistically significant (p=0.00) but not week 14 (p=0.390).

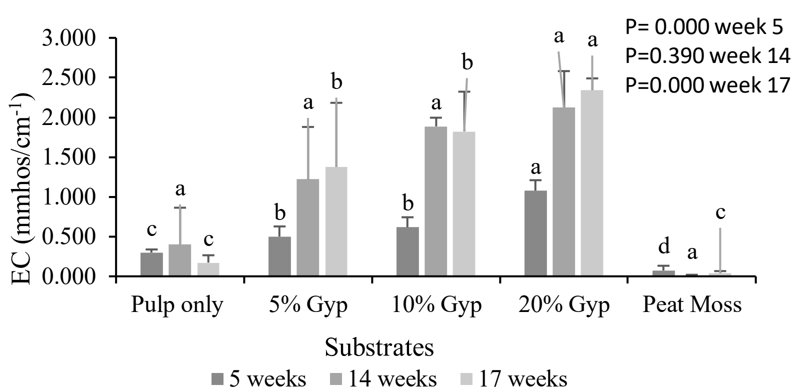

Figure 5: EC measurements of substrates with SD at 5, 14 and 17 weeks old.

4.1.7 Substrate Nutrient Analyses

There are clear differences resulting from the addition of gypsum to the PHP pulp sludge. As can be seen in Table 3, Ca and S are clearly present in relatively large quantities. Except for peat moss, the quantity of Ca increased across the substrates with pulp only moving from a low of 20.47 ppm to a high of 673.98 ppm Ca in the 20%gyp blend. Similarly, the amount of S in the pulp only substrate went from a low of 470.82 ppm to 2213.64 ppm, in the 20% gyp blend. Conversely, however, a decreasing rate was observed as the amount of gypsum added to the pulp increased. Gypsum, clearly had a very small amount of P, totalling 0.6 ppm. Variation in the quantities of the nutrients can be seen when one compares the normal quantities to be present in a greenhouse substrate as proposed by Bailey et al., (2000).

Table 3: Nutrient analysis of non-autoclaved substrates used for LBT trial.

Parameter	**Substrates**						**Comparison**
	Pulp Only	**5% Gyp**	**10 % Gyp**	**20% Gyp**	**Peat Moss**	**Gypsum**	(Bailey et. al. 2000)
Conductivity (mmhos)	1.91	4.36	3.65	4.36	1	3.35	---
pH (pH Units)	6.13	5.66	5.7	5.77	5.78	8.58	---
Nitrate-N (ppm)	0.86	0.88	0.92	1.06	28.55	1291	75 – 150
Calcium (ppm)	20.47	610.96	637.1	673.98	85.11	679.06	125 - 175
Potassium (ppm)	45.95	79.83	89.61	108	96.65	311.86	75 – 150
Magnesium (ppm)	7.92	52.94	53.28	55.05	21.72	11.68	1-2
Phosphorous (ppm)	108.58	64.45	58.33	42.57	47.46	0.58	10 – 20
Sodium (ppm)	153.46	234.97	240.5	246.31	18.43	63.4	< 25
Sulphate (ppm)	470.82	2351.24	2321.01	2213.64	291.11	1783.16	75-125
Chloride (ppm)	19	19	19	19	10	29	< 25
Aluminum (ppm)	4.73	0.29	0.42	0.15	0.19	0.16	---
Boron (ppm)	0.23	2.65	5.52	15.29	ND	139.6	0.1 -0.5
Copper (ppm)	ND	ND	ND	ND	ND	ND	0.1 – 0.5
Iron (ppm)	1.23	0.65	0.71	0.59	0.58	ND	1 – 2
Manganese (ppm)	4.7	26.03	26.12	26.34	0.14	0.41	1 – 2
Zinc (ppm)	0.42	0.32	0.31	0.29	0.48	ND	1 – 2

ND = none detected. Conductivity = EC

4.1.8 Ash Content of Primary Substrates.

The changes for ash content across the primary blends for this trial was an increasing one. 'Pulp only' had an ash content of 17.1%, and an immediate increase to 28.32% was observed upon creating the 5% gyp blend. However, when the 10% gyp blend was prepared, the ash content dropped slightly to 27.89%, while it increased to 46.94% for the final blend containing 20% gyp. The pulp from PHP contains clay particles from the manufacturing process which adds at least 35% (King, 2017) to its paper making process.

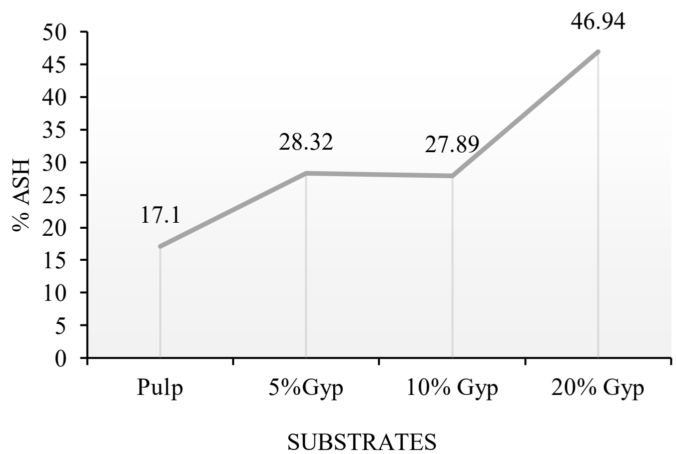

Figure 6: Ash content of substrates (NSDA).

4.1.9 Microbiology of PHP's Non-Autoclaved Pulp

Table 4: Fecal coliform and E. coli in the pulp sludge from PHP.

Parameter	Unit	Pulp Sludge Cake
Total coliforms	CFU/g (d.w.)	21000
Fecal coliforms – Solid	CFU/g (d.w.)	3700
E. coli – Solid	CFU/g (d.w.)	<340
Temperature upon receipt	°C	15.6

Table 4 above, shows the levels of fecal coliform and E. coli present in a sample of the sludge being used in this trial. It is critical to note that steps are being put in place to eliminate the blending of the sewage waste from PHP's washrooms with the pulp sludge. Therefore, except for the existing pulp on the capped land, this may not have any implications for future trials involving the PHP's pulp.

4.2 Physical Properties of The Substrates

4.2.1. Characteristics of Popular Plant Substrates

Table 5: Physical and chemical features of leading substrates

Substrate	Bulk Density (g/cm^3)	Total Porosity (%)	Water Holding Capacity (%)	Air Filled Porosity (%)	pH
Peat Moss	0.07-0.11	90-95	40	18-25	3.8-4.2
Coir	0.08	~80	40	13	slightly acidic
Comp. Bark	0.2	80	-	22	Close to neutral
Sand	1.6	35	15	7	3-6
Perlite	0.1	75	-	30	7
Rockwool	0.85	96	91	11	~8

(Buechel, 2018).

4.2.2 Summary Characteristics of Pulp only and Gypsum-Pulp Blends.

The uncompacted BD's for pulp only, 5%, 10% and 20% gyp were 0.53, 0.44, 0.41 and 0.38 g/cm^3 respectively. The trend shows that as the amount of gypsum increased the BD decreased. Uncompacted pulp had a porosity of 68% while the compacted pulp was 64%. At the other extremes, uncompacted 5%, 10% and 20% gyp all had 65% porosity measurements [which are worse than compacted pulp] and the compacted versions of the three were 61%, 60% and 61% respectively. The margins that separates the pH among the primary substrates were relatively narrow.

Table 6: Characteristics of pulp and gypsum-pulp blends used in the LBT trial.

Substrate	**Uncompacted Bulk Density (g/cm^3)**	**Total Porosity (%)**	**Water Retention Capacity (%)**	**pH**
Pulp Only	0.53	68	28	6.13
5% Gyp	0.44	65	28	5.66
10% Gyp	0.41	65	29	5.7
20% Gyp	0.38	65	29	5.77
Peat Moss (Buechel, 2018).	0.07-0.11	90-95	40	3.8-4.2

4.3 Growth Trial

4.3.1 Preliminary Germination% in Autoclaved Pulp.

Preliminary trials involving the use of sweet pepper, tomatoes, wheat, basil, and pak-choi were undertaken at the Dalhousie agricultural campus, and there was 100% germination using pulp only. Subsequently, the material was autoclaved and while the results of germination trial number one using autoclaved pulp were relatively good (Table 7), the second trial using autoclaved pulp sludge resulted in no germination in the pulp only substrate (Table 8). Importantly, the surviving seedlings within the pulp-gypsum blends (autoclaved pulp) of both trials showed symptoms of what may be severe nutrient or related deficiencies. This was visually evidenced by bright yellow colour in the interveinal portions of the leaves and extremely retarded growth rate. This resulted in the growth of the seedling in all, except those in the peat moss, being severely stagnated. After 4 weeks of growth in the germination trays, seedlings in the peat moss substrates, grew at an apparent normal rate which made them suitable for transplanting after 4 weeks. On the other hand, seedlings in the pulp and pulp gypsums blends grew to an average of only 5 cm.

Table 7: Germination results of trial number one using autoclaved pulp sludge.

Substrate	**Germination %**
Pulp only	70
5% Gyp	90
10% Gyp	90
20% Gyp	100
Peat moss	100

Table 8: Germination results of trial number two using autoclaved pulp sludge.

Substrate	**Germination %**
Pulp only	0
5% Gyp	100
10% Gyp	90
20% Gyp	95
Peat moss	100

4.3.2 Germination % and Average Time to Germination in Non-Autoclaved pulp

Germination became 100% across the five (5) substrate blends where autoclaved pulp was replaced by non-autoclaved pulp in the LBT growth trial. Fifty-two (52) seeds were sown in the seed tray containing peat moss, all seedlings emerged over a period of 7.2 days; making it the fastest in this regard. On the other hand, 5% and 10% gyp took

7.8 and 7.9 days respectively, for their 20 seeds to emerge. Pulp only and 20% gyp both took 7.5 days to emerge.

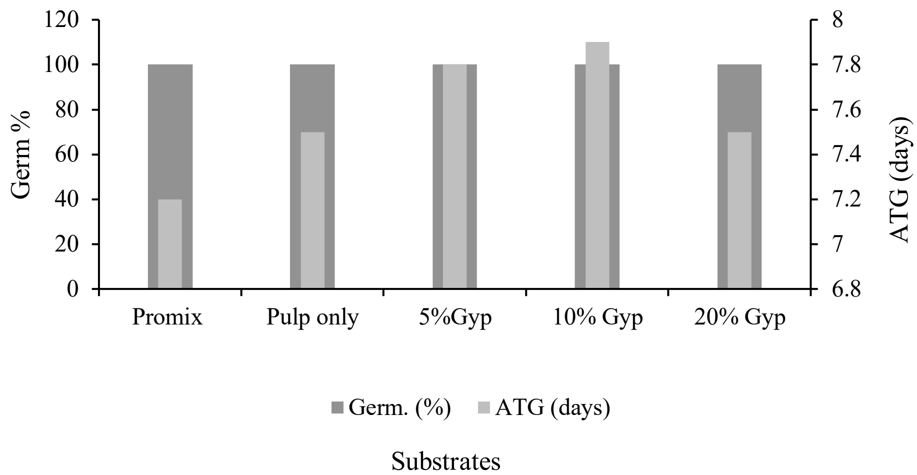

Figure 7: Germination % and ATG for LBT in each substrate.

4.3.3 Stem Diameter at 4 and 21 Weeks Old

At week 4, the mean thickness of samples in peat moss substrate was 4.35 mm and was by far thicker than those in the other substrates. There were fluctuations in the mean stem diameter among the other substrates; 20% gyp had a mean stem diameter of 3.2 mm, 10% gyp = 2.5 mm and pulp only had a mean of 1.43 mm. At the 4-week stage, it was evident that although there was 100% germination across all blends, the growth of seedlings in the pulp only substrate was stunted.

Week 21 plants in the peat moss substrate had a mean stem diameter of 9.38 mm, however, this represents the lowest mean across the substrates and a complete turn around from its leading size at the 4-week juncture. At this stage (21 weeks), plants in the pulp only substrate had 9.94 mm; [these plants are the seedlings which were taken from the peat moss at transplant due to the small size of those sown in the pulp only substrate]. There was a slight fluctuation in mean stem diameter as the ratio of gypsum to pulp increased; 5% gyp = 12.57 mm, 10% gyp had the highest mean stem diameter of 13.22 mm while 20% gyp = 12.95 mm. The differences among means for stem diameter were statistically significant at weeks 4 and 21, with a p-value of 0.000 in both instances.

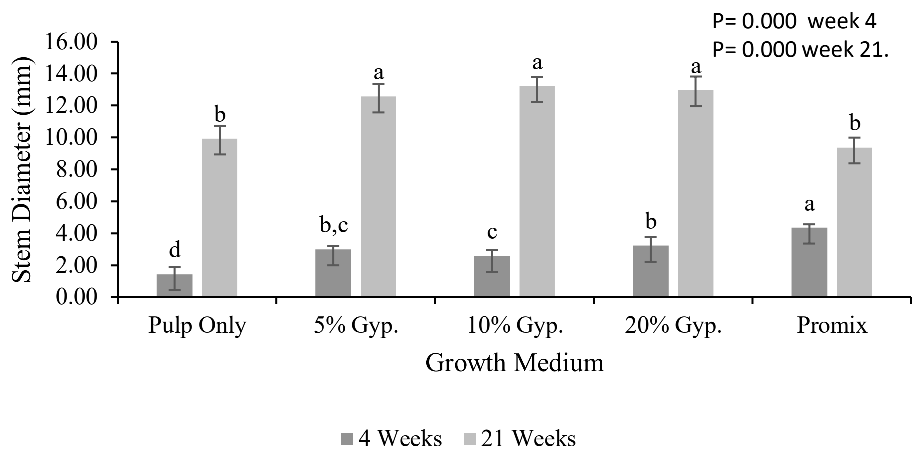

Figure 8: Stem diameter with SD of LBT at 4 and 21 weeks old.

