THESIS

EVALUATION OF COW PEAT AS A PLANT GROWTH MEDIA

Submitted by

Amrish Nath Thena Surendran

Department of Civil and Environmental Engineering

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Master's Committee:

Advisor: Sybil Sharvelle
Co-Advisor: Kenneth Carlson

Yaling Qian

ABSTRACT

EVALUATION OF COW PEAT AS A PLANT GROWTH MEDIA

Almost 63% of non-CO_2 greenhouse gases, mostly methane and nitrous oxide, are produced by the agricultural industry. As Livestock waste lagoons are designed to prevent the nutrient transport and treat manure, they are major contributors to the release of these non-CO_2 greenhouse gases. They have to be controlled and one such way is to harness these gases by implementing anaerobic digestion. Anaerobic digestion of livestock waste has shown very good potential but, handling of digested solid end products require extensive management. One potential option is to recover fiber from the solid digestate to make a cow peat plant growth material.

Peatlands are one of the most important natural ecosystems in the world which have key values for biodiversity conservation, climate regulation and support welfare, water regulation in drylands, acts as an enormous carbon sink and also an agricultural land. But overexploitation of peatlands has led to adverse effects on the environment. Peat mosses have well defined lignified cell structure as a soil material which makes them perfect media for plant growth. All these degradations and its effects have made peat extraction unsustainable and so search for alternatives have begun over the last decade. The fiber components of digested dairy manure (Cow Peat) have been evaluated by researchers as a suitable substitute for peat moss along with many other products such as biochar, rice husk, wheat straw, sewage waste, potato waste etc. Results have shown that the cow peat has similar physicochemical properties to peat moss and so, they have been widely used in the horticulture and floriculture industries as a replacement for peat moss.

In this study, we assessed the potential to recover cow peat from a novel multi-stage anaerobic digester that processes high solids content manure. Edible crops were grown in the digestate and cow peat for the first time, as they have been already proven in the other industry such as the growth of perennial plants, strawberries, bedding plants etc. The study has been carried out in two trails without nutrient amendment. The first experiment was conducted with bean plants and 6 soil mixes with digested manure. The performance was compared with commercially available soil mixes including peat moss. The best performing soil mixes were utilized in a second experiment assessing two more plant types, beet, and lettuce.

The results of both the experiments have revealed that digested manure (well composted digested manure solids) and fiber (component separated from manure solids by fractionation) component has produced plants with significantly similar ($p > 0.05$) shoot dry mass and root structure as commercially available plant media. The digested dairy fiber contains a significant amount of nutrients for the plant to germinate. Carbon/Nitrogen ratio was higher than recommended range and so may have had an adverse effect on pH and reducing the availability of micronutrients. Results demonstrate the potential for anaerobically digested fiber to replace peat moss as plant growth media providing growers with a local, renewable substitute for peat and a supplemental income for animal farm operators.

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Finally, and most importantly, I would like to express my love and gratitude to my family and friends back in India for their undying love and support.

DEDICATION

I dedicate all my hard work and achievements to my beloved parents, Narmatha and Surendran, without them, none of this would have been possible.

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LIST OF ACRONYMS

ACRONYM	DEFINITION
CO_2	Carbon-Di-Oxide
GHG	Green House Gases
EPA	Environmental Protection Agency
AD	Anaerobic Digestion
MSAD	Multi-Stage Anaerobic Digester
LBR	Leach Bed Reactor
ADDF	Anaerobically Digested Dairy Fiber
EC	Electrical Conductivity
DM	Digested Manure
BM	Black Magic
FS	Field Soil
TN	Total Nitrogen
TP	Total Phosphorous
TK	Total Potassium
C/N	Carbon – Nitrogen Ratio
ppm	Parts per Million
ANOVA	Analysis of Variance
HSD	Highest Significant Difference

CHAPTER 1: INTRODUCTION

1.1 Research Motivation

Approximately 63% of non-CO_2 greenhouse gases are produced by the agricultural industry, mostly in the form of methane and nitrous oxide (US-EPA, 2013). The release of methane gas is of particular interest because it has 21 times the heat-trapping capacity of CO_2. Ironically, livestock waste lagoons, which are designed to prevent nutrient transport, are major contributors to methane production. Controlling the release of methane from farm waste lagoons has the potential to reduce atmospheric greenhouse gases while enabling producers to harness biogas for energy production. Biogas utilization offers the potential to reduce global emissions of methane, reduce CO_2 released from fossil fuels, diminish odor from agricultural facilities, and improve water quality, even while providing increased revenues for producers (Martin, 2004).

While anaerobic digestion (AD) of animal waste offers many advantages as a waste management tool, it has not been widely adopted in Colorado animal feeding operations. Previous work conducted by Dr. Sharvelle's research group has shown that waste management practices employed in Colorado (dry lot scrape) yield wastes that are too dry for convention anaerobic digesters (Sharvelle, Keske, Davis, & Lasker, 2011). Therefore, Dr. Sharvelle's research group has developed a new novel multi-stage anaerobic digester (MSAD) technology which is capable of digesting high solids content waste (Figure 1). Recent research on the MSAD has focused on the design of a scaled-up system and the ability to compost the solid end product. Critical to the success of the MSAD technology is that high-value co-products are formed. Due to low energy prices in Colorado and low paybacks for alternative energy sources (Sharvelle et al., 2011), anaerobic digestion projects must rely on revenues from co-products produced through the process.

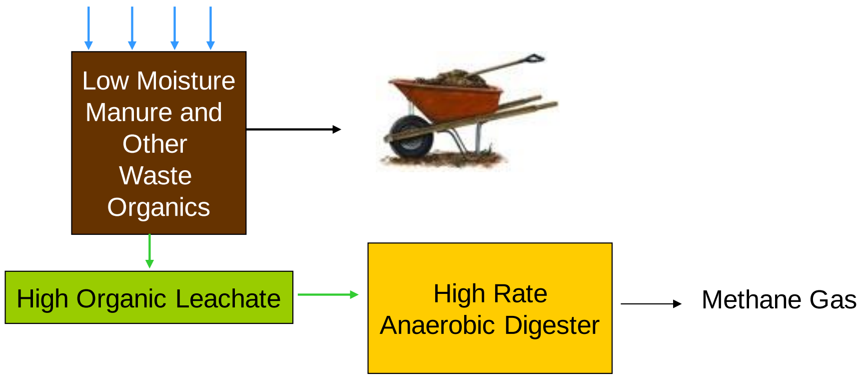

Figure 1. Multi-Stage Anaerobic Digester

Many anaerobic digestion technology providers neglect to address solid and liquid products formed in the process, thus leaving producers with the burden of management of these products. In order for the MSAD to be a holistic solution for animal feeding operations, the solid and liquid products of processed manure must serve as a resource rather than a nuisance. Previous projects conducted by Dr. Sharvelle's group have demonstrated successful composting of the solid product from the LBR (Sandefur, 2017), but this product is not of high financial value (Sharvelle et al., 2011). It is now of interest to evaluate the potential to form a high-value cow peat product from the solid product.

Cow peat has the potential to serve as a replacement for commercially available peat products that serve as mediums for plant growth. Sphagnum Peat Moss or Peat is plant material that has partially decomposed under low-nutrient, acidic, anaerobic conditions in bogs, leaving only a lignified cell wall structure. Due to its lignified skeleton structure, it has extensive pore space. The combination of a well-defined structure and pore space has provided peat with physical and chemical properties that are well suited to the horticulture industry (Bullock, Collier, & Convery, 2012). These qualities have rendered peat one of the principal components of potting media or growing media in the horticulture industry for decades. Another attractive attribute of peat is that it can be adaptable to a wide range of management practices.

Recently, concerns about the sustainability of peat have been raised. Peatlands are wetland ecosystems that are both economically and ecologically important. They play an important role in water purification and are enormous carbon sinks (CC-GAP, 2005). Peat mining harvests from deep in the bogs and can represent hundreds of years of peat accumulation. Mining of peat drastically alters the chemical, physical and biological composition of peatlands (CC-GAP, 2005) and takes a long time to re-establish their ecological functionality of peatlands (Bullock et al., 2012). As a result of degradation and exploitation, peat extraction releases greenhouse gases (GHG) in large amounts accounting for about $600x10^3$ tons of CO_2 eq per year (Cleary, Roulet, & Moore, 2005), thus having an impact on global climate change. Although peatlands accumulate more peat over time, it is only about 0.5-1.0 mm per year (CC-GAP, 2005). Most peat is produced in cold, northern regions and must be shipped long distances to more temperate horticultural areas. Concerns over peat extraction have fostered a search for mostly sustainable media components.

Many potential peat alternatives from the agricultural (Beeson, 1996), sewage sludge compost (Hernández-Apaolaza, Gascó, Gascó, & Guerrero, 2005), coconut coir (Evans & Stamps, 1962), guar, jantar, wheat straw & rice hull (Mustafa et al., 2016) and food industries (Ostos, López-Garrido, Murillo, & López, 2008) are appealing. and used over the past years as they are renewable and also readily available from the local sources. Growth patterns of plants grown in these mediums were highly invariable due to inconsistent and varying physical and chemical properties of the soil media. Thus, after the search for much more appropriate material, anaerobically digested dairy fiber (fiber), a by-product of the methane production from dairy manure raised itself to the point of interest (Barrett, Alexander, Robinson, & Bragg, 2016). Also, the problem of handling waste was also minimized or even nullified as it changed the problem of waste management into lucrative high-value horticulture product. Previous research studies are focused on using the fiber obtained after the anaerobic digestion of dairy manure from conventional AD system as plant media for horticulture and floriculture industry. This study expands the scope further for using the solid fiber product, obtained from feedlot manure rather than dairy manure through a novel MSAD technology which is different than conventional AD technology as growth media for edible plants.

1.2 Objectives of the Research

The objectives of the research are

1) To assess the Physical and Chemical properties of digested cow peat and fiber product obtained from MSAD.
2) To evaluate the cow peat processed via MSAD and fiber as a potential Plant Growth Media without adding additional nutrients.