4.3.4 Plant Height

The week - 4 measurements of seedlings in the peat moss substrate demonstrated good vigor and had the highest mean height of 14.4 cm. This was followed by 20 % and 5 % gyp which measured 8.4 cm and 8 cm respectively. The seedings in 10% gyp substrate had a mean height of 7.2 cm while those in the pulp-only medium had a mean height of 5 cm.

The mean trend observed in the 21st week of life are slightly different to that observed in the mean trends at 4 weeks old. Plants in the peat moss substrate maintained the highest mean height with 84.6 cm while pulp only which had the lowest mean height at 4 weeks now had a mean height of 80.8 cm, making it the second highest. Keep in mind that the LBT plants which matured in the pulp only were the ones started in the peat moss substrate. Height differences among LBT plants at week 4 were statistically significant (p = 0.000) but not at week 20 (p = 0.276).

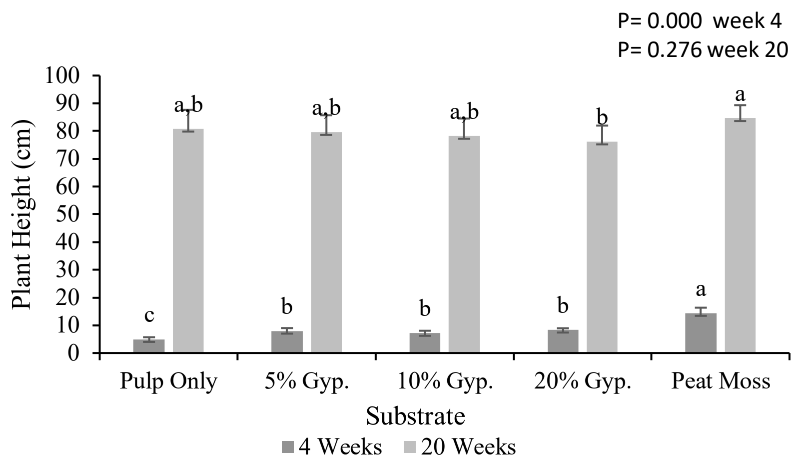

Figure 9: Average height of LBT and SD at 4 and 20 weeks old.

4.3.5 Leaflet Count

At four (4) weeks old, seedlings in the pulp only substrate had a mean of 4 leaflets while those in peat moss doubled that count with a mean leaflet count of 8. There was mean leaf count of 7 each, for the 5%, 10% and 20% gyp substrates. The final mean leaflet count for pulp only and 10% gyp were both 10 while 5% and 20% gyp both had a mean count of 11 leaflets. However, the mean count for plants in the peat moss substrate was the highest, with 12 leaflets.

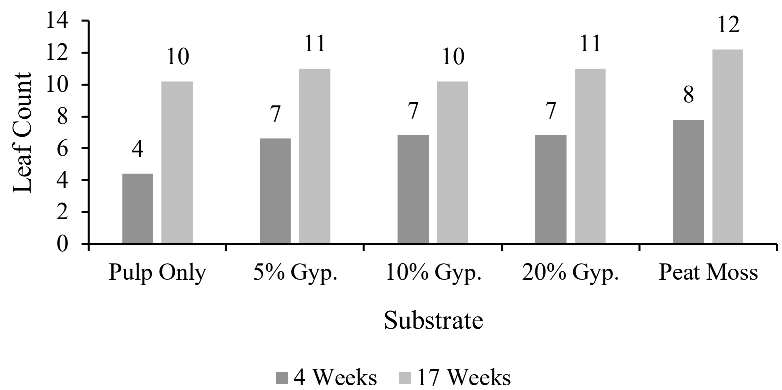

Figure 10: Average leaflet count for LBT plants at 4 and 21 weeks old.

4.3.6 Growth Rate of LBT

Based on the results obtained (Figure 11), it is evident, most of the growth across all substrates took place within the first 12 days of tagging. Notably, within this 12-day period, plants in 20% gyp had the sharpest decline in growth rate while those in 10% gyp had the most stable growth rate. On the other hand, plants in the peat moss substrate started with the highest growth rate but became the one which slowed down the fastest.

When it comes to the overall averaged 3-day interval growth rate of the LBT across the substrates, all the leaves grew by 2.6 cm in length, except those in the pulp only blend which added only 2.1 cm within this same time period. The plants in the pulp only substrate are those plants which were transplanted as replacements for the slow growing and poor survival rate of seedlings initially sown in pulp only at the beginning of the trial. Differences in growth rates among LBT plants were statistically insignificant ($p = 0.993$)

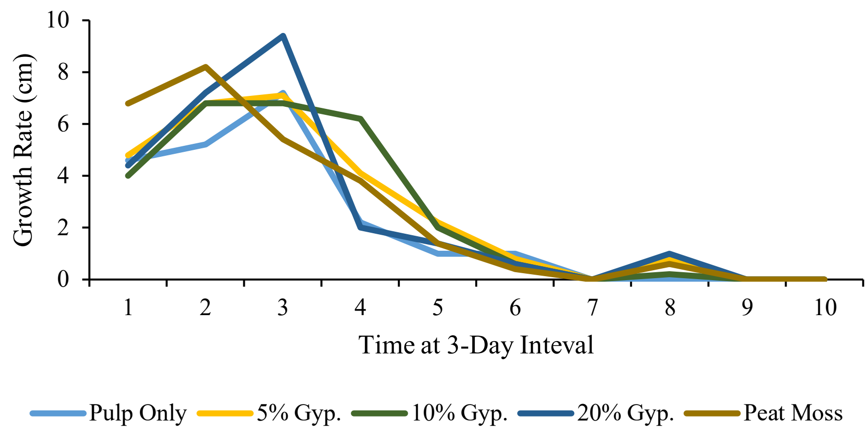

Figure 11: Growth of LBT plants taken at 3-day intervals.

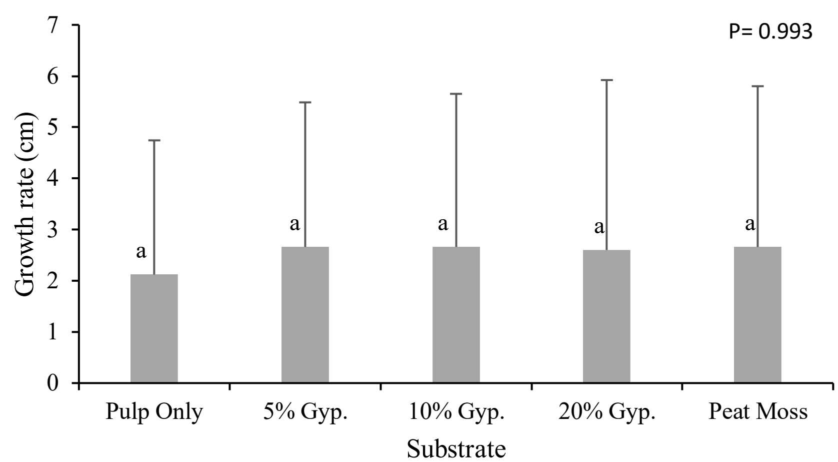

Figure 12: Mean growth rate and SD of LBT in each substrate.

4.4 LBT Harvest

4.4.1 Fresh and Dry Root Weight

Having weighed the plants samples grown in the various substrate blends, 10% gyp had the highest mean fresh root weight of 58 g; it also experienced the smallest percent change in weight moving down to a dry weight of 6 g or retaining 10.34% of its original mass. Root from the 5% gyp had a mean fresh weight of 73 g and retained only 4 g (5.48%) of its original weight. Mean weights of roots from pulp only and 20% gyp were both 56 g, however, weight retention after drying were 2 g (3.57%) for pulp only and 5 g (9%) for 20% gyp. The roots from the peat moss substrate had the lowest mean fresh weight of 53 g but was able to retain 4 g (7.55%) after the drying process. The differences between fresh and dry root weights were insignificant (p = 0.746) and (p = 0.661) respectively.

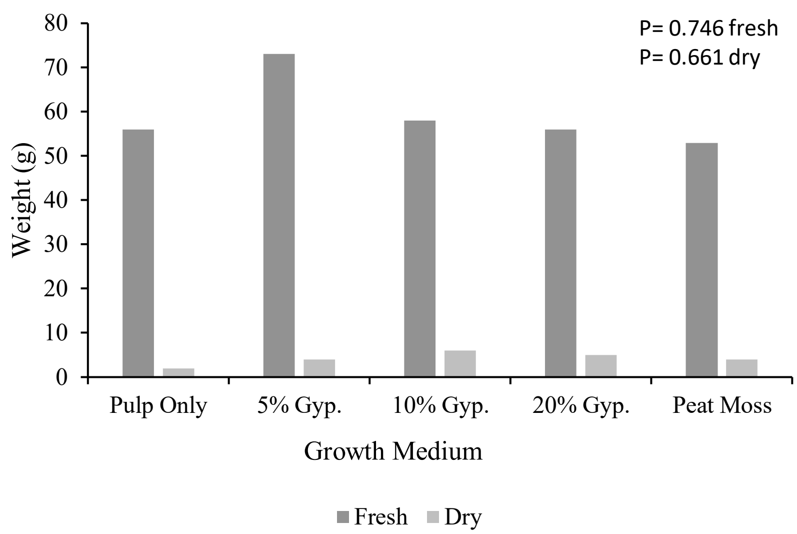

Figure 13: Average weight of fresh and dry roots from LBT plant roots.

4.4.2 Fresh and Dry Stem Weights

The mean fresh stem weight of plants from the peat moss substrate was the highest at 791 g, however, upon the completion of the drying process it was able to retain 136 g (17.19%) of its original weight. Plants from the 10% gypsum substrate had a mean fresh weight of 522 g and at the end of the drying process, this was reduced to 118 g (22.61%) of the original weight.

The mean fresh weighs of pulp only, 5% gyp and 20% gyp were relatively close, having 420g, 421g and 424g respectively. However, the difference in mean dry weight across these three substrates were much greater, with pulp only substrate yielding 31 g (7.38%), 5% gyp = 61 g (15%) and 20% gyp returning 58 g (13.68%), when compared to their fresh weights. The differences among fresh weights were significant (p = 0.007), but not for dry weight (p = 0.056).

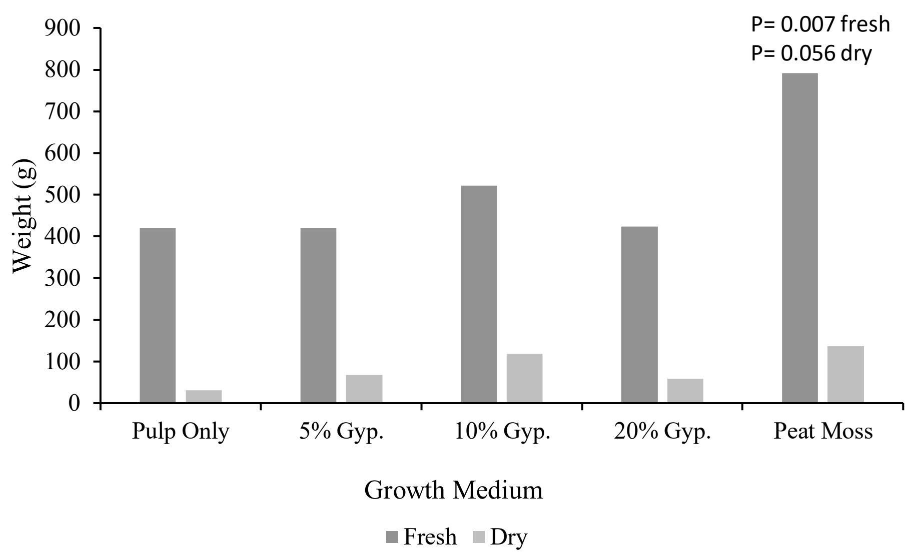

Figure 14: Mean fresh and dry stem weights of LBT plants at 21 weeks, (n=3).

4.4.3 LBT Harvest – Ripe and Green

The combined harvest for peat moss was 2.35 kg (5.2 pounds) and represents the lowest of the substrate categories (Figure 15). However, ripe fruits accounted for 68.9% (1.62 kg/3.6 pounds) of the peat moss total and is the largest relative to the substrate being used. Pulp only and 10% gyp both had slightly lower volumes of ripe to green tomatoes, with 56.9% (1.45 kg/3.2 pound) and 50.5% (1.6 kg/3.5 pounds) of their respective 2.55 kg and 3.17kg totals. Worthy of note is the fact that the 5% and 20% gyp substrates both realized lower quantities of ripe to green tomatoes. There were 1.52 kg/3.4 pounds (48.3%) ripe tomatoes harvested from the plants grown in 5% gyp. Plants grown in the 20% gyp was only able to yield 33.8% (.88 kg/1.9 pounds) ripe fruits within the same time period.

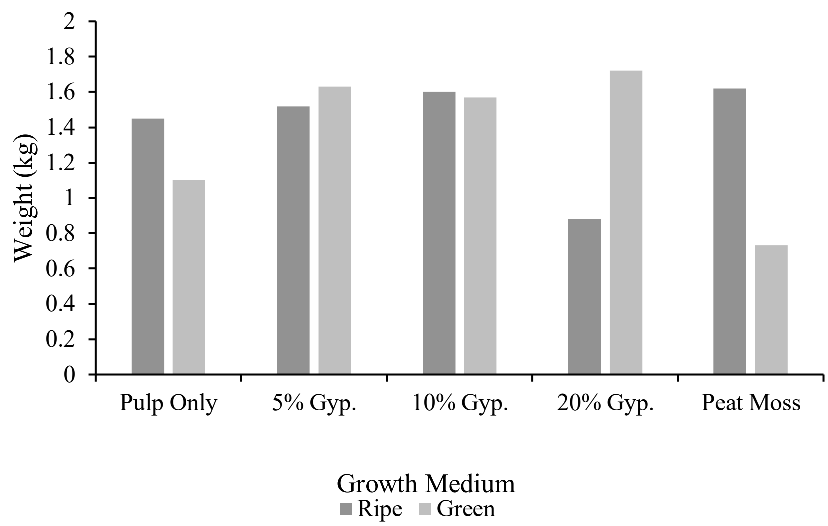

Figure 15: Actual harvest weights of ripe and green LBT fruits at the 21 weeks old.