CHAPTER – 2: BACKGROUND AND LITERATURE REVIEW

2.1 Multi-Stage Anaerobic Digester (MSAD) technology

MSAD is an optimized conventional AD with two separate components for the hydrolysis and methanogenesis to take place. Figure 2 represents the layout of the process flow of the MSAD reactor system. High solids cattle manure is first packed in the trickle flow leach bed reactor (TFLBR), where hydrolysis takes place. Water is allowed to trickle through the TFLBR and all the soluble organic molecules broken down by microorganisms in the form of leachate flow out of the component. This leachate liquid is pumped into the second-high rate anaerobic digester (HRAD) chamber where further degradation in the form of methanogenesis takes place and methane is produced. This leachate can be circulated through the first component and they can act as inoculum to the reactor substrate. Then, fresh water should also be added to reduce the toxicity of the formed leachate liquid. (Karim, 2013) As only the leachate liquid is the main substrate required for the methanogenesis to take place, the hydrolyzed solids left behind in the TFLBR chamber can be removed and used as a various other material. One such way to use those solids is to separate fiber solids from them and employed as plant growth media. The digested manure solids are taken out, composted and then the fiber component is removed by fractionation process as explained in the methods (Refer 3.1).

They are better than single stage reactors as the acidogens and methanogens are sensitive to the environment (Chen, Cheng, & Creamer, 2008). Failure to maintain the balance between these two groups can cause reactor instability, whereas in this MSAD both the chambers are separated. This could substantially reduce the digestion time and serves as the good application for high solids cattle manure (Gunaseelan, 1997).

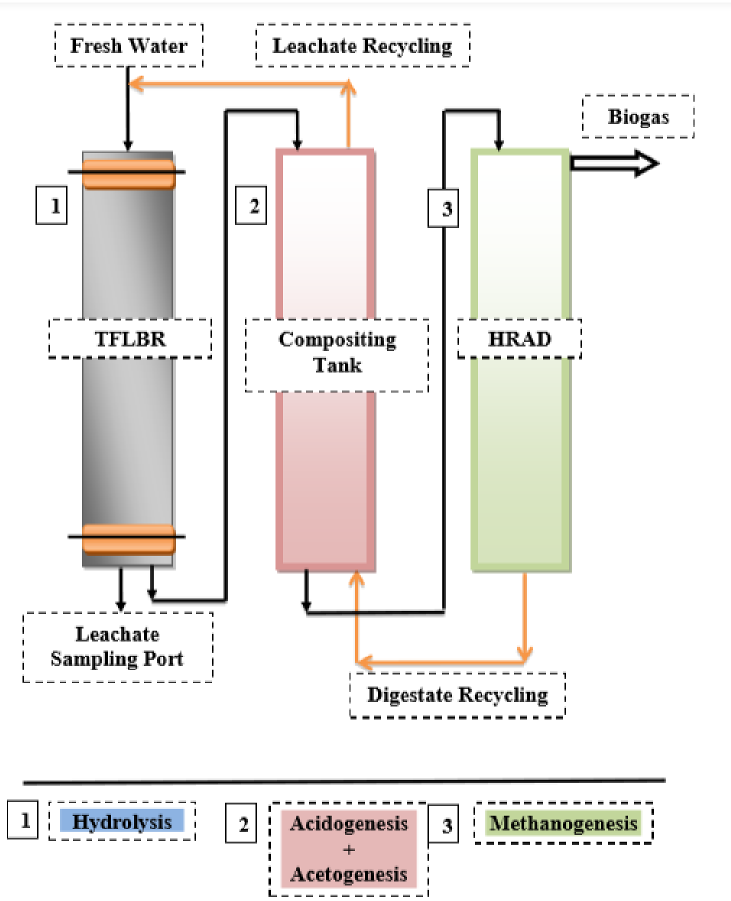

Figure 2. Schematic Diagram showing the process flow of MSAD reactor system (Karim, 2013)

2.2 Peat Land and its Characteristics

Peatlands are wetland ecosystems that are characterized by the accumulation of organic matter called "peat" which derives from dead and decaying plant material under high water saturation conditions. They are one of the most important natural ecosystems which have key values for biodiversity conservation, climate regulation and support for human welfare (CC-GAP, 2005). Peat is organic material formed from dead organic matter – partly decayed leaves, stems and roots of plants that have accumulated in a water-saturated environment in the absence of the oxygen. Peat comprises more than 90% of water and so peatlands have unique ability to store large amounts of water. They act as major carbon storage comprising nearly 30% of carbon on land while covering only 3% of worlds land area (CC-GAP, 2005). As the exploitation and degradation of peatlands have resulted in 50 to 100 tons of CO_2 per ha/year, or approximately 350 to 700 million tons/year (CC-GAP, 2005). Also, agriculture, timber extraction, and forestry activities have led to unsuitable soil structure, acidification of soils, flooding and other negative consequences on those peatlands. These consequences have had a direct impact on global climate change have been explained in detail by Coordinating Committee for Global Action on Peatlands (CC-GAP, 2005).

Due to the exploitation of peatlands and peat extraction, the economic value of those lands has decreased significantly over the last decade. However, these lands maintain public value if they are preserved well by formulating policies with the perspective of preserving bogs (Bullock et al., 2012). Bullock et al. (2012) discusses the current implications on peatlands management and explains various policy options for achieving success in sustainable future of peat and peatlands. Restoring the peatlands by imposing warning on industrial bog extraction is one such option which helps in sequestration of carbon more than restoration. The other policy is based on maintaining the peatlands and their structure. Stringent laws have to be introduced by imposing the charge on the users such as carbon tax and government subsidies should be stopped. (Bullock et al., 2012)

GHG emissions due to peat extraction and transport were studied by (Cleary et al., 2005). GHG emissions during the life cycle of peat extraction in Canada were increased from 0.54 million tons per year in 1990 to 0.89 million tons in 2000. Peat decomposition was the major source of GHG emissions comprising 71% of total emissions. The research concludes by indicating that to restore the carbon pool to its original size, it would take 2000 years only if the restoration process becomes successful. (Cleary et al., 2005).

2.3 Substrates as Replacement for Peat

Various substrates such as coconut fiber, pine bark, guar, Jantar, rice hull, municipal solid waste, yard waste, biochar etc., are used as a substrate for container plants replacing peat. Experiment with coconut fiber and pine bark with composted sewage sludge by (Hernández-Apaolaza et al., 2005) on ornamental plants has shown very good results with observed healthy plant growth. Physical and chemical properties of the substituted mix were consistent with the conventional peat, while electrical conductivity exceeded the recommended range. pH was maintained between 6.4 to 7.0, which is within a good range for media with coconut fiber and pine bark. Nutrients were present in adequate amounts and no toxicity was reported in the research. Consistent plat shoot and root growth were observed in the media with coconut fiber with 30% compost. (Hernández-Apaolaza et al., 2005)

Composted yard waste along with pine bark and sand was tested on Rhododendron plant species and pittosporum tobira ornamental plant species (Beeson, 1996). Irrigation regime and its impact on the plant shoot and root growth were studied extensively by using a low and high irrigation regime. Under low irrigation, compost substrates did not have any impact on the plant growth but with higher irrigation regime. Azaleas rhododendron grew in 20 and 40% compost substrate had higher shoot and root dry weight than control. Water conservation was not achieved with this composted yard waste was the main inference and it can be proved by indifferences in water holding capacity and root growth between the low and high irrigation regime. Therefore, composted yard waste provided inconsistent results and required high water supply for better growth.(Beeson, 1996)

Another experiment with guar, jantar, wheat straw and rice hull (Mustafa et al., 2016) were tested as possible peat replacements by testing it with muskmelon plant. Composted Guar, Jantar, Wheat straw and Rice hull were blended at 0 – 50% with peat moss on a volumetric basis. The physicochemical properties of all the mixes were within recommended ranges with pH only being exception exceeding recommended ranges. Total nitrogen content increased with increase in guar and jantar compost whereas no such change was observed in rice hull compost in which 100% rice compost has total N near zero. Fresh weight, height and root length of the seedlings grown in rice hull and wheat straw compost were higher than those in other mixes. The Guar and Jantar mixes had higher tissue nutrient concentration compared to other two compost. All these results were appealing as they can be substituted for peat.(Mustafa et al., 2016)

Experiments using coconut coir dust (parts remained after removing the large coir fibers) as peat replacement product (Evans & Stamps, 1962) was studied by testing floriculture crops marigold, geranium, and petunia. Peat was substituted by coir (volume/volume) in a media with perlite. Coir based substrates had greater water holding capacity than peat-based substrates. Water filled porosity was greater than air-filled porosity as the proportion of peat and coir increased. No significant differences were found in bulk density, solids percentage between peat and coir substrates. Geranium grew in coir-based substrates (80% coir - 20% perlite) has greater root fresh weight whereas petunia and marigold had greater shoot fresh weight and height when grown in the same. This experiment proved to be a successful one but no information about nutrients was recorded which is very important. (Evans & Stamps, 1962)

Partial replacement of peat was studied by using sewage compost and municipal solid waste compost (Ostos et al., 2008) by experimenting it on Pistacia lentiscus, an aromatic gun shrub. Plants grown in compost-based substrates had better growth and nutrition compared to those grown in peat-based substrates. Phosphorous intake was enhanced in the media with compost. But most of the physical and chemical characteristics of the compost-based substrates were either below or above the recommended ranges especially pH and EC. Trace nutrients were very low in compost-based substrates which could have caused phytotoxic effects. (Ostos et al., 2008)

Strawberry production by using coir, peat-perlite, peat-rice hull and the peat-coir-rice hull was carried out in an open field as a test for peat replacement (Wang, Gabriel, Legard, & Sjulin, 2016). After nutrient fertilization, all the micro and macro nutrients were in the recommended ranges. Over the 2-year growing period, the yield from coir, peat-perlite and the peat-rice hull was not significantly different. Also, the study outlined 100% coir had all the required hydraulic and chemical properties to be used as peat replacement. (Wang et al., 2016)