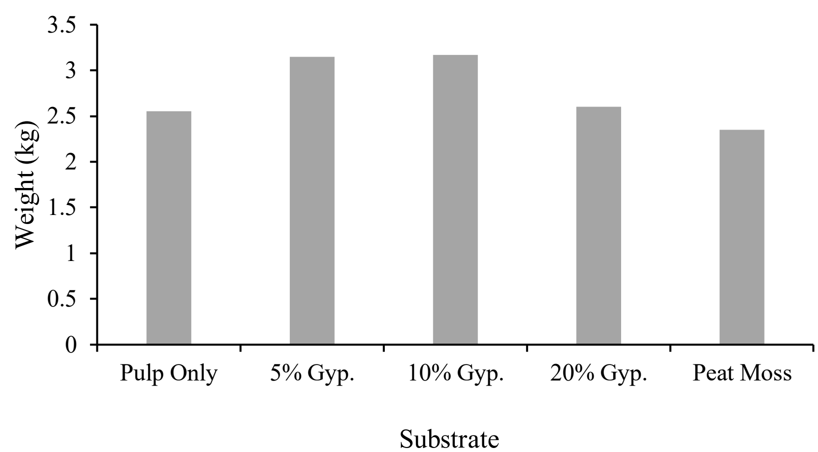

Figure 16: Total LBT fruit harvest obtained, across the substrate blends.

4.4.4 Fruit Size

Based on the means, LBT fruits of the plants transplanted from the peat moss substrate into the pulp only substrate had a mean diameter of 25.67mm, while 5%, 10% and 20 % gyp had mean measurements of 27.86 mm, 28.73 mm and 28.56 mm. Fruits from the Peat moss had a mean diameter of 27.44 mm. The differences among fruit sizes at week 17 were significant (p = 0.000)

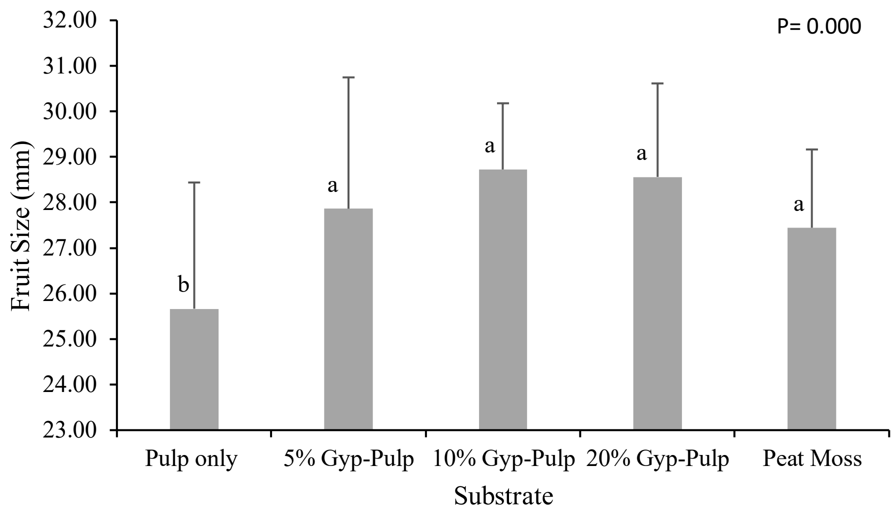

Figure 17: Fruit sizes and SD of LBT plant at 17 weeks old.

4.4.5 Visual Observations During LBT Cultivation

Visually examining one's crop as it grows is important, however, there are certain features the natural eye cannot detect. In such cases, the use of lab-based analyses become necessary (McCauley, Jones & Jacobsen, 2009). The following (Table 9) is a summary of visual observations during the cultivation of LBT for this trial. Seeds were sown on February 15, 2019.

Table 9: Visual observations during the production cycle of the LBT crop.

Stage of Growth	Visual Observation
6 days after sowing seeds (Feb. 21, 2019)	Germination began in all blends. Peat moss had the largest number of seedlings emerge.
2 weeks post emergence	Seedlings in pulp only visibly growing slower than other blends. Green algal growth on the surface of the pulp only substrate with reduced drainage and a 'clumped' look
3 weeks post emergence	Symptoms resembling Mg and or Fe deficiency visible across gyp blends. Seedlings in peat moss elongating fastest and had wider canopy than all blends.
4 weeks post emergence	A single unknown weed found in the 20% gyp tray. Symptoms resembling Mg and or Fe deficiency seemed to be improving. Growth of seedlings in pulp only visibly stagnant. White crusting inside seed trays and ~1cm up the stem of seedlings across gyp blends.
5 weeks post emergence	Seedlings transplanted. Seedlings in pulp only too small/stunted to be transplanted. Symptoms resembling Mg deficiency especially visible in 10% gyp blend. Leached particles of gypsum visible on floor of greenhouse.
1st week post transplant (week 6)	Rough, spotty and chlorotic interveinal regions developed on the existing young leaves of seedlings which were transplanted from peat moss to pulp only blend as replacement for stunted seedlings in pulp only germination. The tips of these leaves also curled under to some degree. Transplants in other blends settling in well.
2 weeks post transplant (week 7)	Insects resembling thrips (*Frankliniella occidentalis*) inflict damage to the surface of lower leaves across all blends. Safer's End All Miticide/Insecticide Acaricide used as control.
3 weeks post transplant (week 8)	Newly formed leaves on plant transplanted from peat moss to pulp only show no signs of rough, spotty and chlorotic appearance. Plants in peat moss and pulp only began flowering. White crusting at drain holes on pots across the gypsum blends.

Stage of Growth	Visual Observation
Weeks 9-13	Plants continue to grow at their respective rates, flowering and fruiting. All plants appeared to be healthy. Some blossom-drop across all blends observed. Plants in peat moss remain visibly the tallest of all blends.
Week 14	First harvest [small] from plants across all blends.
Weeks 15-17	Second harvest [large] from plants across all blends. A few branches broke under pressure from the fruit load.
Weeks 18-21 (Final harvest and sampling July 20, 2019)	General decline in plant physical appearance especially in the gypsum and pulp only blends. Plants in peat moss appeared relatively healthy compared, at this stage. Relatively large fruit load but ripening across gypsum blends, [especially in 20% gyp] appears to be much slower than pulp and peat only blends.

4.5 Chemical Analyses of Plants

4.5.1 Tissue Analyses

Seedlings grown in the gypsum-pulp substrates recorded the highest number of nutrients over the limit, these include Ca, Mg, P, B, Mn and Zn. Importantly, Fe and Mn were over the allowable limits by a 5.01 and 2.38 ppm respectively, among seedlings from the peat moss substrate. The only deficiencies observed in seedlings at this stage were N in the 5% gyp, and Mg in the 5%, 10% and 20% gyp blends.

Table 10:Tissue analyses of LBT grown in pulp, peat moss and gyp substrates.

LTB Seedling Tissue Analyses					
Parameter	**Pulp Only**	**5% Gyp**	**10% Gyp**	**20% Gyp**	**Peat Moss**
Nitrogen (%)	3.69	2.84 **(d)**	3.58	3.44	4.12
Calcium (%)	1.155	3.13 **(h)**	2.863 **(h)**	2.748 **(h)**	1.735
Potassium (%)	4.349	3.907	4.771	4.231	4.3
Magnesium (%)	0.41	0.152 **(d)**	0.124 **(d)**	0.14 **(d)**	0.413
Phosphorus (%)	0.889 **(h)**	0.977 **(h)**	0.975 **(h)**	0.986 **(h)**	1.19 **(h)**
Sodium (%)	0.0724	0.236	0.244	0.273	0.405
Boron (ppm)	41.09	55.55 **(h)**	59.15 **(h)**	64.72 **(h)**	24.81
Copper ppm)	13.57	12.4	15.25 **(h)**	15.72 **(h)**	9.16
Iron (ppm)	139.3 **(h)**	95.45	98.8	97.27	105.01 **(h)**
Manganese (ppm)	170.24 **(h)**	210.04 **(h)**	202.23 **(h)**	153.46 **(h)**	102.38 **(h)**
Zinc (ppm)	91.23 **(h)**	98.71 **(h)**	117.48 **(h)**	116.56 **(h)**	79.66 **(h)**

d = deficient   h= high (Hochmuth, et. al., 2004).

Table 11: Nutrient contents of substrates and LBT seedling at five weeks.

Nutrient	**Presence in Substrate (NSDA)**	**Presence in Plant tissue (NSDA)**
N	Low in all.	Deficient in tissues from pulp only blend.
Ca	*High in all gypsum.* Low in pulp and peat.	*High in tissues from gypsum blends.* Optimum in tissues from peat and pulp blends.
K	Optimum in all except pulp only.	Optimum in plant tissue from all blends
Mg	High in all.	Deficient in tissues from gypsum blends. Optimum in tissue from peat and pulp blends.
P	*High in all.*	*High in tissues from all substrates.*
Na	High in all except peat moss.	Optimum in tissues from all substrates
B	*High in all gypsum.* Low in pulp only. None detected in peat moss	*High in tissues from gypsum blends.*
Cu	None detected.	High in tissues from 10% and 20% gypsum blends.
Fe	Below maximum levels in all.	High in tissues from pulp and peat only blends.
Mn	High in all but peat moss.	High in tissues from all blends.
Zn	Below maximum limits in all.	High in tissues from all blends.

Table 12: Nutrients added to substrates and their presence in LBT plant tissue.

Action	**Findings in 5-week old Seedlings**
No Ca supplied	Ca above the range (h) in plant tissues from gypsum pulp blends.
Mg supplied at .05%	Mg deficient (d) in plants tissues grown in gypsum-pulp blends.
N supplied at 10%	N deficient (d) in pulp only blend.
P supplied at 15%	P above range (h) in plant tissues from all blends.
No B supplied	B above range (h) in plant tissues from gypsum-pulp blends.
Fe supplied at .05%	Fe above range (h) in plant tissues from pulp and peat only substrates.
Mn supplied at .05%	Mn above range (h) in plant tissues grown in all blends.
Zn supplied at .05%	Zn above range (h) in plant tissues grown in all blends.

4.5.2 Fluorescence (Stress Levels - F_V/F_M) Within the LBT Plants

The mean values of the stress tests for peat moss ranged from slightly > 0.800 but <0.820. While the mean values for the stress levels across the substrates were relatively close to the established range, all realized their lowest stress levels as measured in the MRM leaves at peak harvest (2nd stress test) and their highest stress levels in the 1st stress test (4th week) and 17th week (3rd stress test) of life (Figure 18). The lowest measurement (0.702) was observed in plants growing in 5% gyp during the 17th week, while the highest (0.839) were seen in plants growing in 10 and 20% gyp substrates during the 14th week. It is important to note that plants growing in peat moss recorded the most consistent numbers of 0.811. 0.817 and 0.802 during the 1st, 2nd and 3rd stress tests, respectively. Differences among fluorescence levels at weeks 4, 14 and 17 were insignificant (p = 0.340, 0.241 and 0.470), respectively.

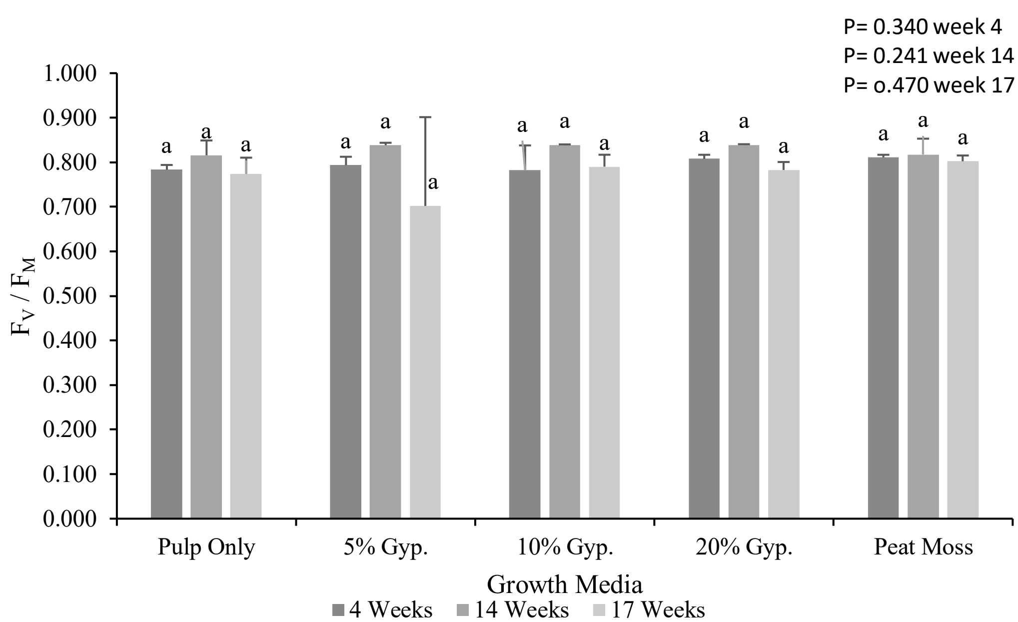

Figure 18: Fluorescence (F_V/F_M) and SD of LBT at 4, 14 and 17 weeks old (n=5).

4.5.3 Chlorophyll Content

Like anthocyanin content (Figure 20) and fluorescence (Figure 18), the chlorophyll content was seen to yield low measurements in the early stages (4th week) of growth, rising to a peak in the flowering and fruiting stage (14th week) then returning relatively close to the original levels in the 17th week (Figure 19). Chlorophyll content was measured using Minolta Chlorophyll Meter SPAD-502. Again, the measurements were relatively close among the plants in peat moss which had approximately 14 chlorophyll values separating the highest recording from the lowest – weeks 4 and 14. Pulp only recorded chlorophyll values with the highest separated from the lowest by 24. The differences across the gypsum-pulp blends were slightly higher.

The chlorophyll values obtained in the 17th week of life also reflect the continued downward trend in the 5, 10 and 20% gyp substrates (Figure 19). Differences among chlorophyll content at weeks 4 and 14 were insignificant ($p = 0.097$ and 0.339) respectively, but were significant for week 17 ($p = 0.009$).