2.4 Anaerobically Digested Dairy Fiber as Peat Replacement Product

Digested and well-composted dairy manure can improve soil quality (Johnson, Davis, Qian, & Doesken, 2006) by protecting the well-established soil turf without increasing any under-zone nutrients with ammonia-nitrogen being the only exception. Increased compost topdressing results in higher water retention capacity of the soil. Nutrients such as phosphorous, potassium, iron and manganese increased. Higher compost application increased the electrical conductivity which could bring adverse effects on soil and its structure, but no such negative impact on the soil quality was reported. Run-off nutrient levels were the same in both composted and non-composted soil turfs. Topdressing composted manure improved soil physical properties and nutrient concentrations helping to maintain the turf in good quality. (Johnson et al., 2006)

Utilization of re-processed anaerobically digested dairy fiber (MacConnell & Collins, 2009) as a container media substrate was studied by testing it with petunia species. The digested fiber removed mechanically from digested manure solids from a conventional anaerobic digestion system had desirable physical properties to be used as a plant growth media substrate. Results of the first experiment showed a deficiency in iron and manganese so additional treatment by supplementing manganese and ferrous sulfate was carried out. pH adjustment and fiber treated with elemental Sulphur and Calcium Sulphate was also carried out to foresee if better results were obtained. Mean pH of fiber was 8.4 and so pH adjustment was done to maintain it at in a recommended range (5.5-6.5). Fiber substrate had better porosity and container capacity than peat. Plants were grown in media with elemental sulfur produced plants with greater fresh weight and greenness, but with inadequate root development where a substrate with gypsum and elemental sulfur produced plants with greater quality than any other media. This study has proved that digested cattle manure fiber has physical properties and nutrients required to be used as plant media.(MacConnell & Collins, 2009)

Anaerobically digested dairy fiber (ADDF) as a partial replacement of peat by using poinsettias was studied by (Lamont & Elliott, 2016a). The media with ADDF-peat-perlite had similar physicochemical properties as of peat-perlite mix, but A the DDF mix produced plants with greater shoot fresh weight, dry weight, and taller leaves. Leaf tissue concentration of nitrogen, phosphorous, manganese, sodium and zinc were higher than peat control mix. Drained leachate liquid samples from ADDF media mix had higher phosphate concentration which might affect the soil quality. The results of this study demonstrated that the ADDF can be a potential peat replacement with some additional measures taken to control the soil quality. (Lamont & Elliott, 2016a)

Chrysanthemum plants were tested with various recycled organic materials (ROM) (Krucker, Hummel, & Cogger, 2010) as peat replacement substrate. ROM substrates include groco (anaerobically digested biosolids) along with sawdust, Targo (thermophilically digested class A biosolids) mixed with sawdust and sand, dairy compost, dairy fiber along with peat as a control. pH and Electrical Conductivity (EC) of the dairy compost and dairy fiber were higher than all other mediums, so they were leached with water at a volume 4 times the volume of the substrate. All other physicochemical properties were maintained in same range by adding a required macro and micronutrients among all the substrates. Sub-irrigation with high and low Nitrogen (N) supplement was done to study the behavior of the substrates and corresponding plant quality. Both produced plants with the same quality and the higher N did not have any impact on the growth and nutrient regime. The leachate N content was inconsistent with all media and so further study was required. This study has demonstrated that with proper fertilization and irrigation, the dairy fiber and compost can be successful peat replacement product. (Krucker et al., 2010)

A composted dairy fiber as a peat replacement media for foliage plant propagation (Li, Chen, Caldwell, & Deng, 2009) was studied. Canadian and Florida peat was used as a control. All the physio-chemical properties such as airspace, bulk density, pH, EC, and total porosity was largely similar to control mixes whereas EC increased with an increase in cow peat substitution. Plants grown in control mixes had significantly greater root dry weight and length than those grown in cow peat substituted mix. This signifies that the plants are not tolerant of higher electrical conductivity. Shoot to root ratio was also greater in control than cow peat mix which in turn signifies that higher nutrient content present in cow peat substituted mixes. Results show that proper maintenance and application of cow peat may still be alternative to peat. (Li et al., 2009)

Herbaceous perennials such as Brunnera, Coreopsis, Shasta Daisy, Liatris, and Phlox were studied with ADDF media (Lamont & Elliott, 2016b) as a replacement of peat. Bark-peat-perlite (4:2:1) and Bark-ADDF-perlite (4:2:1) was used as substrate media in which these plants were grown. All the media had similar physicochemical properties with EC in the bark-ADDF mix was higher than the peat mix. Shasta daisy grown in bark-ADDF mic had greater mean shoot dry weights than those in peat mix. Brunnera and Coreopsis grew in ADDF mix showed signs of chlorotic leaf margins. A greater amount of phosphate-P, ammoniacal-N and nitrate-N was leached from the pots containing the ADDF mix which is a concern. ADDF can be employed as 100% replacement if all these fertilizer and irrigation was correctly managed. (Lamont & Elliott, 2016b)

Fibrous manure solids were produced from the leaching bed system (Liao, Frear, Oakley, & Chen, 2010) and Petunia was used as a plant for the study. Leaching bed reactor in this research study has two components where manure solids were hydrolyzed by passing water in leaching fiber component and methanogenesis has been carried out in the other. The settled fiber material in the leaching fiber reactor was separated from the treated manure solids by the inclined auger mechanical setup. The fibrous material has same physicochemical properties as of natural peat. The growth trials showed that the plants grown in treated fibrous solids media had greater root surface and root length compared to peat mix, demonstrating that due to leaching of nutrients from fiber solids roots must expand to take up nutrients. Therefore, the excellent root growth observed in treated manure solids along with controlled nutrient addition as preferred by the plant nursery could result in a plant growth medium of a peat replacement. (Liao et al., 2010)

Experiments with bedding plants (pansy, viola, petunia, geranium) and vegetable seedlings (chrysanthemum, cyclamen, poinsettias, woody nursery crops) (Lamont, 2015) was studied by supplementing peat with ADDF as growth media. Water holding capacity and bulk density of the mixes were not significantly different while the EC of ADDF was greater than peat control mix. pH range of coir-ADDF mix was higher than the recommended range and did not produce plants with quality matching other mixes. All the plants showed different results as some of them had fresh weight and quality greater in control mix (e.g. geranium) than petunia which had greater fresh weights in the ADDF mix. Geranium and cucumber had greater tissue phosphate concentration than other mixes. Leaching was observed in higher amounts from all the pots and needs to be addressed or it would affect the soil quality. The results show that ADDF has the potential to serve as a peat replacement if the nutrient condition was rightly managed. (Lamont, 2015)

2.5 Financial Viability of Anaerobic Digestion - impact on cow peat production

Anaerobic digester installation at animal feeding operations can be a viable option but economic viability of installing it on farms, particularly small-scale farms, remains a big question. EPA's AgSTAR (Roos, Martin Jr., & Moser, 2004) recommends a herd size of at least 500 cows for a viable operation of digesters but more research has been conducted on how to extract much revenue by decreasing the herd size. Economic analysis of small-scale digesters conducted by (Klavon, Lansing, Mulbry, Moss, & Felton, 2013) and (C. Bishop, Frear, Shumway, & Chen, 2010) indicated that digesters with only baseline conditions met such as exporting bio-solids as bedding material, electricity generation cannot have positive cash flow on small-scale digesters with herd size less than 500.

Additional revenues can be generated by implementing procedures such as producing fiber solids and marketing them, biogas capture and using it on site, collecting tipping fees for other wastes, cost-sharing etc. can bring positive cash flow. Discount rates at 4% and 8% with 10 and 20-year period produced acceptable returns whereas instigating 50% cost sharing i.e., capital and operating cost shared between the US farmers owners and various US federal, state and local agencies providing grants, tax exemptions, and loans etc., would bring positive net returns (C. Bishop et al., 2010; Klavon et al., 2013). A study by (Pelaez-Samaniego et al., 2017) has briefly laid down the various approaches available to make successful use of digested manure and fibers, process. In order to run financially viable digester, the small farm owner should implement all the mentioned revenue-generating ways. One such approach is to separate digester fiber solids and sell or use it as either a bedding material or plant growth media. Current agricultural practices involve more usage of sustainable fiber solids as plant growth media, producing it would definitely help owners to generate and improve the financial stability (C. Bishop et al., 2010; C. P. Bishop & Shumway, 2009; Ma et al., 2016).

2.6 Summary

Much of the non-CO_2 GHG are emitted from agricultural operations and its due to the difficulty in the management of the waste generated. The AD has the potential to capture GHGs while also converting waste to energy sources. Another valuable product that can be generated from the AD of animal manure is a peat replacement. Sphagnum peat used as plant growth media in various industries has become sustainably questionable and thus the search of the similar product has been ongoing for decades. Many other products have been studied but the results were inconsistent. The anaerobically digested dairy fiber has demonstrated to be a successful replacement in the horticulture and nursery industries. In this research, dry feedlot manure was processed via the MSAD system and the fiber was separated by fractionation process. Other studies reported in the literature used dairy fiber obtained from conventional AD system that was separated mechanically. Current work aims to assess the media by growing edible crops which is less studied as many horticulture and nursery crops have been extensively studied in the past. The goal of this study was to evaluate the soil media without adding additional nutrient solutions by conducting greenhouse studies.

CHAPTER – 3: MATERIALS AND METHODS

3.1 Fractionation of Digested Manure Solids

The composted digested manure (DM) was then taken and allowed to air dry for 1 week. Once the DM was sufficiently dry it was processed through the on-site chipper at the SIM lab, where it was grounded to a solid homogeneous material of small particle size. Two types of the component were formed from the DM and named as DM-30% and DM-60% respectively. Local field soil was obtained from the Pioneer Sand Company and that soil is the topsoil of Fort Lupton area.

A couple of mixtures were formed using the field soil and manure and named as DM-FS 30% and DM-FS 60% respectively. The greenhouse study utilized this "unfractionated" DM for the DM, DM-30%, DM-60%, DM-FS 30%, and DM-FS 60% media types. The fiber component from the digested manure was obtained through the process of fractionation.

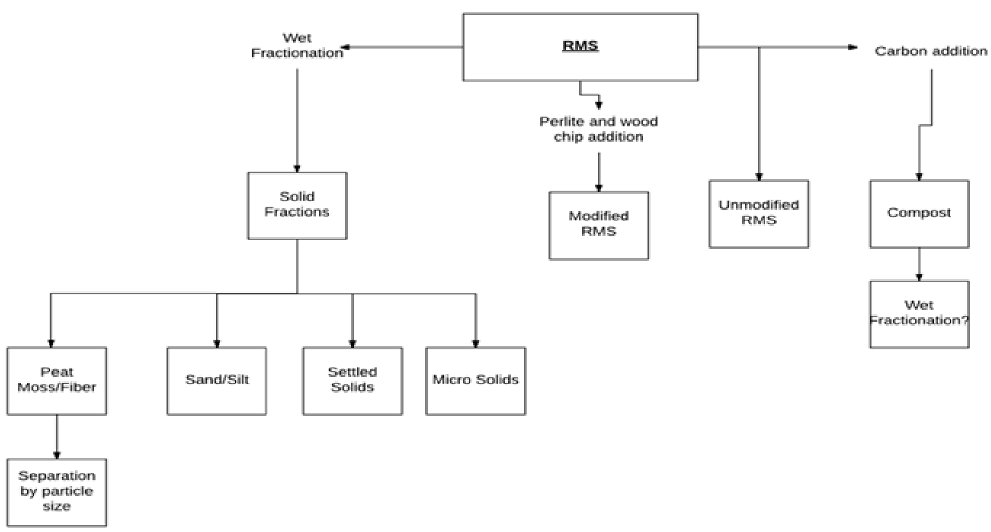

Figure 3. Layout for Fractionation of Digested Manure Solids (DM) (Presentation from Andrew Carroll & Matthew Lewis)

Next, the DM was mixed with water at approximately 40 degrees Celsius and added to a blender. This was done to further separate the fractions and create a liquid homogenous material as depicted in the wet fractionation pathway (Figure 1).

Once the hot water and DM were sufficiently mixed, the solution was poured into a bucket. The solution was subsequently decanted into a second bucket in order to allow the sand and heavy inert material to settle out. The fiber and low density suspended solids remained in the supernatant. The supernatant was poured through a cheesecloth filter and once the wash water drained into the 5-gallon bucket, the solid material left behind was deemed fiber and was used in the subsequent greenhouse study.

3.2 Media Type Preparation

A total of Nine different types of growth media were formulated from the digested manure, local field soil and commercially available peat soils. Sphagnum peat moss was chosen as the one of the commercially available peat moss along with BM. Many different types of peat moss media were available in the market such as hypnaceous peat, reed and sedge peat, hummus or muck peat.

Hypnaceous peat is readily decomposable material but has the characteristics of good water and nutrient retention to be used as plant media. The reed &sedge peat and hummus or muck peat consists of a lot of silt and clay material along with very few fibrous particles with a high rate of decomposition. These factors made them an unsatisfactory material to be used in the growing media. Sphagnum peat moss has more moisture retention along with good drainage and aeration making them a perfect material to be used in the media production. Also, mentioned previous researchers also used sphagnum peat as a control in their respective experiments as it also has good physicochemical properties. So, with this comparison and characteristics, sphagnum peat moss was chosen as control media mix to compare the results of our experiment (Aggie Horticulture, 2018). Table 1 shows the composition of different soil media prepared from the sources. Wood Chips and Perlite were added to increase the water holding capacity and also to provide more pore space. Adding these enables very good and consistent water & nutrient movement along the whole media.

Figure 4. Digested Manure and hot water mixture poured through Cheese Cloth

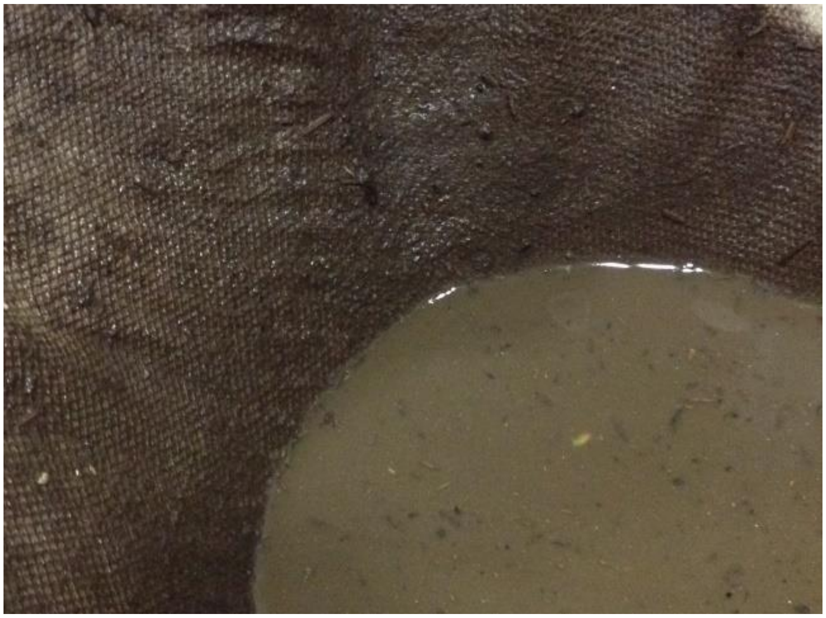

Figure 5. Zoomed to Visualize Fiber Component

Table 1. Soil Mixes used in this research project and its definitions

Soil Mixes	Composition
DMS (DM)	Digested Manure Solids
Fiber	Fiber
DM-30%	30 % DM, 35% Perlite, 35% wood chips
DM-60%	60% DM, 20% Perlite, 20% wood chips
DM-C	50% DM, 50% wood chips
DM-FS 30%	30% DM, 70 % Field Soil
DM-FS 60%	60% DM, 40% Field Soil
Field Soil	Topsoil from Ft. Lupton obtained from Pioneer Sand Company.
Black Magic (BM)	Black Magic soil ($45/3.8 cu ft)
Peat Moss Tourbe (peat)	Peat Moss Tourbe ($8/3.8 cu ft)

For mixed media, e.g. DM-30%, all "ingredients" were added into a 5-gallon buck in their respective ratios based on volume i.e., 30% of DM, 35% of perlite and 35% of wood chips. The bucket was then shaken to homogenize the mixture making it as one soil media type. The same procedure is carried out for DM-60%, DM-FS-30%, and 60%.

3.3 Experimental Setup, Media, and Plant Analysis

The research study was carried out in two-stage experiments, where the first stage focuses on determining the best-performing media mixes with single plant type (Bean). The biomass weight i.e., the wet and dry weight of the shoot and root were weighed and recorded. The root length was measured for all the grown plants and documented. The second experiment focuses on determining the efficiency of the germination with different plant types such as Beet (root vegetable family) and Lettuce along with bean. Biomass weight and root lengths of all the germinated plant seeds were documented. As one of the objectives of this project is to evaluate the performance of the raw fiber media the external nutrient solutions to maintain the media characteristics were not added. Also, to make a fair comparison between different media used, the addition of nutrients as followed in many previous research studies (Lamont & Elliott, 2016a, 2016b; Liao et al., 2010; MacConnell & Collins, 2009) was not adopted in this research. Procedures for all the media setup and analysis were discussed in the following sections.

3.3.1 The First Stage Experiment Setup and Media Analysis

In this first experiment, Green beans were grown for the purposes of this study. All the soil mixes were used to form 9 different media types. Each media had 5 replicates resulting in 45 containers. Each of these containers was filled with 1000 mL of media and the wet weight of just the soil (excluding the potting container) was recorded. To determine the characteristics of all the media, the samples were given to the Colorado State University Soil, Water, and Plant Testing Lab.

All the media type was analyzed for relevant characteristics such as total solids, pH, C/N ratio, ash content, total nitrogen, organic matter, plant available potassium and phosphorous etc., and metals such as zinc, copper, sodium through the methods defined by US composting council (Composting Council, 2002), EPA (US EPA, 2014; USEPA, 1996), soil survey laboratory methods manual (Soil Survey Laboratory Staff, Government Printing Office DC, & Soil Survey Division Staff, 1992) and soil analysis methods by soil science society of America (Paige, 1982). The bulk density of the soil media was determined by the procedure described in the manual by U.S. department of agriculture (USDA, 1998). Porosity of fiber, BM and peat was determined using the relationship equation between bulk density and porosity as explained in the book by (Bunt, 1988) whereas for DM and FS it was determined by water saturation method.

All the seeds were planted in the containers on 5th December 2016. Two seeds were planted per plant in order to increase the odds that at least one would sprout. This totaled for 90 seeds (45 containers * 2 seeds each). The Seeds were pushed into the media to a depth of about 1.5 inches. Next, the soil was thoroughly soaked and allowed to drain. All containers were then moved to the greenhouse misting bench in the plant growth facilities building. This bench misted the media four times a day and kept it moist so that the beans could sprout. But the drip irrigation at the Colorado State University (CSU) greenhouse was deemed to not deliver equivalent water to each plant, so the irrigation was done by hand.

The plants were irrigated every 2-4 days depending on how dry the soil was and how much light the greenhouse was receiving. The irrigation amount varied from 50 to 70 mL and it was based on the soil condition as discussed above. After about 10 days most of the containers had sprouted. Sprouting dates can be found in the following Table 2.

Table 2. Sprouting Dates of Seeds Planted

Soil Type	**Time to sprout (days after planting)**	**Rank**
DM Chipped	14-16	5th
DM-30%	11-13	3rd
DM-60%	12-14	4th
Field Soil	11-12 (only 1 sprouted)	2nd
Fiber	12-14	4th
DM-FS 30%	15-18	6th
DM-FS 60%	15-18	6th
Black Magic	9-10	1st
Peat Moss	11-12	2nd

Seeds in the black magic were the first one to sprout followed by the DM-30% and peat moss. While the majority of the seeds sprouted, there were some which did not sprout at all. The following Table 3 shows the number of seeds sprouted out of 5 seeds planted in each media. All the seeds were irrigated in equal amounts as stated earlier and no special treatment was given to any of the media and seeds by adding nutrient. The germination of seeds may not have happened due to various reasons such as environmental difficulty, tight packing of the soil media etc.