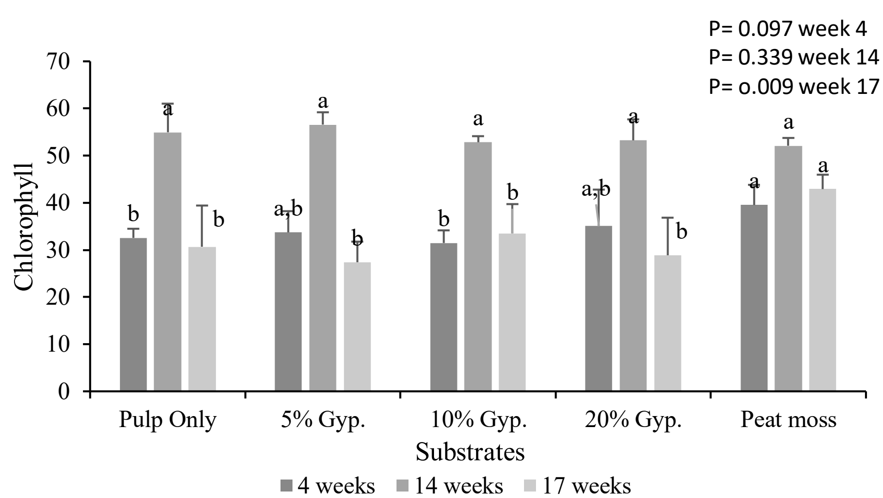

Figure 19: Chlorophyll content of LBT leaves and SD at 4, 14 and 17 weeks of age.

4.5.4 Anthocyanin Content of Tomato Plant Leaves

Plants in all substrates had the highest levels of anthocyanin in the 14th week when plants were flowering and fruiting heavily. Those in pulp only substrate had the highest levels (10.34) and peat moss, the lowest (7.8).

The levels of anthocyanin seemed to have started out relatively low, rising to a high then returning to low levels similar to those observed in early life. This trend coincides with the measured fluorescence (Figure 18) and chlorophyll content (Figure 19). It was quite evident that plants in pulp only and in the gypsum-pulp blends showed the greatest variations among the three (3) measurements. Upwards of 4 points separated the highest from the lowest readings. On the other hand, only 2 points separated the highest reading from the lowest for plants growing in peat moss as recorded at 4, 14 and 17 weeks. Differences among the anthocyanin contents of week 4 were significant ($p = 0.037$), but not for weeks 14 and 17 ($p = 0.193$ and 0.066), respectively.

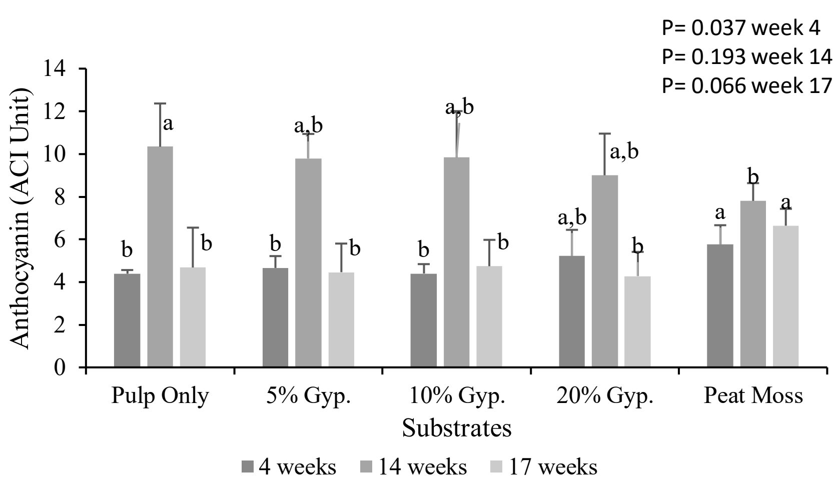

Figure 20: Anthocyanin content of LBT and SD at 4, 14 and 17 weeks of age

4.5.5 LBT Juice Analyses

The pH and Brix contents of the tomato juice from plants grown in the different substrates were relatively close. pH measurements ranged from 4.24 to 4.85 while Brix levels went from a high of 6.9% to a low of 6.2%, with pulp only and 10% gyp sharing a measure of 6.6% each. LBT juice obtained from plants grown in the peat moss substrate produced a high EC reading of 6.63 mmhos/cm^{-1} while those in the pulp only and pulp-gypsum blends yielded measurements between 5 and 5.99 mmhos/cm^{-1} (Figure 21).

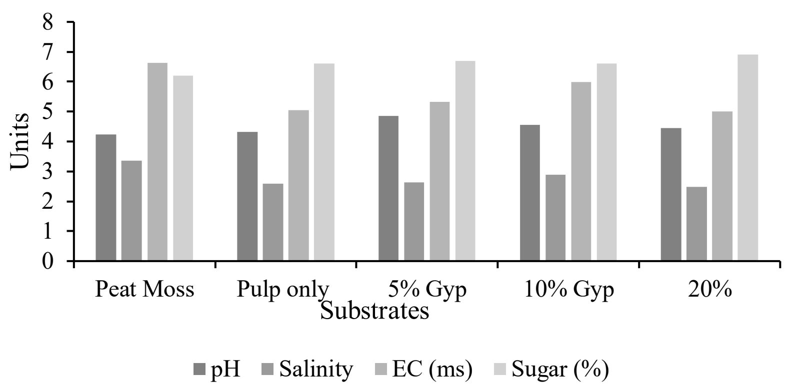

Figure 21: EC, Salinity, pH and TSS of extracted ripe tomato juice (n=5)

4.6 Summary of Significance Levels Across Blends

Data collected during the LBT trial were subjected to one-way ANOVA and the results tabulated below. Where p-value is > 0.05, differences of means are not significant and where p-value is < 0.05, the differences of means are significant (Minitab 18).

Table 13: Fisher LSD's as generated by the Minitab 18 data processing software.

Parameter	Age of LBT Plants (weeks)	Samples (n)	Significance (p)
pH	5	5	0.000
	14	5	0.000
	17	5	0.256
EC	5	5	0.000
	14	5	0.390
	17	5	0.000
Stress Levels (F_V/F_M)	4	5	0.340
	14	5	0.241
	17	5	0.470
Anthocyanin Content	4	5	0.037
	14	5	0.193
	17	5	0.066
Chlorophyll Content	4	5	0.097
	14	5	0.339
	17	5	0.009
Stem Diameter	4	5	0.000
	21	5	0.000
Plant Height	4	5	0.000
	20	5	0.276
Growth Rate	8-13	5	0.993
Fruit Size	17	20	0.000
Fresh Root Weight	21	3	0.746
Dry Root Weight	21	3	0.661
Fresh Stem Weight	21	3	0.007
Dry Stem Weight	21	3	0.056

Chapter 5: Discussion

5.1 Conceptual Layout of Reusing Paper Mill Pulp Sludge and Gypsum

Based on the knowledge generated from the Kalundborg Industrial park (Gulipac, 2016) a conceptual layout was developed to depict what could become a scaled up agro-eco-industrial park within the environs of PHP. This concept lends itself to incorporating the waste drywall board being generated by CG, located less than a kilometer away.

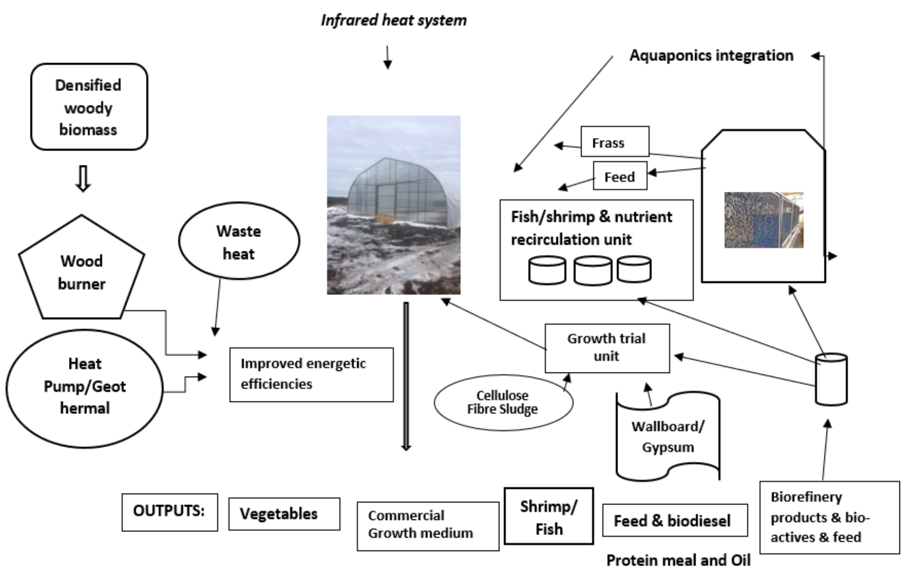

Figure 22: Conceptual layout of symbiosis among waste streams from PHP and CG.

While this experiment was done at the bench-scale, the intent and the resources exist to further test any successful blends at a larger, demonstration scale. Given the volumes of pulp and gypsum that would be required to develop a potential product it could significantly reduce such materials heading to both private and provincial landfills. However, as is evident in Figure 22, there are several components with which the introduction of pulp and gypsum would have to successfully synchronise.

Both PHP and CG are located within 1.6 km of each other and are major employers within the Port Hawkesbury community. PHP directly employs 300 people, while contractors amount to another 400 making a total of 700 jobs (Port Hawkesbury Paper, 2018). On the other hand, CG employs approximately 50 individuals on site (CBC News, 2016). Given the magnitude of work that would be needed to build a scaled-up model of this agro-industrial part, its clear there could be addition job created locally, even in the short-term. Once the construction phase is completed, there will be the need for additional skill sets to operate the related facilities and move the material between the points where they are generated and the points where they are utilized.

Assuming that PHP decides to build a processing plant in the general area where the pulp is currently being disposed of and establish the greenhouse on the roof of the current paper mill; this would mean neither of the waste streams would be traveling more than 1.6 km to the point where they are both processed and utilized in the agro-eco-industrial setting. The cost of processing the material was not factored into this LBT crop trial.

However, based on the basic methods used to prepare the material used in this trial, it is safe to state that even with the construction of a suitable batching plant; the cost of the finished product could compete relatively well with other established growing media. When this price is passed on to the farmers; the local community people who purchase the commodities produced could also see a better price when compared to imported foods. As mentioned earlier, income seem to be the biggest threat to food security in Nova Scotia. Therefore, this could bolster the level of food security among vulnerable groups withing the province.

5.2 The Substrates

5.2.1 Heavy Metals Content

The allowable limits as listed in Table 2, represents the maximum amount of each metal that soils being used for agricultural activities should possess (Nova Scotia Environment, 2019). The results of the tests revealed the heavy metals content of all substrates used in the experiment were well below the established limits. This is because the production and post production processes did not encourage the excessive buildup of heavy metals in either material, and this presents a positive case for both.

5.2.2 pH of Substrates

The results of pH measurements revealed gypsum having a relatively high pH of 8.58, which makes it strongly alkaline while pulp only recorded a pH of 6.13. It is worthy to note that after adding the strongly alkaline gypsum to the slightly acidic pulp, the pH for all the gyp blends became medium acidic (Appendix A). However, it was observed that once the quantity of gypsum increased, the pH of the pulp-gypsum blends also increased.

Having over 20 years working with gypsum, Professor Warren Dick indicated in one of his presentations that it can alter the pH of soils mildly and this has benefits for warding off the negative side effects which could arise from soluble aluminum when the pH is low (Penton Business Media, Inc. 2019). One can see that prior to the addition of 5, 10 and 20% gypsum to the pulp sludge, the Al content was much higher, which suggests that if the pH became low during the germination stage; that could have been one of the contributors to the low survival and growth rates in the pulp only blends. It may also be used to help explain the sudden change in the appearance of the ‘first’ leaves on tomato plants that were transplanted from the peat moss to the pulp only blend. Hjelm & Rytter, (2016) confirmed some of the effects of soil acidity on the cultivation of poplar spp. and indicated that Ca, P and Al are prone to having negative impacts on the growth of plants, particularly at low pH.

While gypsum is highly soluble in the lower regions of the soil profile, the change in pH observed may not be a function of the added gypsum, because gypsum does not readily neutralize or form an acid (Zoca & Penn, 2017). This, therefore, raises questions about the effect of the paper lining which was blended with the wallboard and the degree to which the pulp and gypsum were blended. This latter situation may be having an impact on the pH reading; nevertheless, there may be other synergistic reactions taking place within the substrates that this trial was not able to identify. The peat moss used in this trial yielded a pH value of 5.78 as expected, because peat moss is known to be acidic in nature (Buechel, 2018).

Clearly, the pH of a substrate material remains one of, if not the most important chemical features that determines how well a crop will perform. Ideally, pH between 5.5 and 7.5 is good for tomatoes, however, the availability and toxicity of nutrients become evident outside these limits (Havlin et al., 2013).

The pH of the substrates at the point of mass fruit ripening (14 weeks) and then again at the 17th week of life (Figure 2) appeared to have been problematic for the plants. Interpreting the guide provided by Havlin et al., (2013) supported the notion that in week 14, the plants in pulp only and gypsum blends were possibly exposed to severe N, P, K and Mg deficiencies, as well as Mn toxicity as it occurs at pH $< 5.0 - 5.5$. Ca deficiency was possible for the 5 and 10% gypsum blends, with these symptoms showing up at pH <

4.5 - 4.8 with low CEC. In week17, N and Mg deficiencies remained while Mn toxicity was still a threat (Havlin et al., 2013). The resulting drop in pH seem to support the notion that gypsum has little or no effect on neutralizing the acidic nature of the medium especially close to the surface of the soil (Zoca, & Penn, 2017). There is also the likelihood that nutrients such as Ca, Mg and K became adsorbed to the surface of soil particles and were therefore unavailable to the plants (Havlin et. al. 2013).

5.2.3 The EC of the Media

The EC readings, after the substrates were flushed with water supplied by the greenhouse, were aligned with Tripepi, (2011); they suggested a range of 0.75-1.99 mmhos/cm^{-1} specifically for seedlings and substrate that contain high amounts of organic matter. The substrates contain significant amounts of wood fibre (i.e. organic matter); therefore, the EC's were well within the suggested limit after flushing. There was an observed increase in the EC over the life of the crop; testing at the 5-week transplant, and 14 and 17-week harvest phases indicate gypsum remained a salt that continued to be dissolved while nutrient-rich water was being added to the substrates over time (Zoca, & Penn, 2017). While nutrients (salts) were being added to the substrates to support plant growth, it is clear from the results that the EC's were highest in the 20% gyp substrate – likely due to the fact that this contained the greatest amount of gypsum.

Vieira et al., (2019), used a combination of lime and agricultural gypsum as amendments in soils for soybean production and found that gypsum was quick to increase the Ca^{2+} contents of the soil, but lime was better able to address conditions that leads to acidity problems. This finding corresponds with Fernando et al., (2007) who tested the nutrient concentration in soil water after adding gypsum, and found that gypsum increased the ionic activities of Ca^{2+} along with sulphate, however, noticeably less Mg was observed in the upper layers when compared to the lower layers in the soil.

While it is not possible to rule out the effect of nutrients (salts) in the irrigation water and the pulp, the effect of these are likely being compounded by the increasing quantities of gypsum added to the pulp (Zoca, & Penn, 2017). This is because the gypsum has a relatively high nutrient content on its own.

Arising from the results of this trial is the understanding that the relatively high EC's recorded across the gypsum blends have implications for the microbial community within the root zone. Adviento-Borbe (2006) studied the effects EC on carbon dioxide production in heavily used soils and found that as the as the EC increased, the microbial activities decreased. This came as a result of the microbes having to adjust to the stress brought on by the salty conditions within the soil. In this instance, Adviento-Borbe (2006) further noted reduced production of N and linked it to the reduced productivity of the nitrifying bacteria. The relatively high EC's are being considered in the context of the less than acceptable pH measurements obtained. Given that the negative impacts of a nutrient such Al is amplified when the pH is low. These conditions could have affected entire cropping cycle.

This situation clearly presents a challenge where irrigation management is concerned (Haj-amor et al., 2016). With this understanding, the relatively flat EC in the peat moss substrate may have been the result of over irrigation, efficient up take by the plants or an undersupply of nutrients. Nevertheless, a combination of efficient nutrient uptake by the plants, an undersupply of nutrients or over irrigation, cannot be ruled out as possible cause of the flat EC's recorded in peat moss.

5.2.4 Physical Characteristics of the Substrate

Bulk density (BD) is an important feature with the soil that influences soil-related functions such as allowing plants or even buildings to stand securely, while allowing the movement of water and air; optimum bulk BD for clayey soils is < 1.10 g/cm^3 (Arshad, Lowery & Grossman, 1997). When BD exceeds 1.47 g/cm^3 the roots of plants in clayey soils may experience difficulty penetrating the soil (Arshad, Lowery & Grossman, 1997). Except for peat moss, the substrates used in this trial all contain at least 35% clay.

When compared to leading substrates such as peat and coir (Table 5), the BD for the pulp and gypsum-pulp substrate are relatively high, nevertheless, it is still within the established safe limits (Arshad, Lowery & Grossman, 1997). Therefore, the growth of plant roots within the medium could be adequately supported. The positive effects of having relatively good bulk densities was reflected in the overall growth and distribution of plant roots throughout the substrates as seen through actual visual inspection. Based on visual observation, the root volume of those plants sampled across all the substrates did not demonstrate significant differences.

With the exception of peat moss, particle density was calculated for all blend used in the LBT trial and they differed when compared to the standard 2.65 g/cm^3 for most mineral soils (Thien & Graveel, 2000). This difference may be based on the fact that the majority content in of each substrate is made up of plant biomass. The standard PD for organic matter is 0.8 g/cm^3 (Peterson, 2020). The pulp only medium is a mixture of 35% clay (King 2017); the woody biomass accounts for the remaining 65%. The 5, 10 and 20% gypsum were added to the same pulp (35% clay, 65% biomass) to make up the gypsum-pulp blends. It is with this understanding that the standards: 2.65 g/cm^3 for mineral and 0.8 g/cm^3 for organic, were not used to determine the porosity, instead, PD's were calculated for each substrate and therefore used in this regard.

Total porosity within soils is comprised of the openings or pore spaces within the soil and shares a very close relationship with BD. If the BD of the substrate increases then porosity is reduced and will typically result in reduced volumes of air and water (Peterson, 2020). Beginning with pulp only, porosity decreased steadily for the compacted and uncompacted blends of gypsum and pulp and this may have been a result of the high BD compared to established substrates, as mentioned earlier.

5.3 Growth Trial

5.3.1 Germination in Autoclaved Pulp Sludge Substrates

From the two attempts to produce suitable seedlings using the autoclaved pulp sludge, it is speculated that the 250 °F temperatures significantly altered the microbial community and the nutrient content within the pulp. It was hypothesized that this was linked to the resulting low germination, stagnated growth in LBT seedlings which did germinated, and production of the orange algae observed in the pulp before the seeds were sown. Anderson & Magdoff (2005) tested the effects of autoclaving on the production of P used for the production of alga in soils and found that there was no change in the rate when compared to non-autoclaved soils. Therefore, autoclaving may not have been responsible for the growth of the orange algae in this trial. On the contrary, however, Serrasolses, Romany, & Khanna (2008), argues that when soils are autoclaved or heated to very high temperatures, organisms in the soil die and the amount of phosphorus in the soil increases, which can result in other negative impacts on growth.

In the second trial, the seeds germinated in all except the pulp only substrate; however, there was clearly a phenomenon having a negative effect on the growth rate of the seedlings which made them unsuitable for further use in the trial. Tests conducted by the NSDA indicated the differences in P contents of autoclaved and non-autoclaved blends used may be seen in Appendices B and F. These were high when compared to the guidelines provided by North Carolina State University (Bailey, et al., 2000). It is important to note that the P content of the non-autoclaved pulp was higher than the P content of the autoclaved pulp. This phenomenon appears to contradict the arguments by Serrasolses, Romany, & Khanna (2008), however, given the comingled nature of the pulp sludge there is the chance that the distribution of P in the substrate samples may have been uneven. Further, a nutrient solution containing 15% phosphorus was added to the soil during the seedling stage.

Contributions to the non-germination and retarded growth of LBT in this non-traditional plant substrate may also have come from the loss of vital soil microbes during the process of autoclaving at 250 °F (Serrasolses et al., 2008). Based on the likely oversupply of P during irrigation and the death of microbes during autoclaving resulting in the releasing additional phosphorus (Serrasolses et al., 2008), the uptake of Zn and Fe may have been significantly impeded (Pitt & Privin, 2020). This condition may have given rise to the non-germination and stagnated growth.

Alternatively, the success achieved in the non-autoclaved pulp may be related to the presence of an active microbial population. The Ca, Mg, Fe and Al within the substrate may have reacted with the excess P at different acid and alkaline levels to produce other forms of phosphates. Considering that P is one of the key nutrients for young seedlings and its likely reaction with these other nutrients, its possible that became unavailable to the plants (Arnall, 2017) and thereby stagnated the growth of the LBT seedlings. In fact, after working with gypsum for more than 20 years, Professor Warren Dick indicated that “it cuts down on phosphorus movement from soils to lakes and stream” suggesting that the P is bound within the soil and becomes less leachable (Penton Business Media, Inc. 2019). This scenario was evidenced in the nutrient analyses provided by NSDA which indicated the P content of the blends decreased as the quantity of gypsum increased. While these considerations remain high possibilities, there may have been other factors at work that contributed to the stunted growth. Such factors should not be isolated as the only issues impacting young seedlings which experienced stunted growth in the non-autoclaved pulp and pulp-gypsum blends of 5, 10 and 20%.

5.3.2 Germination in Non-Autoclaved Pulp Sludge Substrates

It is important to note that while germination percentages were excellent in all groups, survival rate in the pulp only substrate was only 50%; i.e. 10 of the 20 seedlings that germinated. Additionally, the growth of the 10 surviving seedlings was stunted from a very early stage. Based on the 100% germination obtained across substrates, the ATG among the substrate categories were relatively close. While germination was successful in all blends, the number of days to germination was doubled for the LBT seeds. PanAmericanSeed (2019), suggests LBT seeds are to germinate 2-3 days after sowing, however, seeds started germinating in all substrates on the 6th day after sowing. Importantly, however, the ATG across the blends were all within the general time frame for tomatoes as suggested by Isben & Lacey (2019). It is also important to note that the higher BD and the resulting less porous substrate could have affected the survival of seedlings in the pulp only blend (Peterson, 2020).

5.3.3 Stem Diameter

By week 21, LBT plants being grown in the peat moss substrate had a mean stem diameter of 9.38 mm; however, this represented the lowest mean across the substrates. This was contrary to the findings at week 4 when such seedlings were leading in size. Kanai, et al., (2008) reported that when N was deficient in their trial with tomatoes, the diameter of the stem was increased over a two-week period but eventually decreased to sizes below the tomato plants being used as control, due to reduces photosynthesis the leaves of the plants.

However, the phenomenon is seemingly being better explained by findings reported by (Jing, Ruiping, & Hongyi, 2015), who found that as the EC within the nutrient supply increased, the diameter of stems increased. These researchers noted that was true for the plants grown in the pulp only and gypsum-pulp blends (Jing et al., 2015). One can see the EC levels rising as recorded in Figure 5 and the gradual increase in stem size across the pup and pulp-gypsum blends in Figure 8. Nevertheless, the variations observed, cannot be discussed in isolation to the possible effect of other conditions within the substrates or environment outside of the pots and plants.

5.3.4 Plant Height

The findings for plant height also aligned with those reported by Jing et al., (2015), who found that high EC content contributed to the shorter plants with thicker stems, while lower EC resulted in tomato plants which grew faster and taller, but had smaller stems. Clearly, the EC measurements were extremely low for the peat moss solution in all three (3) measurements during the growing period, as opposed to the baseline EC readings. Pulp only recorded the second lowest EC's and shared the height dominance with peat moss, by being the second tallest of the crops. Hence, the height differences observed is likely associated with the differences in EC measurements across the substrate blends.

5.3.5 Leaflet Count

The variation in leaflet count with the LBT crops stood out in the 4-week and 17-week accounts. This may have affected the growth rate, given that the final leaf length was in part determined by the size of each leaflet. Cytokinin (CK) have been known to play important roles in the physiological processes within plants especially in cells, which ultimately influence the development of the plant as a whole (Stirk, & van Staden, 2010). However, an increase in the knowledge base surrounding CK over the past 50 years, there is now an understanding that it may not be singlehandedly influencing development in the plant, but require interaction with other substances (Wybouw & De Rybel, 2019). In an earlier study Shani et. al., (2010) concluded that CK plays a vital role in compound leaves being able to adapt to various environments.

5.4 LBT Harvest

5.4.1 LBT Harvest – Ripe and Green

Tomato plants are grown primarily for their fruits, so the fruit harvest may be used as an indicator of how well the crop performed. In the case of plants grown in 20% gyp, only 1.9 pounds or 33.9% of the overall bearing matured to ripening, while 76.1% remained green at the end of the trial period. The relatively low ripening of the fruits may be associated the high EC levels recorded in the substrates (Figure 5) This is so because high EC levels typically result in less than acceptable amounts of water getting to the fruits and water is essential for the ripening process (Adams, 1991).

5.4.2 Fruit Size

The average fruit sizes were slightly above the 25mm suggested by the developer of the LBT seeds, (PanAmerican Seed, 2019). Fruit size as measured in the tomato crop, is a significant contributor to the overall yield of each tomato plant (Hernández-Bautista et al., 2015). However, the final factors contributing to this overall crop yield lie in the how well the fruit clusters mature and the cell count within each (Ariizumi et al., 2013).

5.4.3 Stem and Root Weight

Jing et al., (2015) concluded that; higher EC levels was a factor that contributed to less than normal growth in the vegetation; however, growth associated with reproduction was improved. These findings support the results obtained from the LBT trial; it is evident that EC levels were higher across the pulp only and gypsum-pulp blends and overall production in these groups were much higher when compared to the total yield obtained from plants grown in peat moss. The EC in peat moss was low compared and the vegetative growth was much greater than all the other blends. In short, plants grown in peat moss grew more vegetative while those in pulp only grew more reproductively.

While its is clear the EC plays a vital role in the developmental processes within plants, the role played by cytokinin, auxins and gibberellins cannot be overlooked. It is also important to understand that while we still do not fully understand the interaction;

there are several other hormones working in concert to generate the characteristic features observed in the LBT plants. One team of researchers proposed that the movement of auxin from one cell to another is impacted by cytokinin (CK) which ultimately contributes to the meristematic region of root systems, (Růžička, et al., 2009). Additionally, another study into the influence of CK on plant growth, confirms that it works with other hormones while significantly impacting growth in the shoot system of plants, with strong influence on how the leaves age (Raines, et al., 2016).

5.5 Chemical Analyses of the LBT Crop

5.5.1 Tissue Analyses

It is well known that N is typically in low supply in most cropping environments and this held true for all substrates used in the LBT trial. Based on the outcome of this crop trial, it is worthwhile noting the possible relationships between the nutrient content of the substrates and the nutrient contents of the plant tissues at 5-weeks old. The closest relationships were seen between Ca and B which recorded high levels in gypsum substrates and high levels in the tissues of plants from the gypsum substrates. Additionally, P was seen to be high in all substrates and it was found also to be high in tissues from all the substrates. Although these relationships may seem to be direct relationships, it might not be the result of one influencing the other, as there are clearly inverse relationships between nutrient concentrations in substrates and the corresponding plant tissues in this trial. The presence of the nutrients in the substrates were compared to the guideline from North Carolina State University (Bailey, et al., 2000), while their presence in the tissue of plants were compared to those suggested by (Hochmuth, et al., 2004).