Table 3. The efficiency of Germination - First Experiment

Soil	Seeds Planted	Seeds Sprouted	% Sprouted
Black Magic	5	5	100
Peat Moss	5	5	100
DM-60%	5	5	100
DM-30%	5	5	100
Fiber	5	4	80
DM-C	5	4	80
DM-FS 60%	5	1	20
Field Soil	5	1	20

3.3.2 Plant Take-Down and Analysis – 1st Experiment

Plants were taken down on 9th March 2017 with a total growing time of just over 3 months. No bean growth was observed in any of the media. For better analysis, plants were separated into above ground growth which was done by cutting the plant right at the soil surface, and below ground growth which consisted of the roots. The below ground was somewhat difficult to separate because there was occasional root breakage as it was removed from the soil. This was inevitable, but they are separated in a best possible way (see Figure 6). The soil below ground growth, and above ground growth was separated and stored in marked zip lock bags.

After Splitting it in to above and below growth, the shoots and roots are air dried for 3 days so that the soil attached to the plant would dry and detach themselves. Both the above and below ground growth weights (i.e., wet and dry) were measured. Wet weights of both shoot and root were measured straight away after drying and documented. Then, both shoots and roots are dried by placing them in the oven at 110-degree Fahrenheit. After 3 hours of drying, they are taken out and dry weights are measured using the balance and results were recorded. Statistical analyses (refer 3.3.5) were performed by using Minitab'17 to test the significance of media types and plant growth. In container and media type where there is no growth is observed, the weight is recorded as zero and used as the same in the statistical tests too. By following the same procedure, the black magic sprouted 100% compared to field soil and DM-FS 30% (Table 3) which spouted only 20%. As the maximum efficiency was 100%, the plant seed where no growth is observed is taken as zero (i.e., real value) in the analysis by understanding the fact that similar approach is followed for all the seeds planted in the growth media.

3.3.3 The Second Stage Experiment Setup and Media Analysis

To perform this stage of the experiment, four best-performing media mixes Black Magic, DM-60%, fiber and DM-Chipped was picked from the previous experiment. The main motive of this experiment is to evaluate the efficiency of the media mixes for different plant types. So, the experiment is expanded by planting two new plant types i.e., beet and lettuce along with bean. Each media had 3 replicates resulting in 12 containers for one seed type. Therefore, a total of 36 containers were used in this experiment. Each of these containers was filled with 10 mL of media excluding the weight of the container. All the relevant characteristics of the plant media were measured and recorded by following the same procedure as described in the first experiment.

All the seeds were planted on 30^{th} of May, 2017. Two seeds were planted in one pot per plant for all the 3 plants which count to the total of 72 plant seeds. Seeds are pushed down to a depth of 1 inch into the soil. Then, the planted seed pots were moved to the misting bench in the greenhouse. There, it has been irrigated by the automated sprinkler irrigation machine every 30 minutes for the whole day. Seeds started to sprout by 7^{th} day (Table 6) in the BM media and bean was the first one to sprout whereas the bean seeds in DM-C was the last to sprout.

Figure 6. Roots of the Bean seeds grown in Black Magic (BM) Soil

Figure 7. Been Seeds Placed in each of the Different Soil Media

In the following days, seeds in the other media were also started to germinate while the seeds in the DM-C took the longest time in germinating by taking an average of 12 – 13 (Table 6) days after planting. The shades of color represent the time taken to germinate, where yellow represents faster germination to red which indicated no germination. Black magic has the germination efficiency of 100% for all the three plant types, while others have different efficiency for different plants (Table 4). Less efficiency denotes the non-germination of certain seeds planted. Although the same procedure and treatment were given to all the media, the cause for non-germination is unclear. This may result from over compaction of the soil media which led to lower pore space and lower water holding capacity and poor sowing of seeds, etc. As the weight and root length of those thwarted seeds could not be measured they are taken as zero (i.e., real number) in the calculations for statistical analysis.

3.3.4 Plant Take-Down and Analysis – 2nd Experiment

Table 4. The efficiency of the germination - Second Experiment

Soil	Plant	Seeds Planted	Seeds Sprouted	% Sprouted
BM	Bean	6	6	100
	Beet	6	6	100
	Lettuce	6	6	100
DM-60%	Bean	6	6	100
	Beet	6	3	50
	Lettuce	6	2	33
Fiber	Bean	6	4	67
	Beet	6	2	33
	Lettuce	6	5	83
DM-C	Bean	6	2	33
	Beet	6	2	33
	Lettuce	6	2	33

All the plants were taken down on 18^{th} of June with a growing period of 18 days. No Bean, lettuce or beet growth was observed. The plant has been separated into two components as above and below ground to make it easy for the analysis. The same procedure as in the first experiment was followed and the wet and dry weight of all the plants were noted along with their root lengths. In this second experiment, some data were normal and so parametric ANOVA was performed and the significant differences were laid down by Tukey's highest significant difference (HSD) test whereas, for non-normal data, the same procedure was followed as discussed in the previous experiment (Refer Section 3.3.5).

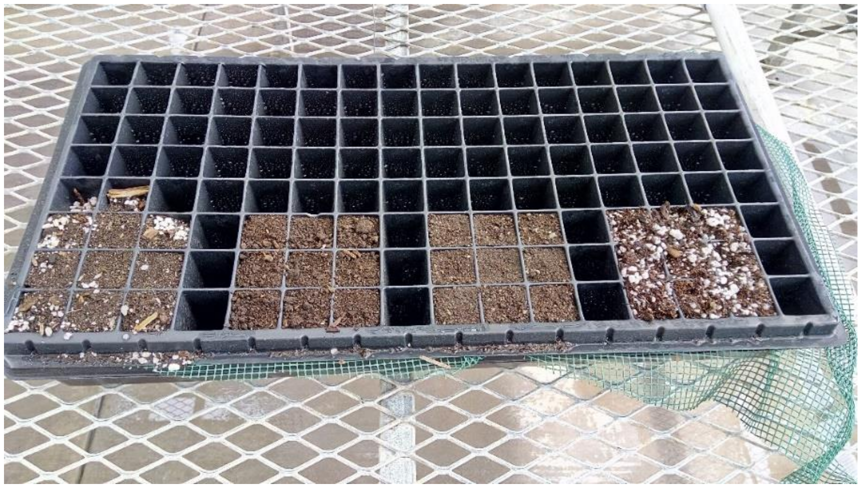

Figure 8. Bean, Beet, and Lettuce Placed in Different Soil Media

3.4 Statistical Analysis

Statistical analysis was performed by using the Minitab'17 software. Analysis of variance (ANOVA) was used to find the statistical significance of the different media type used. In the first experiment, data was non-normal, so non-parametric ANOVA was used as the parametric tests can't be used. Kruskal-Wallis and Mann-Whitney tests were used to test the significance and comparisons of different media type respectively. In the second experiment, some data was normal and thus parametric ANOVA and tukey's highest significant difference test was used to determine the significance between the means. For non-normal data same tests mentioned in the previous experiment was used.

CHAPTER – 4: RESULTS AND DISCUSSION

4.1 Physical Characteristics of Media

An important criterion for a material to become peat substitute is to have similar physical characteristics to peat. Bulk density (Figure 9) is one of the important parameters as it is responsible for air and water transport in the medium. The bulk density of the peat and BM are 0.10 and 0.11 g/cm^3 respectively while it is greater in both the DM and fiber media mixes at 0.68 and 0.59 g/cm^3 respectively.

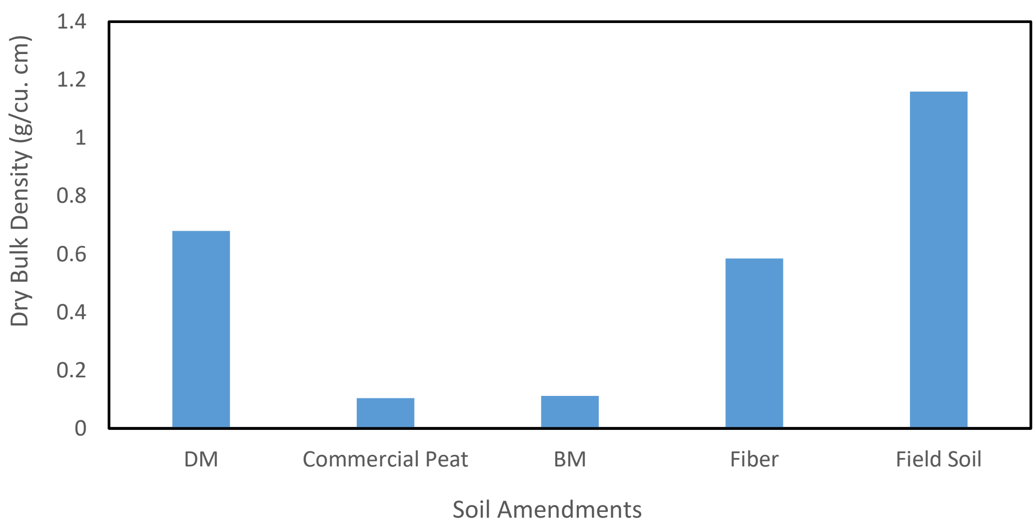

Figure 9. Bulk Density of the Various Media Mixes

Porosity (Figure 10) plays a significant role in the plant growth as optimum level of porosity should be present for the healthy growth of plant especially root structure. Bulk density and porosity are inversely related. The porosity of BM is at 94.52% compared to DM at 70%, fiber at 77.05% and peat at 94.81%. Fiber and DM had values in the same range which demonstrates that the media are less porous compared to commercial soil mixes. BM and peat had higher porosities which could have supplied the potting media with higher water retention and aeration. The porosity of fiber and DM was in range with the literature reported value at 68.8% (Li et al., 2009) and lesser than other reported values which were ranging at 88 to 89% (Lamont & Elliott, 2016b; Liao et al., 2010).

Table 5. Porosity of Soil Media

Soil Media	Porosity (%)	Method used to determine porosity
DM	70.00%	Water Saturation method
Fiber	77.05%	Obtained from relationship equation between total pore space and bulk density (Bunt, 1988).
BM	94.52%	
Peat	94.81%	
FS	36.00%	Water Saturation method

4.2 Chemical Characteristics of Media

As stated earlier, the substrate which has similar chemical characteristics like peat can alone substitute it. The pH of the DM and fiber solids are slightly above the neutral at 7.3 and 7.8 respectively, while the pH of the commercially available BM and peat which has a value of 6.3 and 4.3 respectively (Figure 10). The local field soil which is unmodified soil also has pH near to the neutral.

The electrical conductivity (EC) (Figure 11) of the DM is higher than all the other media mixes, whereas the EC of peat is equal to the average listed in many published literature (Krucker et al., 2010; MacConnell & Collins, 2009). As found with pH, the EC of the field soil does not fall in any of the other mixes values and has a value of 2.1 dS/m. EC of our fiber soil mix was 1.30 dS/m and is in same range as of the EC found from other experiments such as 1.23 dS/m (Lamont & Elliott, 2016a), 2 dS/m (MacConnell & Collins, 2009), 1 dS/m (Krucker et al., 2010) using different substrates along with fiber and peat. The EC of BM mix was in same range matching other cited articles (Lamont & Elliott, 2016b; MacConnell & Collins, 2009; Macconnell, Frear, &

Liao, 2010) while the peat had EC more than two times of what has been observed in fiber. The DM showed abnormal value compared to all other mixes ranging at 6.30 dS/m. EC of the aerobically composted cattle manure was at 2.5 dS/m (Sandefur, 2017) which is slightly higher than the range but can be optimized to be well within the recommended range. The EC of soil plays an important role in many processes such as respiration, nitrification, and denitrification (USDA & NRCS). Soils with EC of about 1~1.5 dS/m are termed as non-saline soils and are considered as ideal for plant growth.

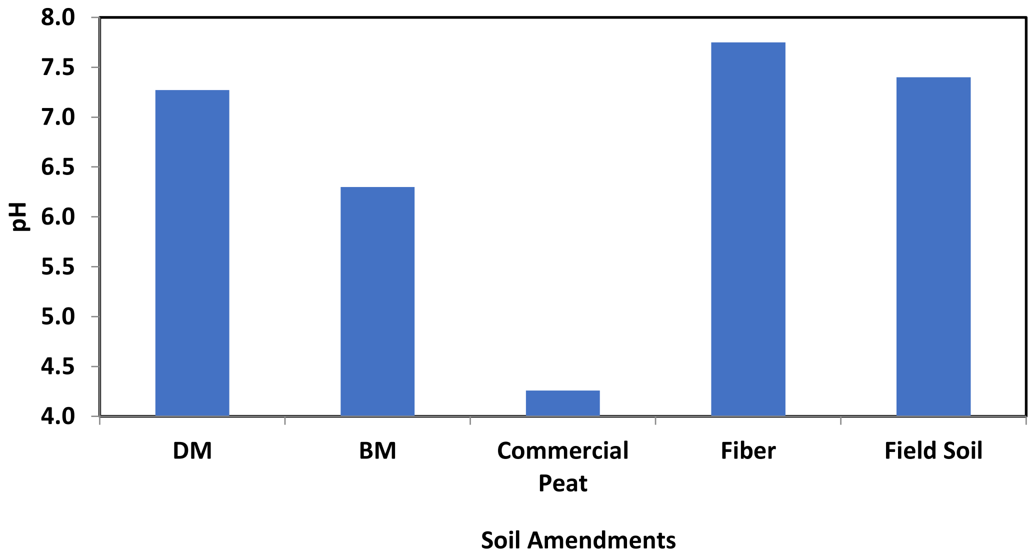

Figure 10. pH of the Soil Mixes

The Carbon-Nitrogen (C/N) ratio (Figure 12) of both BM and peat are higher than the other mixes ranging at 53 and 35.10 respectively whereas the C/N ratio of DM and fiber was 5.30 and 13.60 respectively. Again, field soil is in close relation to fiber and has the value of 12.80. Optimum C/N ratio for container plant growth would be 20-40 (Ostos et al., 2008) as reported however in DM and fiber soil mix, it was pretty low at 13.60 whereas BM and peat have the values in the optimum range.

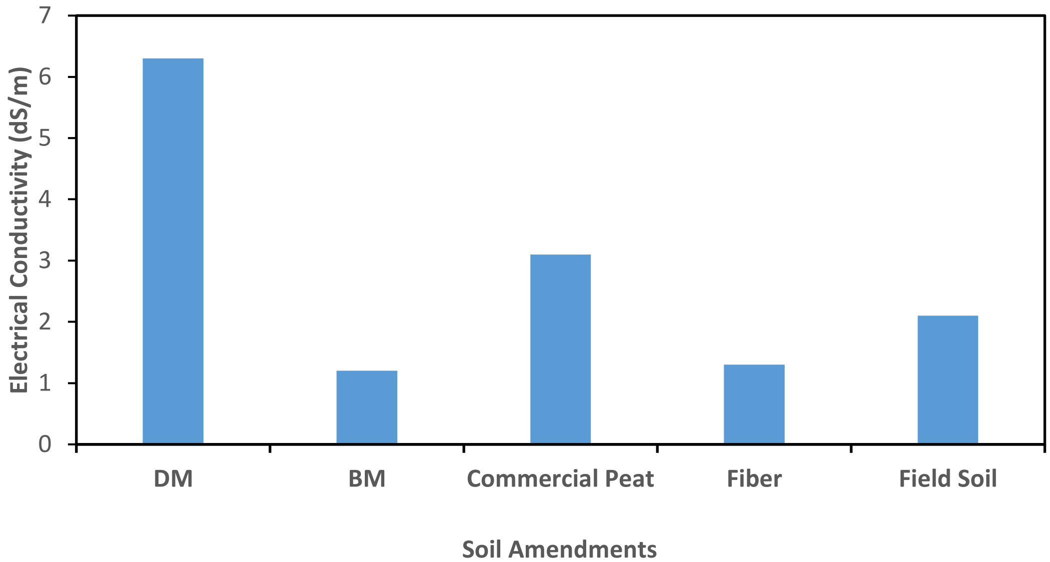

Figure 11. Electrical Conductivity of all Media Mixes

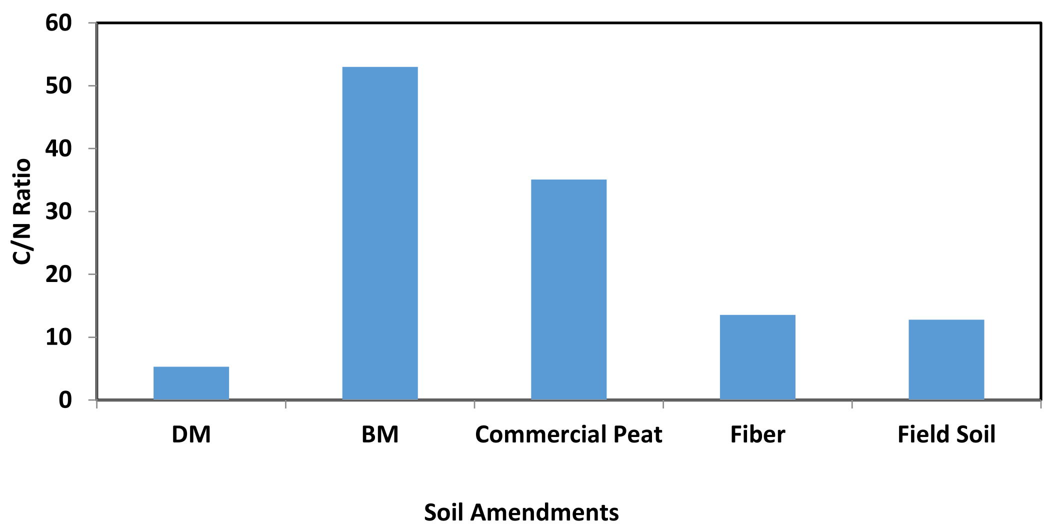

Figure 12. C/N ratio of different Media Mixes

The ash content (Figure 13) of BM, fiber, and peat is 43%, 44.90% and 51% respectively which are present in the same range. The fiber which is derivative from the DM has value in a similar range with commercially available mixes, while the ash content of DM present at 82.80% which is very much higher and almost doubled that of BM and peat. The local field soil's ash content is more than 95% which is higher than 2 times of BM and peat.