It is worthy to note that Mg deficiency was observed across the gypsum blends. According to Hochmuth, et al., (2004), the relationship between Mg and Ca is of such that the latter competes with the former during uptake. In this instance, if the Mg supplied is low when compared to the Ca, there is the chance of this competition within the plant (Hochmuth, et al., 2004).

The results of NSDA lab analyses of seedlings indicated the presence of some nutrients in high concentrations while Mg was seen to be deficient in the gypsum blends. This condition may be explained by the immobile, but, very reactive nature of P and Mg. These combine to form rock phosphates and thereby resulting in both nutrients being unavailable to the plant (Arnall, 2017). In addition to competition between Mg and Ca (Hochmuth, et al., 2004), the reactivity of P and Mg (Arnall, 2017) also offers some explanations for the reported Mg deficiencies in the LBT plant tissues.

The presence of K in the tissues of the 5-week old seedlings was deemed optimal. However, at the beginning of the 14^{th} week of life, plants in pulp only, 5,10 and 20% gypsum substrates all began to show signs of burns along the edge of especially older leaves. Burns along the edge of leaves are a classic symptom of K deficiency (McCauley, Jones & Jacobsen, 2009). The supposed K deficiency was most visible in the 5 and 10% gyp blends but was noticeably less in plants growing in the pulp only and 20% gyp substrates.

In addition to the K deficiency in the later stages of the production cycle, symptoms resembling Mg deficiencies were again apparent on the leaves of plants being grown in the pulp only, 5 and 10% gyp. However, unlike the obvious K-like deficiency in the 20% gyp, the Mg-like deficiency was less visible. Of utmost importance are the presence of

Mg and chlorophyll which further influences the production of adenosine triphosphate (ATP) and K for enzyme activation, which bolsters the formation of proteins, while aiding the movement of sugar and photosynthetic processes within the plant (McCauley et al., 2009). Given the awareness of the importance of K and Mg in the metabolic processes of the plants, the visible leaf discolorations support the roles played by these two elements and may be aligned with their deficiencies.

The K and Mg-like deficiencies emerged at the 14-week stage and coincides with the first harvesting period which was followed by periods of heavy blossoming, fruit setting and ripening. While maintaining the prescribed dosage as per the Miracle Gro fertilizer being used, the conditions did not improve, instead, they became more prominent as the plants continued with their natural biological processes. The Mg-like deficiency symptoms became more obvious on plants growing in 20% gyp at week 17. Blossom drop was quite noticeable for a short period following the week 14 harvest, to the extent that some sets were fruitless within a couple of days. Except for blossom drop, none of the K or Mg-like deficiencies were noticeable on the plants growing in the peat moss substrate. While not conclusive, this seem to suggest, that at a minimum, the nutrient supply was relatively good. This then brings the characteristic traits within the substrate material, mode of application, quality and quantity of nutrients applied and the synergistic relationships among the nutrient element in the substrates into question.

K and Mg are classified as mobile nutrients which means they will typically be moved from older leaves on the plant to the fresh leaves growing further up the plants (McCauley et al., 2009). For emphasis, the apparent K and Mg deficiencies were reflected in the older leaves on the plants in the pulp only, 5 and 10% gyp substrates while the Mg deficiencies were present in the pulp only, 5 and 10% gyp blends substrates in week 14, however, this did not become visible until week 17 in the 20% gyp blends. Reflecting on the stress levels at 14-weeks old, they suggest the leaves of the plants were physiologically sound. However, at the end of the trial it became apparent, plants grown in the 20% gyp substrate had more green than ripe fruits, in what seems to be delayed maturity.

The question at the center of the perceived deficiency of K and Mg is linked to understanding the root cause. At this time, it would seem logical to form a correlation between the relatively low stress levels as reflected in the younger leaves with K and Mg-like deficiencies in the older leaves, due to their mobility. Part of the answer to the question seems to lie in the results obtained from the week 14 substrate pH measurements; pulp only, 5,10 and 20% gyp were 4.94, 4.78, 4.8 and 5.2 respectively. Peat on the hand had a Ph of 5.58.

Havlin et. al (2013) indicates that K becomes deficient at pH <5 while symptoms of Mg deficiency will be visible at pH <5.5 among other conditions such as low CEC or BS. Its is also quite suggestive that the perceived K and Mg deficiencies contributed to reduced maturity of fruits on plants growing in the 20% gyp substrates. However, the limitations of determining precise nutrient problems purely based on visual observations are well documented. Nevertheless, the results obtained from growing LBT in the various substrates are useful to the extent that they provide a general direction for further investigation.

5.5.2 Fluorescence (Stress Levels - F_V/F_M) Within the LBT Plants

The optimum fluorescence (F_V/F_M) range that measures the ability of plants to adapt to changes in lighting conditions has been established as 0.79-0.84 (Maxwell & Johnson, 2000). The measurements obtained from samples of the LBT plants growing in peat moss suggest they were well within their comfort zone for this parameter for all three measurements (Figure 18).

The pH measurements obtained in week 14 for pulp only, all the gypsum/pulp substrates and in week 17 for all the gypsum/pulp substrates, were all below the acceptable pH limit for supplying critical nutrient elements. Similarly, the stress levels (fluorescence) obtained for LBT growing in the pulp only and pulp-gypsum blends experienced stress levels which were outside the range established by Maxwell & Johnson (2000). While it seems plausible to limit this occurrence to challenges arising from the less than appreciable pH reading, the LBT crop trial has demonstrated quite s wide array of possible factors which may have had a combined effect on the results obtained.

Nevertheless, the results obtained seemed consistent with the observed physical appearance of the plants at both stages of testing. Given that, while the most recently matured leaves (MRM) were selected for assessing the stress levels yielded relatively good results, the older (lower) leaves on LBT plants growing in the pulp only and gypsum-pulp blends were showing visible signs of being stressed, especially during the collection of the final data sets.

5.5.3 Chlorophyll Content

The measured chlorophyll content appears to correspond with visual observations at weeks 4, 14 and 17. Random seedlings were seen (visually) as being mildly chlorotic in the 4^{th} week. The chlorophyll content of the MRM leaves at week 17 was visibly greater than in the older leaves on the lower portion of the plants especially across the pulp only and gypsum-pulp blends and this was reflected in the SPAD values. This phenomenon is being considered in light of the existing knowledge that low pH were recorded in week-14 across the pulp only substrates, and week-17 across the gypsum-pulp blends, might have been contributing the reduced availability of Mg, N, P K, and Ca deficiency while promoting Mn toxicity (Havlin et al., 2013).

This low pH condition typically leads to the mobile nutrients (P, Mg, N, K, Mo and Cl) being moved from older leaves to the newer leaves due to lower supply in the substrate (McCauley et al., 2009). This resulted in the older leaves dying before they could be replenished by the nutrient supply in the substrate. While the mobile nutrients may have been moving around, it is worthy to note that the leaves on the plants growing in the pulp only and gypsum-pulp blends had visibly darker green when compared to those growing in the peat only substrate. However, the leaves on plants in peat moss did not die back. The chlorophyll values obtained in week 17 also reflect the continued downward trend in the pulp only, 5, 10 and 20% gyp substrates when compared to the two earlier measurements.

5.5.4 Anthocyanin Content of Tomato Plant Leaves

It is well known that tomato is a perishable produce. Anthocyanin has the potential to reduce the likelihood of rapid spoilage (Petric, Kiferle, Perata, & Gonzali, 2018). However, when its presence become evident in the vegetative portions of the plant, it typically signals the onset or presence of stresses (Hodges & Nozzolillo, 1995) arising from reduced P availability accentuated by a purple colour in the leaves of plants which would otherwise have green leaves (Bhattacharya, 2019). While this purple condition was not readily visible to the naked eye during the cultivation of the LBT, the evidence seem to coincide with conditions with that, the availability of some nutrients is determined by the prevailing pH of the substrates.

It was found that the pH for pulp only, 5 and 10% gyp were 4.94, 4.78 and 4.8 respectively. Havlin et al., (2013) suggests phosphorus become deficient at pH <5.0. Hence, the spike in anthocyanin content in week 14 for plants growing in pulp only, 5 and 10% gyp substrates may be related to the pH as recorded in Figure 2. These results do not seem to explain the degradation which persisted in the plants from week 14 onwards, and the subsequent drop in the anthocyanin content in the week 17. However, without any empirical data, it may be helpful to consider that by week 17, the plants were seemingly on the lower end of their production cycle, which means, demand for certain nutrients were not as high as in the peak production period leading up to and during week 14.

5.6 LBT Juice Analyses

According to Herzog (2008), the safe ~Ph level for canning tomatoes without additional acid, is a high of 4.6. Except for tomatoes obtained from plants grown in 5%

gyp – which was slightly above 4.6, the juice from peat moss, pulp only 10 and 20% gyp were all below this pH threshold. Stevens, Kader, & Albright-Houlton, (1977) argue that the taste and flavour of tomatoes are closely linked to the total soluble salts (TSS) as represented by the Brix %. They suggest these determine the sugar content or sweetness of the fruit. Of importance however, are the arguments put forth by Mitchell, Shennan, & Grattan (1991) and Cornish, (1992) that the elevated EC of the nutrient-substrate solution significantly reduce the amount of water that gets to the tomato fruit and there by its taste or sugar content is improved. This concept seemed to have held up in the case of this LBT trial, as the Brix% of the fruits obtained from the 20% gyp substrate was the highest (6.9), keep in mind, this substrate also recorded the highest EC level (Figure 5). On the other hand, fruits produced in peat moss which recorded almost flat EC's yielded the lowest Brix% (6.2).

Chapter 6: Conclusion

The LBT plant used for this experimental growth trial included the use of one leading and four (4) novel blends, namely: (1) peat moss only, (2) pulp only, (3) 5% gyp, (4) 10% gyp, (5) 20% gyp. The main trial was conducted over a period of 21 weeks with the goals of:

a. Optimize a plant growth medium using paper mill (cellulose-based) pulp sludge and waste gypsum (high mineral fiber board).
b. Carry out plant growth trials for comparative analyses of physical and chemical characteristics of each substrate and biometric parameters using Little Bing tomato as the indicator species.
c. Offer recommendations in relation to the viability or suitability of the growth medium as a whole.

Chemical features of the substrates assessed included: EC, pH, salinity, nutrient content. Additionally, the physical features assessed included: water retention capacity, bulk density, particle density and porosity.

Plant related components were subjected to, leaflet count, ripe-green yields, total yield. Measurements included growth rate, stem diameter, fruit size, plant height, fluorescence (stress levels), anthocyanin content, chlorophyll content, fresh and dry shoot weight, fresh and dry root weights. The juice of the tomato fruits was assessed for EC, pH, salinity and TSS (Sugar/Brix %).

The LBT was used in a bench scale experimental growth trial with very minimal modification to the raw material used. This was done on the basis of allowing the ‘new’ media mixes to demonstrate their ability to foster the growth and development of the LBT crop – then use the data to help inform next steps. This was based on using them in the typical setting with standard nutrient applications. While this is a baseline study and cannot be used as the final determinant of whether the substrates can be successfully used in greenhouse crop production; it has provided a platform that should be considered for future research.

Having completed the above-mentioned measurements and assessments, the following conclusions are being made:

6.1 Optimizing the Waste Pulp Sludge and Drywall.

- Both pulp sludge and gypsum wastes presented their own unique set of challenges in the process of getting them to a state of readiness for the actual trial. These included conducting laboratory analyses, physically breaking the drywall board, assorting and combining the materials in the afore mentioned percentages. However, this process was accomplished relatively smoothly and within the limits of available resources.
- The 1:1 mix of fresh non-autoclaved pulp only substrate seem to be limited in its ability to foster the sustained growth of germinated seedling to the point where they can be transplanted. This was evident in the 100% germination achieved. However, survival rate was cut in half and the growth of the remaining 50% was stunted.
- Autoclaved pulp sludge is seemingly not suitable for germination or the accommodation of seedlings which germinated in it, to the point of being transplanted to grow out pots. This was evident in the preliminary trials which yielded 70 and 0% germination in successive trials.

- The gyp substrates demonstrated their ability to foster reproductive growth as opposed to vegetative growth. This was due to the slightly high EC levels observed as the quantity of gypsum increased. This is a highly desirable trait to be optimized in so much that the effects on the physiological processes within the plants are reduced while maximizing the reproductive processes.
- Both gypsum and the pulp sludge revealed their nutrient compositions in unique ways. This had implications for the nutrient program and will require special attention be given to the formulations and the timing of these application to the medium in future trials.

6.2 The Growth Trials

- Peat was an under-performer in this setting, in terms of its overall productivity and this may have been due to leaching caused by over irrigation or an under supply of nutrients at crucial points when the plants demand was highest. Extremely low EC's were recorded over the life of the crop and this may have influenced extensive growth of the shoot system at the expense of its reproductive capacity.
- Plants grown across all the substrate blends, exceeded the seed manufacturer's (PanAmerican Seeds) height specifications. While this may be related to the combination of EC and other factors such as lighting restraints, the fact that plants grew extensively, may be an indicator of the possibility of the blends supporting the cultivation of crops when conditions are 'fully' optimized.

- The pH of the pulp and gypsum-pulp blends was unstable over the 21-week production cycle. This may have affected the availability of critical nutrients during the life of the LBT crop. Observations made over the course of the cropping cycle captured what appeared to have been symptoms of nutrient deficiencies at critical points that aligned with the pH readings at the same stage.
- The nutrients added during the irrigation cycles may have compounded the nutrient conditions within the pulp-gypsum blends. The extent to which toxic conditions could have been encouraged may have been exacerbated by the application of the commercially sourced nutrients. The NSDA lab analysis shows there were higher than acceptable levels in most plant tissues.
- Microbes within the pulp sludge may have been killed during the autoclaving process, and thereby contributed to the lack of germination and the poor growth rate in those that germinated.
- The size of the fruits was slightly above the manufacturer's specification for plants across all substrate blends. While plants may have had to work harder to achieve this, it again underscores the fact that a combination of gypsum and pulp or pulp on its own may be used in cold weather greenhouse tomato production.
- The juice obtained from the LBT fruits underscored the overall performance of the crops. The EC, pH, salinity and TSS (Sugar/Brix %) were all relatively well withing the limits of good-tasting tomatoes. This

means they would have been perfectly suitable for market. Importantly, except for fruits obtained from the 5% gyp, the pH for all were in the acceptable range to be processed for canning.

6.3 Recommendations

The non-autoclaved pulp in addition to gypsum crushed with its paper lining are being recommended for further trials as a plant substrate in different states of decomposition and combinations that will allow for the most seamless optimization. This could include not exceeding a 10% gypsum-pulp mix. The results show that while the plants in the 20% gyp survived and produced fruits, the ripening was significantly delayed. Clearly, this is not a feature that would be desired generally for intensive greenhouse production with a view to increase agricultural productivity toward meeting population increases to come. Other key aspects will need special attention.

6.3.1 Managing pH

While gypsum has some benefits for managing the alkalinity and acidity in the lower levels of the substrate, it is apparent that a more reliable means of stabilizing or raising the pH will become necessary for future crop trials. This could be limited to the application of traditional lime. Importantly, the fall in the pH after gypsum was added to the pulp sludge should be investigated further, as part of the decision making for its control.

6.3.2 Nutrient Supply

Further investigations could simulate this LBT trial along with trials that seek to optimise the chemical, physical and environmental conditions. This would be of particular importance for assessing the reactivity among Ca, Fe, Al, Mg and P in the Pulp and pulp-gypsum substrates. It could also be used as a guide for developing nutrition programs throughout the cropping cycle. This will need to be aligned with a robust irrigation plan that is compatible with the way soluble salts dissolve from the gypsum in addition to the nutrients being supplied. Clearly, there were higher than normal quantities of some nutrients present in plant tissues at the seedling stage.

6.4 Limitations of the Research

The nutrition program could have been formulated to better synchronise with the conditions within the substrates. This could have fostered a clearer understanding of the chemical processes within the substrates and thus better inform the next steps.

Although most of the plants appeared healthy from visual observation at the seedling and early post transplantation phase, more frequent pH measurements could have been taken. This could have provided vital data for monitoring during the cropping cycle.

Nutrient formulations were prepared and administered through watering can by hand application. This could have affected the volume and distribution of nutrients and water received by each plant.

Plants were grown in a setting that had other unrelated bench scale crop trial underway. The floor was often wet and contained the residue of substances applied to those plants in solution. These could have affected the LBT plants.

The blends of gypsum and pulp were blended by hand. This could have affected the consistency of their distribution in the individual pots used particularly at the grow out stage.

6.5 Future Research

Given that the pulp from PHP was used as a mix of old and new pulp; it would be in order to conduct future trials which include fresh pulp only, old and fresh pulp and old weathered pulp. These would be mixed with drywall bord at the desired rates.

6.6 Closing Thought

There were potentially adverse chemical and physical conditions within the substrates at the seedling and grow-out phases of the LBT crop trial. The overall performance is an indication of: (1) the resilience of the LBT variety and (2) the substrates ability to sustain the lives of the crops for a period of 21 weeks. Therefore, these findings are a testament that with further research, there is the possibility that they could lead to the development of a viable greenhouse growth medium that helps to close the loop on waste gypsum from CG and pulp sludge from PHP. Arising from the results of this trial, it is anticipated that PHP will consider a scaled-up version of this trial to be undertaken in the short term.

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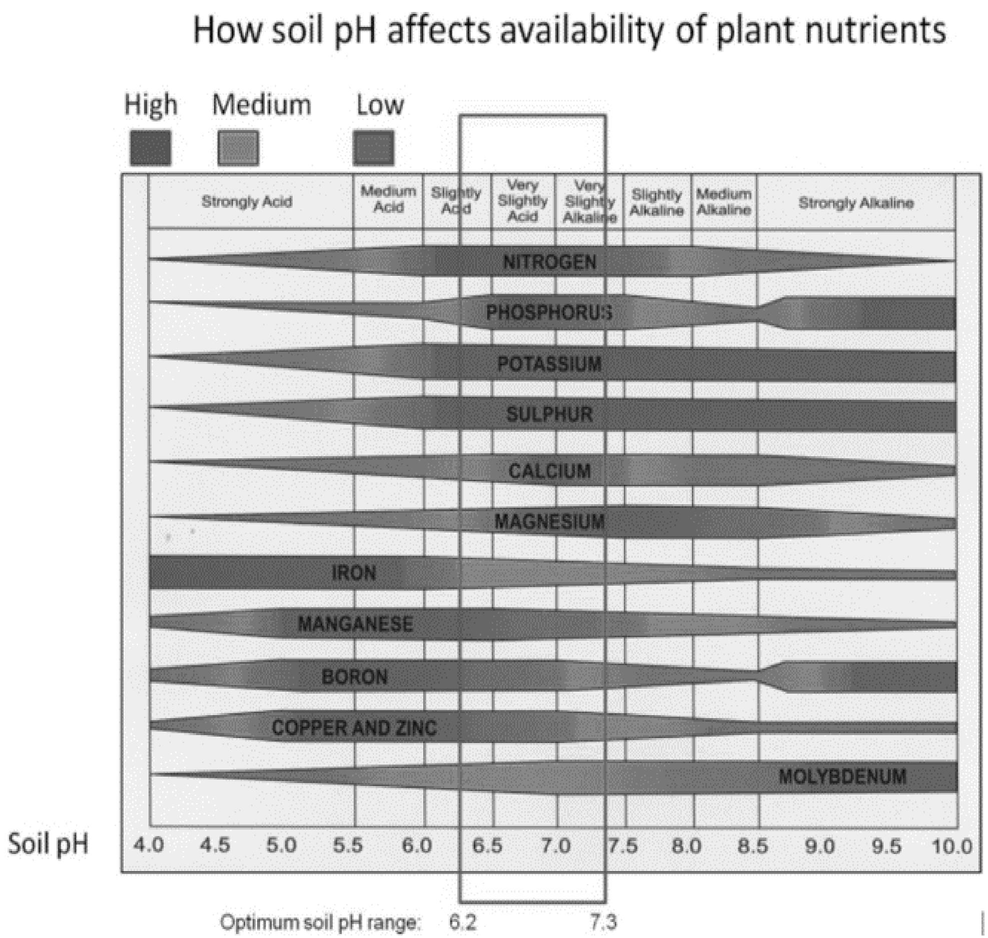
APPENDIX A: Optimum pH range for the nutrient uptake by plants



(University of California, 2019)

APPENDIX B: Ash and dry matter content of PHP's pulp sludge

NOVA SCOTIA

Feed Test Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C19913
Order ID: 1801472
Samples Reported: 06-Mar-18
Samples Received: 05-Mar-18
# of Samples Received: 1

SIMMS, KEVOY
36 KELLY STREET

HALIFAX, NS
B3N 1W2

Lab #	1801472-001							
Sample ID	PHP - PULP #1							
Feed Type	Unknown							
Parameter	As Fed	Dry	As Fed	Dry	As Fed	Dry	As Fed	Dry
Dry Matter (%)	27.81							
Ash (%)	5.78	20.80						

APPENDIX C: Nutrient content of PHP pulp sludge.

NOVA SCOTIA

Greenhouse Soil Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

SIMMS, KEVOY
36 KELLY STREET

HALIFAX, NS
B3N 1W2

Client ID: C19913
Order ID: 1801471
Samples Reported: 09-Mar-18
Samples Received: 05-Mar-18
# of Samples Received: 1

Lab #	1801471-001							
Client Sample ID	PHP - PULP #1							
Registration #								
Sample Type	Unknown							
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Conductivity (mmhos)	2.78	0.00						
pH (pH Units)	5.74	0.01						
Nitrate-N (ppm)	116.00	0.10						
Calcium (ppm)	40.40	0.20						
Potassium (ppm)	48.77	1.50						
Magnesium (ppm)	14.10	0.20						
Phosphorus (ppm)	174.37	0.10						
Sodium (ppm)	257.22	1.50						
Sulphate (ppm)	474.72	0.50						
Chloride (ppm)	29	10						
Aluminum (ppm)	6.13	0.05						
Boron (ppm)	0.42	0.10						
Copper (ppm)	0.06	0.05						
Iron (ppm)	0.69	0.05						
Manganese (ppm)	7.90	0.10						
Zinc (ppm)	0.19	0.02						

APPENDIX D: EC, pH and nutrient content of pulp only, 5, 10 and 20% gyp

NOVA SCOTIA

Greenhouse Soil Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1809683
Samples Reported: 30-Oct-18
Samples Received: 26-Oct-18
# of Samples Received: 4

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1809683-001		1809683-002		1809683-003		1809683-004	
Client Sample ID	A PHP - CBT 0%		B PHP - CBT 5%		C PHP - CBT 10%		D PHP - CBT 20%	
Registration #								
Sample Type	Unknown		Unknown		Unknown		Unknown	
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Conductivity (mmhos)	2.50	0.00	6.47	0.00	6.39	0.00	6.69	0.00
pH (pH Units)	7.99	0.01	7.99	0.01	8.00	0.01	7.98	0.01
Nitrate-N (ppm)	38.70	0.10	3.72	0.10	6.87	0.10	5.42	0.10
Calcium (ppm)	18.54	0.20	407.79	0.20	512.61	0.20	519.08	0.20
Potassium (ppm)	24.11	1.50	49.54	1.50	60.20	1.50	78.26	1.50
Magnesium (ppm)	4.43	0.20	16.22	0.20	16.54	0.20	26.44	0.20
Phosphorus (ppm)	71.75	0.10	15.43	0.10	14.93	0.10	22.14	0.10
Sodium (ppm)	104.66	1.50	153.70	1.50	181.35	1.50	193.07	1.50
Sulphate (ppm)	577.38	0.50	2593.66	0.50	3055.33	0.50	3120.35	0.50
Chloride (ppm)	38	10	38	10	48	10	95	10
Aluminum (ppm)	5.55	0.05	2.08	0.05	0.84	0.05	0.43	0.05
Boron (ppm)	ND	0.10	0.86	0.10	3.16	0.10	11.18	0.10
Copper (ppm)	0.12	0.05	0.08	0.05	0.07	0.05	0.07	0.05
Iron (ppm)	1.50	0.05	0.65	0.05	0.59	0.05	0.61	0.05
Manganese (ppm)	2.88	0.10	3.00	0.10	3.72	0.10	4.68	0.10
Zinc (ppm)	0.20	0.02	0.14	0.02	0.10	0.02	0.11	0.02

APPENDIX E: Ash and dry matter content of pulp only, 5, 10 and 20% gyp..

Feed Test Report

NOVA SCOTIA

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1809684
Samples Reported: 30-Oct-18
Samples Received: 26-Oct-18
# of Samples Received: 4

DALHOUSIE UNIVERSITY
DEPT. OF PROCESS ENGINEERING, ROOM 215
1360 BARRINGTON STREET
HALIFAX, NS
B3J1Z1

Lab #	1809684-001		1809684-002		1809684-003		1809684-004	
Sample ID	A PHP-CBT 0%		B PHP-CBT 5%		C PHP-CBT 10%		D PHP-CBT 20%	
Feed Type	Unknown		Unknown		Unknown		Unknown	
Parameter	As Fed	Dry	As Fed	Dry	As Fed	Dry	As Fed	Dry
Dry Matter (%)	43.81		40.62		40.46		50.09	
Ash (%)	9.84	22.47	12.52	30.83	16.46	40.68	24.16	48.23

APPENDIX F: Nutrient, pH and EC content of pulp only, 5, 10 and 20% gyp.

NOVA SCOTIA

Greenhouse Soil Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1900547
Samples Reported: 29-Jan-19
Samples Received: 28-Jan-19
# of Samples Received: 4

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1900547-001		1900547-002		1900547-003		1900547-004	
Client Sample ID	GP - 5%		GP - 10%		GP - 20%		GP - 0%	
Registration #								
Sample Type	Unknown		Unknown		Unknown		Unknown	
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Conductivity (mmhos)	4.36	0.00	3.65	0.00	4.36	0.00	1.91	0.00
pH (pH Units)	5.66	0.01	5.70	0.01	5.77	0.01	6.13	0.01
Nitrate-N (ppm)	0.88	0.10	0.92	0.10	1.06	0.10	0.86	0.10
Calcium (ppm)	610.96	0.20	637.10	0.20	673.98	0.20	20.47	0.20
Potassium (ppm)	79.83	1.50	89.61	1.50	108.00	1.50	45.95	1.50
Magnesium (ppm)	52.94	0.20	53.28	0.20	55.05	0.20	7.92	0.20
Phosphorus (ppm)	64.45	0.10	58.33	0.10	42.57	0.10	108.58	0.10
Sodium (ppm)	234.97	1.50	240.50	1.50	246.31	1.50	153.46	1.50
Sulphate (ppm)	2351.24	0.50	2321.01	0.50	2213.64	0.50	470.82	0.50
Chloride (ppm)	19	10	19	10	19	10	19	10
Aluminum (ppm)	0.29	0.05	0.42	0.05	0.15	0.05	4.73	0.05
Boron (ppm)	2.65	0.10	5.52	0.10	15.29	0.10	0.23	0.10
Copper (ppm)	ND	0.05	ND	0.05	ND	0.05	ND	0.05
Iron (ppm)	0.65	0.05	0.71	0.05	0.59	0.05	1.23	0.05
Manganese (ppm)	26.03	0.10	26.12	0.10	26.34	0.10	4.70	0.10
Zinc (ppm)	0.32	0.02	0.31	0.02	0.29	0.02	0.42	0.02

APPENDIX G: EC, pH and nutrient content of gypsum and peat moss.