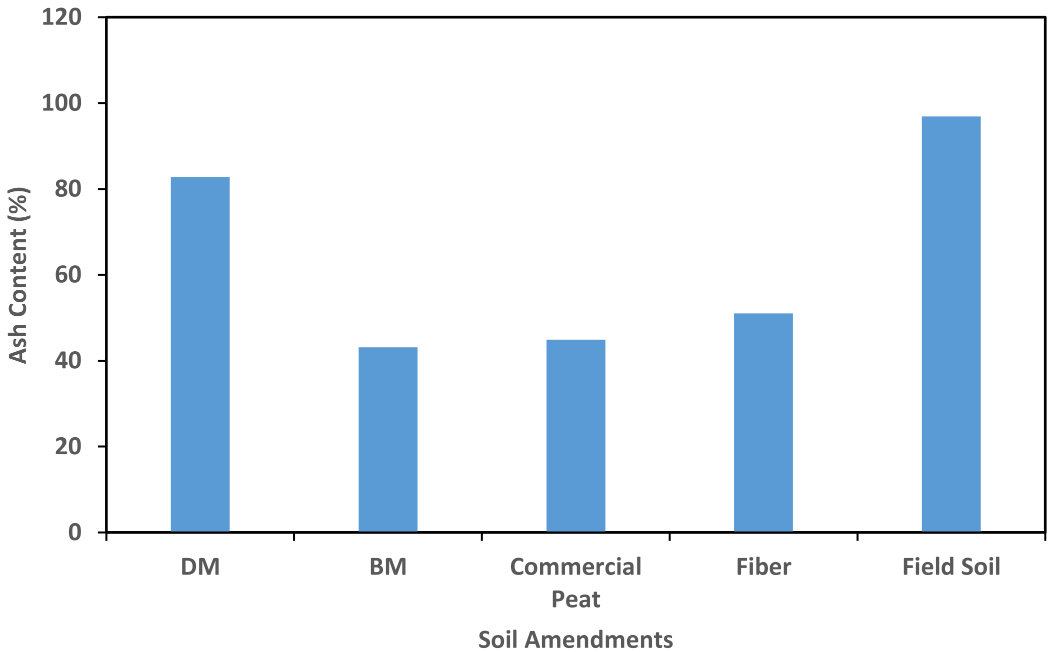

Figure 13. Ash Content of all Media Mixes

4.2.1 Macro Nutrients

Macronutrients such as nitrogen, phosphorous, potassium, magnesium, were measured to be compared across different results across the literature as they form the main component in the plant growth and health. Total nitrogen (TN) available in the commercially marketed mixes are very close, falling in the same range with the values of 6198 and 6772 ppm for BM and Peat respectively. The TN present in the DM was almost doubled falling in the range of 10,215.60 ppm while the N in the fiber was more than doubled that of both financially available soil mixes at 18,225 ppm. Field soil having the lowest TN at about 422 ppm indicating the fact that they are not exposed to many nutrients as it was just a topsoil.

Ammonia-nitrogen and nitrate-nitrogen play an important role in plant growth as it's the main component needed during the germination and further growth of roots and shoots (Bunt, 1988). In our study, the nitrate-nitrogen in DM and fiber is almost 10% and 6% of BM's value, whereas the ammonia-nitrogen is greater than BM and peat. The ammonia-nitrogen present in the DM and fiber is 10.50 and 20.60 ppm respectively which is higher than 8.6 ppm and 7.8 ppm present in the BM and peat respectively. Field soil's ammonia and nitrate nitrogen are almost negligible compared to all other mixes and may have been insufficient to support plant growth.

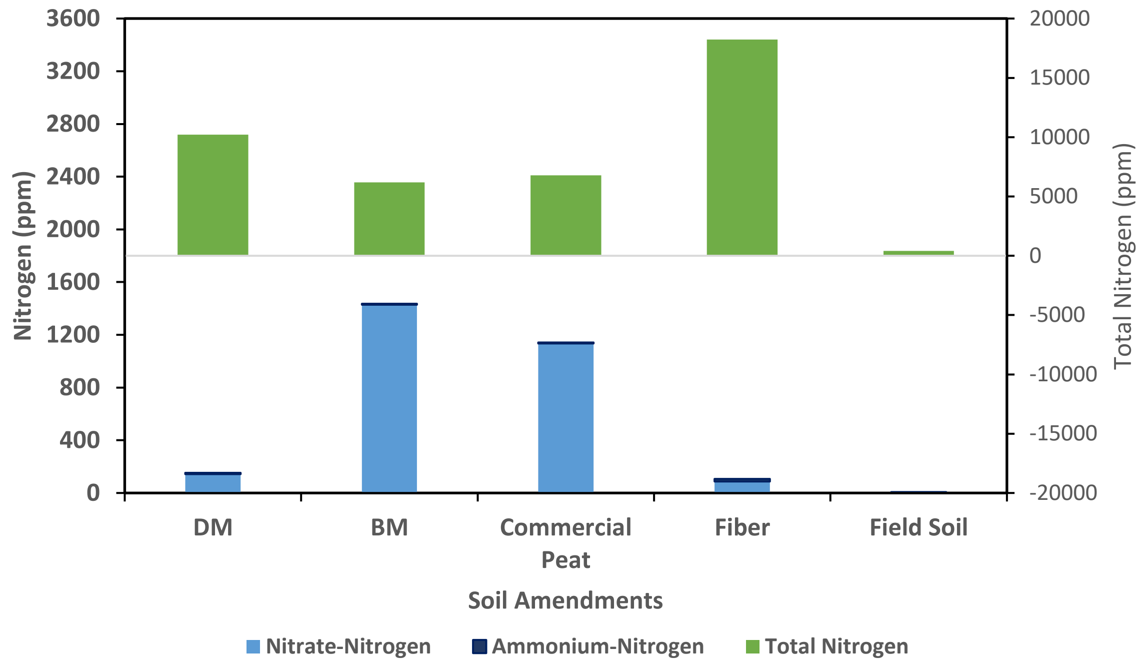

Figure 14. Total Nitrogen, Ammonia-Nitrogen and Nitrate-Nitrogen Present in all mixes

Phosphorous, another essential nutrient for many energy-related processes within the plant cell, should be available in the adequate amounts for the good growth of the plant and leaves. Total phosphorous (TP) (refer Figure 15) present in the DM and fiber is 4292 ppm and 6941 ppm respectively which is much higher than those present in BM and Peat mixes. It might be because of seasoned BM and peat which are amended to perform as good pot mixes while the DM and fiber were applied directly after the composting. Plant available phosphorous also follows the same pattern as found in the total phosphorus. One good thing about the DM and fiber mixes is that the phosphorous is available in an excess amount and so the need of fertilizer addition is nullified.

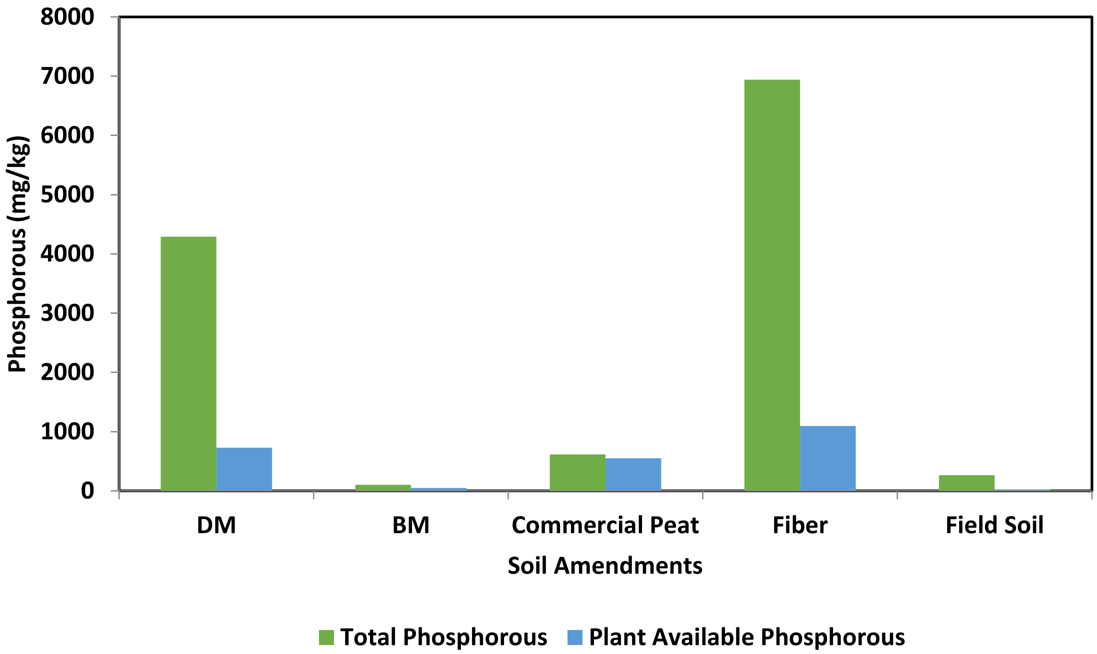

Figure 15. Total and Plant Available Phosphorous

Potassium (Figure 16) is responsible for carbohydrate and nitrogen metabolism. It should the same amount as that of nitrogen in the soil media mix. However, in this study, the total potassium (TK) in the mixes of DM and fiber was present in the same range with 4028 ppm and 3205 ppm respectively. While the BM had 771 ppm TK which was the lowest of all the mixes surprisingly including field soil. Peat had 1553 ppm whereas field soil contained about 2155 ppm which is surprisingly higher than both the BM and Peat.

Out of all the 5 mixes, the DM had the higher amount of the plant available potassium followed by the Peat and fiber. Field soil had much higher total potassium than BM and peat, but the plant available potassium is much lower in this case. One notable variation found in this case was the total potassium available in the peat mix is less than that of plant available potassium. This might have occurred due to some error in the calculation purposes.