NOVA SCOTIA

Greenhouse Soil Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1901694
Samples Reported: 26-Mar-19
Samples Received: 25-Mar-19
# of Samples Received: 2

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1901694-001		1901694-002					
Client Sample ID	PROMIX		GYPSUM					
Registration #								
Sample Type	Unknown		Unknown					
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Conductivity (mmhos)	1.00	0.00	3.35	0.00				
pH (pH Units)	5.78	0.01	8.58	0.01				
Nitrate-N (ppm)	28.55	0.10	1291.00	0.10				
Calcium (ppm)	85.11	0.20	679.06	0.20				
Potassium (ppm)	96.65	1.50	311.86	1.50				
Magnesium (ppm)	21.72	0.20	11.68	0.20				
Phosphorus (ppm)	47.46	0.10	0.58	0.10				
Sodium (ppm)	18.43	1.50	63.40	1.50				
Sulphate (ppm)	291.11	0.50	1783.16	0.50				
Chloride (ppm)	10	10	29	10				
Aluminum (ppm)	0.19	0.05	0.16	0.05				
Boron (ppm)	ND	0.10	139.60	0.10				
Copper (ppm)	ND	0.05	ND	0.05				
Iron (ppm)	0.58	0.05	ND	0.05				
Manganese (ppm)	0.14	0.10	0.41	0.10				
Zinc (ppm)	0.48	0.02	ND	0.02				

APPENDIX H: Microbiology of PHP's pulp sludge cake.

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 18X344313
PROJECT:

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: PORT HAWKESBURY PAPER LP
ATTENTION TO: Bruce Embree
SAMPLING SITE:
SAMPLED BY:

Microbiology - Sludge, Soil, Compost (Montreal)

DATE RECEIVED: 2018-05-30
DATE REPORTED: 2018-06-07

			SAMPLE DESCRIPTION:	Sludge Cake
			SAMPLE TYPE:	Sludge
			DATE SAMPLED:	2018-05-29
Parameter	Unit	G / S	RDL	9281354
Total coliforms - Solid*	CFU/g (d.w.)		100	21000
Fecal coliforms- Solid*	CFU/g (d.w.)		100	3700
E.coli - Solid	CFU/g (d.w.)		100	<340
Temperature upon receipt	°C		N/A	15.6

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

9281354 The sample temperature was over 12°C upon receipt.
Analysis performed at AGAT Montreal's laboratory.
The laboratory is not accredited for the parameters with an asterisk.
Results are given in Colony Forming Units (CFU) per gram on a dry weight basis. The RDL is given in Colony Forming Units (CFU) per gram on a wet weight basis.

APPENDIX I: Metals available in PHP's sludge cake

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 18X344313
PROJECT:

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: PORT HAWKESBURY PAPER LP | **ATTENTION TO: Bruce Embree**
SAMPLING SITE: | **SAMPLED BY:**

Available Metals in Soil

DATE RECEIVED: 2018-05-30 | **DATE REPORTED: 2018-06-07**

			SAMPLE DESCRIPTION:	Sludge Cake
			SAMPLE TYPE:	Sludge
			DATE SAMPLED:	2018-05-29
Parameter	**Unit**	**G / S**	**RDL**	**8281354**
Aluminum	mg/kg		10	631
Antimony	mg/kg		1	<1
Arsenic	mg/kg		1	2
Barium	mg/kg		5	41
Beryllium	mg/kg		2	<2
Boron	mg/kg		2	6
Cadmium	mg/kg		0.3	<0.3
Chromium	mg/kg		2	3
Cobalt	mg/kg		1	<1
Copper	mg/kg		2	3
Iron	mg/kg		50	95
Lead	mg/kg		0.5	2.2
Lithium	mg/kg		5	<5
Manganese	mg/kg		2	407
Molybdenum	mg/kg		2	<2
Nickel	mg/kg		2	<2
Selenium	mg/kg		1	<1
Silver	mg/kg		0.5	<0.5
Strontium	mg/kg		5	8
Thallium	mg/kg		0.1	<0.1
Tin	mg/kg		2	7
Uranium	mg/kg		0.1	0.4
Vanadium	mg/kg		2	4
Zinc	mg/kg		5	7

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard
8281354 Results are based on the dry weight of the sample.

APPENDIX J: LBT plant tissue analysis at five weeks old as grown in substrates.

NOVA SCOTIA

Tissue Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1901693
Samples Reported: 27-Mar-19
Samples Received: 25-Mar-19
# of Samples Received: 5

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1901693-001		1901693-002		1901693-003		1901693-004	
Client Sample ID	PULP ONLY T1		5% GYP T2		10% GYP T3		20% GYP T4	
Registration #								
Sample Type	Unknown		Unknown		Unknown		Unknown	
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Nitrogen (%)	3.69	0.01	2.94	0.01	3.58	0.01	3.44	0.01
Calcium (%)	1.155	0.002	3.130	0.002	2.863	0.002	2.748	0.002
Potassium (%)	4.349	0.015	3.907	0.015	4.771	0.015	4.231	0.015
Magnesium (%)	0.410	0.002	0.152	0.002	0.124	0.002	0.140	0.002
Phosphorus (%)	0.899	0.001	0.977	0.001	0.975	0.001	0.986	0.001
Sodium (%)	0.724	0.015	0.236	0.015	0.244	0.015	0.273	0.015
Boron (ppm)	41.09	10.00	57.55	10.00	59.15	10.00	64.72	10.00
Copper (ppm)	13.57	5.00	12.40	5.00	15.25	5.00	15.72	5.00
Iron (ppm)	139.30	5.00	95.45	5.00	98.80	5.00	97.27	5.00
Manganese (ppm)	1701.24	10.00	210.04	10.00	202.23	10.00	153.46	10.00
Zinc (ppm)	91.23	2.00	98.71	2.00	117.48	2.00	116.56	2.00

APPENDIX K: LBT plant tissue analysis at five weeks old as grown in peat moss.

NOVA SCOTIA

Tissue Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1901693
Samples Reported: 27-Mar-19
Samples Received: 25-Mar-19
# of Samples Received: 5

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1901693-005							
Client Sample ID	PROMIX T5							
Registration #								
Sample Type	Unknown							
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Nitrogen (%)	4.12	0.01						
Calcium (%)	1.735	0.002						
Potassium (%)	4.300	0.015						
Magnesium (%)	0.413	0.002						
Phosphorus (%)	1.190	0.001						
Sodium (%)	0.405	0.015						
Boron (ppm)	24.81	10.00						
Copper (ppm)	9.16	5.00						
Iron (ppm)	105.01	5.00						
Manganese (ppm)	102.38	10.00						
Zinc (ppm)	79.66	2.00						

APPENDIX L: Tissue analysis LBT grown in peat, pulp, 5 and 10% gyp.

Tissue Report

NOVA SCOTIA

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1903883
Samples Reported: 10-Jun-19
Samples Received: 04-Jun-19
# of Samples Received: 5

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1903883-001		1903883-002		1903883-003		1903883-004	
Client Sample ID	PRO		PULP		5% GYP		10% GYP	
Registration #								
Sample Type	Tomato		Tomato		Tomato		Tomato	
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Nitrogen (%)	2.36	0.02	2.46	0.02	2.19	0.02	2.13	0.02
Calcium (%)	0.104	0.002	0.064	0.002	0.093	0.002	0.110	0.002
Potassium (%)	3.606	0.015	2.888	0.015	2.837	0.015	2.724	0.015
Magnesium (%)	0.147	0.002	0.115	0.002	0.103	0.002	0.108	0.002
Phosphorus (%)	0.523	0.001	0.515	0.001	0.488	0.001	0.470	0.001
Sodium (%)	0.051	0.015	0.093	0.015	0.052	0.015	0.046	0.015
Boron (ppm)	14.63	10.00	12.76	10.00	14.05	10.00	14.38	10.00
Copper (ppm)	6.96	5.00	ND	5.00	6.18	5.00	6.60	5.00
Iron (ppm)	59.13	5.00	41.14	5.00	42.35	5.00	42.80	5.00
Manganese (ppm)	11.25	10.00	93.77	10.00	52.69	10.00	46.04	10.00
Zinc (ppm)	29.42	2.00	21.04	2.00	26.38	2.00	25.31	2.00

Comments: 1903883-001: Please see report for Order ID 1903884 for pH results.

APPENDIX M: LBT fruit tissue analysis as grown in 20% gypsum-pulp substrate.

NOVA SCOTIA

Tissue Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

Client ID: C10166
Order ID: 1903883
Samples Reported: 10-Jun-19
Samples Received: 04-Jun-19
# of Samples Received: 5

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Lab #	1903883-005							
Client Sample ID	20% GYP							
Registration #								
Sample Type	Tomato							
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit
Nitrogen (%)	1.98	0.02						
Calcium (%)	0.142	0.002						
Potassium (%)	2.584	0.015						
Magnesium (%)	0.109	0.002						
Phosphorus (%)	0.450	0.001						
Sodium (%)	0.053	0.015						
Boron (ppm)	15.48	10.00						
Copper (ppm)	7.04	5.00						
Iron (ppm)	41.22	5.00						
Manganese (ppm)	39.91	10.00						
Zinc (ppm)	23.65	2.00						

APPENDIX N: pH of LBT juice produced in peat, pulp, 5 and 10% gyp.

NOVA SCOTIA

Feed Test Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Client ID: C10166
Order ID: 1903884
Samples Reported: 05-Jun-19
Samples Received: 04-Jun-19
# of Samples Received: 5

Lab #	1903884-001		1903884-002		1903884-003		1903884-004	
Sample ID	PRO		PULP		5% GYP		10% GYP	
Feed Type	Unknown		Unknown		Unknown		Unknown	
Parameter	As Fed	Dry	As Fed	Dry	As Fed	Dry	As Fed	Dry
pH (pH Units)	4.4		4.5		4.4		4.4	

Comments: 1903884-001: Please see report for Order ID 1903883 for the remainder of test results.

APPENDIX O: pH of LBT juice as grown in 20% gyp substrate.

NOVA SCOTIA

Feed Test Report

Department of Agriculture
Laboratory Services
PO Box 890
Harlow Institute
Truro, NS B2N 5G6

http://www.gov.ns.ca/agri/qe/labserv/
Tel: 902-893-6565
Fax: 902-893-4193

DALHOUSIE UNIVERSITY
PO BOX 15000
6299 SOUTH STREET
HALIFAX, NS
B3H 4R2

Client ID: C10166
Order ID: 1903884
Samples Reported: 05-Jun-19
Samples Received: 04-Jun-19
# of Samples Received: 5

Lab #	1903884-005							
Sample ID	20% GYP							
Feed Type	Unknown							
Parameter	As Fed	Dry	As Fed	Dry	As Fed	Dry	As Fed	Dry
pH (pH Units)	4.4							

APPENDIX P: Volatile organic compounds present in PHP's pulp sludge cake.

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 18X353509

PROJECT:

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: PORT HAWKESBURY PAPER LP

SAMPLING SITE:

ATTENTION TO: Bruce Embree

SAMPLED BY:

Volatile Organic Compounds in Soil - Field Preserved

DATE RECEIVED: 2018-06-21

DATE REPORTED: 2018-06-29

			SAMPLE DESCRIPTION:	SLUDGE
			SAMPLE TYPE:	Soil
			DATE SAMPLED:	2018-06-20
Parameter	Unit	G / S	RDL	9349170
Chloromethane	ug/kg		100	<100
Vinyl Chloride	ug/kg		20	<20
Bromomethane	ug/kg		50	<50
Chloroethane	ug/kg		100	<100
Trichlorofluoromethane (FREON 11)	ug/kg		100	<100
Acetone	ug/kg		500	<500
1,1-Dichloroethylene	ug/kg		50	<50
Methylene Chloride (Dichloromethane)	ug/kg		100	<100
trans-1,2-Dichloroethylene	ug/kg		80	<80
1,1-Dichloroethane	ug/kg		100	<100
cis-1,2-Dichloroethylene	ug/kg		100	<100
Chloroform	ug/kg		50	<50
1,2-Dichloroethane	ug/kg		100	<100
1,1,1-Trichloroethane	ug/kg		30	<30
Carbon Tetrachloride	ug/kg		50	<50
Benzene	ug/kg		6.8	<6.8
1,2-Dichloropropane	ug/kg		50	<50
Trichloroethylene	ug/kg		10	<10
Bromodichloromethane	ug/kg		100	<100
cis-1,3-Dichloropropene	ug/kg		100	<100
trans-1,3-Dichloropropene	ug/kg		100	<100
1,1,2-Trichloroethane	ug/kg		30	<30
Toluene	ug/kg		80	<80
2-Hexanone	ug/kg		500	<500
Dibromochloromethane	ug/kg		100	<100
1,2-Dibromoethane	ug/kg		50	<50
Tetrachloroethylene	ug/kg		100	<100
1,1,1,2-Tetrachloroethane	µg/kg		100	<100
Chlorobenzene	ug/kg		50	<50

APPENDIX Q: Metals content of gypsum from Cabot Gypsum.

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 19X521211
PROJECT: Pulp Research

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: DALHOUSIE UNIVERSITY - FINANCIAL SERVICES
ATTENTION TO: Dr. Michelle Adams
SAMPLING SITE:
SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2019-09-23
DATE REPORTED: 2019-09-30

			SAMPLE DESCRIPTION:	GYP 001
			SAMPLE TYPE:	Other
			DATE SAMPLED:	2019-09-23
Parameter	Unit	G / S	RDL	553211
Aluminum	mg/kg		10	515
Antimony	mg/kg		1	<1
Arsenic	mg/kg		1	4
Barium	mg/kg		5	13
Beryllium	mg/kg		2	<2
Boron	mg/kg		2	173
Cadmium	mg/kg		0.3	<0.3
Chromium	mg/kg		2	<2
Cobalt	mg/kg		1	<1
Copper	mg/kg		2	<2
Iron	mg/kg		50	812
Lead	mg/kg		0.5	2.7
Lithium	mg/kg		5	<5
Manganese	mg/kg		2	53
Molybdenum	mg/kg		2	<2
Nickel	mg/kg		2	7
Selenium	mg/kg		1	<1
Silver	mg/kg		0.5	<0.5
Strontium	mg/kg		5	681
Thallium	mg/kg		0.1	<0.1
Tin	mg/kg		2	3
Uranium	mg/kg		0.1	0.4
Vanadium	mg/kg		2	6
Zinc	mg/kg		5	8

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard
553211 Results are based on the dry weight of the sample.
Analysis performed at AGAT Halifax (unless marked by *)