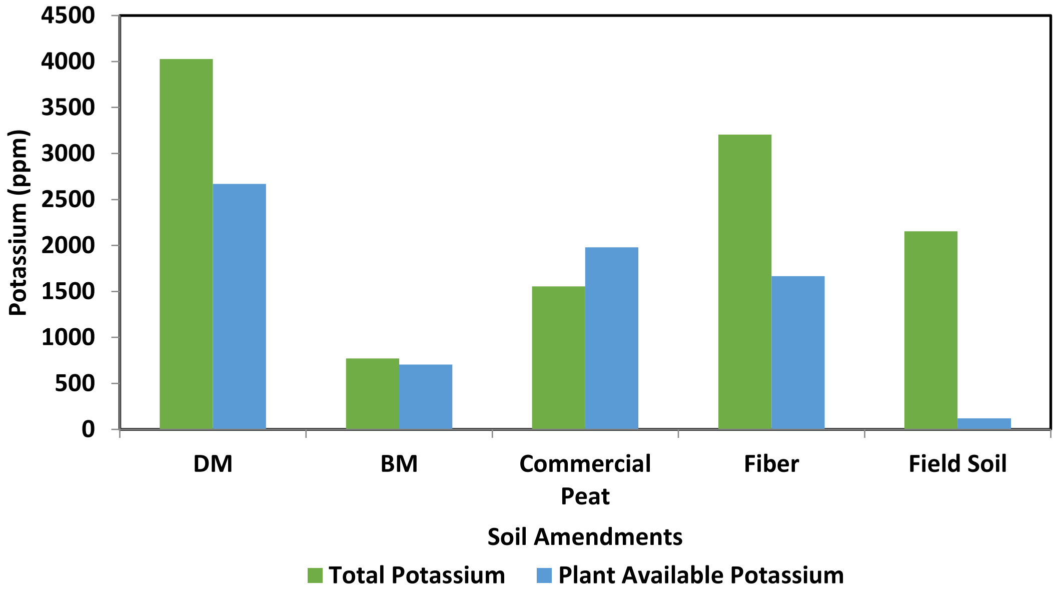

Figure 16. Total and Plant Available Potassium

4.2.2 Micro Nutrients

Micro-elements are much needed to support plant growth and they are as important as the presence of macro-elements. The elements which are generally regarded as being essential micro-elements are boron, chlorine, copper, iron, manganese, molybdenum and zinc. Deficiency of these elements might cause the uncharacteristic growth of the pot plants. Also, the plants are much less tolerant to high levels of micro-elements in the mixture than that of macro-elements. These form the basis for characterizing the mixture so that we could be able to add any nutrients in case of deficiency or treat it with other solutions to reduce the availability in case if high levels are reported. As this was a peat base experiment, the important micro-elements in the form of zinc, copper, iron, and manganese were characterized (Table 6).

Copper plays a vital role in respiration, oxidation-reduction reactions and functionality of various enzymes in the plant (Bunt, 1988; Silber & Bar-Tal, 2008). Deficiency of this nutrient has variable symptoms across different plant types and it is also impacted by pH and nitrogen availability of the media. In the soil media tested in these experiments, BM has the lowest copper availability among the other mixes. The copper content of DM, peat, and field soil are in the same range falling at 9.10, 6.70 and 5.90 ppm respectively whereas the highest of the content was found in fiber mix at 23.30 ppm. Copper available in fiber soil mix was pretty higher than what reported by (Lamont & Elliott, 2016a) which clocks at 12.2 mg/kg while other soil mixes used in this experiment are all less than 10 mg/kg, where closest was present in DM at 9.1 mg/kg.

Table 6. Micro Nutrients present in the soil mixes

Micro Elements	Soil Media	DM	BM	Commercial peat	Fiber	Field Soil
Plant available zinc (ppm)		93.9	7.0	6.1	171.1	2.1
Plant available iron (ppm)		421.8	18.7	126.2	903.9	28.5
Plant available manganese (ppm)		34.0	32.7	57.0	65.4	1.8
Plant available copper (ppm)		9.1	2.4	6.7	23.3	5.9

Manganese is very important for the transfer of phosphate for the energy-related reactions happening in the plant cell. They also play an important role in the chlorophyll formation even though it's not a constituent in the chlorophyll structure (Bunt, 1988). The amount of manganese available to plant is almost a same in the BM and DM at 32.70 and 34 ppm respectively. It was found relatively high in both peat and fiber ranging at 57 and 65 ppm respectively compared to other two. As always, the field soil was not even near to any of the ranges as found in many of the previous findings, falling to 1.80 ppm. The optimum range for manganese levels as reported is 50 to 250 ppm (Silber & Bar-Tal, 2008) and only fiber and peat has manganese content in this recommended range.

Iron and its function in the plant growth are not clearly known. Nonetheless, they are a constituent in the chlorophyll formation as manganese. Iron content found in the BM is lowest ranging at 18.70 ppm followed by field soil at 28.50 ppm. All the other mixes had iron content in hundreds while fiber reaching almost 1000 ppm. Iron found in fiber mix (903.90 mg/kg) was much higher than literature reported (Lamont & Elliott, 2016a) value (140.80 mg/kg) and (Liao et al., 2010)'s value of 182 mg/kg whereas it is in range with raw fiber value at 972 mg/kg reported by (Macconnell et al., 2010). DM's iron content is around half of the fiber's value at 421.80 ppm and peat's value at 126 ppm which is in range with above-cited literature values. Normally, zinc deficiency does not often occur in the pot grown plants. They would be present in small numbers in the seasoned media. The optimum range for zinc availability in the soil ranged from 10 to 300 ppm (Lindsay, 1993). As seen in many of the previous mixes results, the zinc present in the DM and fiber mixes are at 94 and 171 ppm respectively. All the other mixes had the value in the single digit which was less than 10 ppm. Although these micro-elements are clearly characterized and reported for the comparison of results across different studies, we were not able to report the other main micro-elements such as boron and molybdenum in this research study.

4.2.3 Experiment 1: Plant Biomass weight and Root Length

Plant biomass weight i.e., shoot and root dry weights (Figure 17) and root lengths (Figure 21) were measured to assess plant growth in the various soil media. Biomass weight and root lengths of the plants grown are important factors which outline the possibility of using digested fiber solids as plant growth media. Bean plants (Figure 18) grown in digested manure mixes i.e., DM-60%, DM-30% and DM-C had significantly higher shoot biomass weight compared to plants grown in commercial potting mixes such as BM and peat ($p<0.05$).

Plants that were grown in fiber solids also showed analogous results with the other DM mixes (Figure 17). Results from field soil and DM-FS-60% does not seem to support plant growth compared with other results as the weight of the shoots are significantly different than digested mixes and commercial mixes available ($p<0.05$). Statistical analysis results show that although the weights of the plants grown in digested mixes are higher compared to BM, their mean weights are not significantly different from one another with DM-60% as an exception ($p>0.05$).

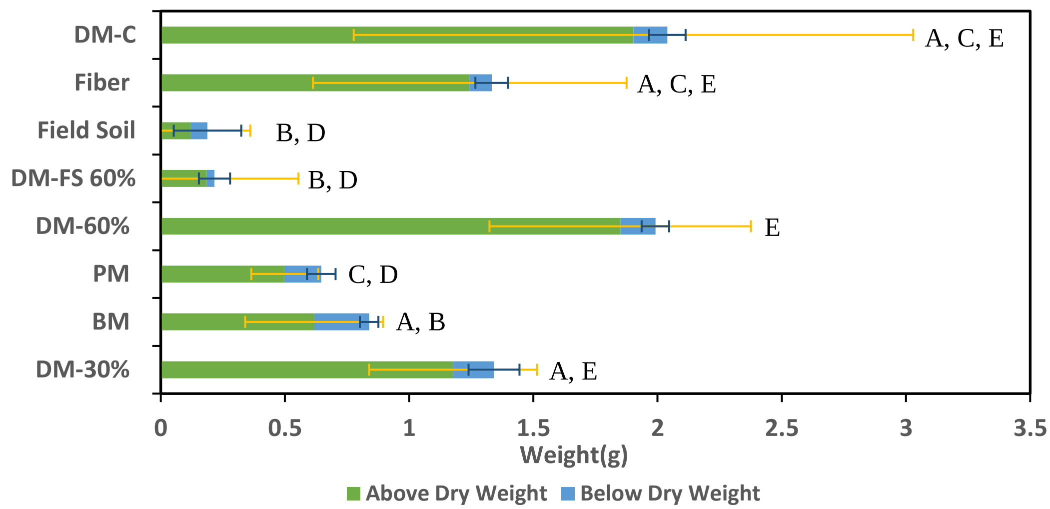

Figure 17. Mean total dry weight for bean plant species grown in media with the error bars representing the standard deviation of means. Means with different letters represent significant difference with other means. (α=0.05)

Means of plant biomass grown in DM-60% are not significantly different than the other DM mixes and fiber ($p>0.05$) but different than BM ($p<0.05$). When compared to peat the DM-C and fiber are not significantly different while the DM-60% and DM-30% are different ($p<0.05$).

One odd outcome of this analysis was the means of plant biomass grown in commercially available mixes BM and peat are significantly different from one another ($p<0.05$). However, peat and BM means are not significantly different than field soil and DM-FS- 60% whereas the means of plant biomass grown in field soil and DM-FS-60% are significantly different than all other digested manure mixes and fiber ($p<0.05$). One important information that should be considered is that only 1 out of 5 seeds germinated in both field soil and DM-FS-60% media (Table 3) and so, all the zeros considered in the statistical analysis by ANOVA could have affected this result of being not significantly different with BM and peat.

Figure 18. Seeds Germinated as Plants in all the soil media - 1st Experiment

Figure 19. Bean Plant grown size at the end of growing period – 1st Experiment

Root lengths (Figure 21) of bean plants grown in peat and BM is larger than those grown in the DM and fiber which was totally opposite to the weight results. The root lengths of a plant grown in DM-C, fiber, and DM-60% are almost equal in lengths while plants grown in DM-30% have a little bit bigger than other DM mixes and fiber media mixes. As found in the weight results, the plants are grown in field soil and DM-FS-60% have the lowest root lengths of all the plant species (Figure 21).

Statistical analysis shows that mean root lengths of plants grown in BM were significantly different than all other plant means grown in different mixes with DM-FS-60% being the only exception ($p<0.05$). Mean root lengths of plants grown in DM-FS-60% were not significantly different than peat moss and BM ($p>0.05$) however we still need to consider the fact only 1 out of 5 seeds germinated in the DM-FS-60% mix and its impact on the statistical analysis. Means of root lengths of plants grown in DM-60%, fiber and DM-30% are not significantly different compared to each other ($p>0.05$) while the root lengths of plants grown in DM-30% is larger than the other two. The means of root lengths of plants grown in DM-C are not significantly different than DM-60%, fiber and DM-30% ($p>0.05$). As found in the weight results, the field soil and DM-FS-60% are significantly different than DM mixes and fiber ($p<0.05$) with DM-30% being the exception which is not different than field soil. Even though the physical properties are good enough for the good root growth, high pH, nitrogen content and deficiency of micronutrients due to high pH has resulted in average root growth (see Section 4.4.4).

Figure 20. Roots of Bean plant seeds grown in DM-60% media soil

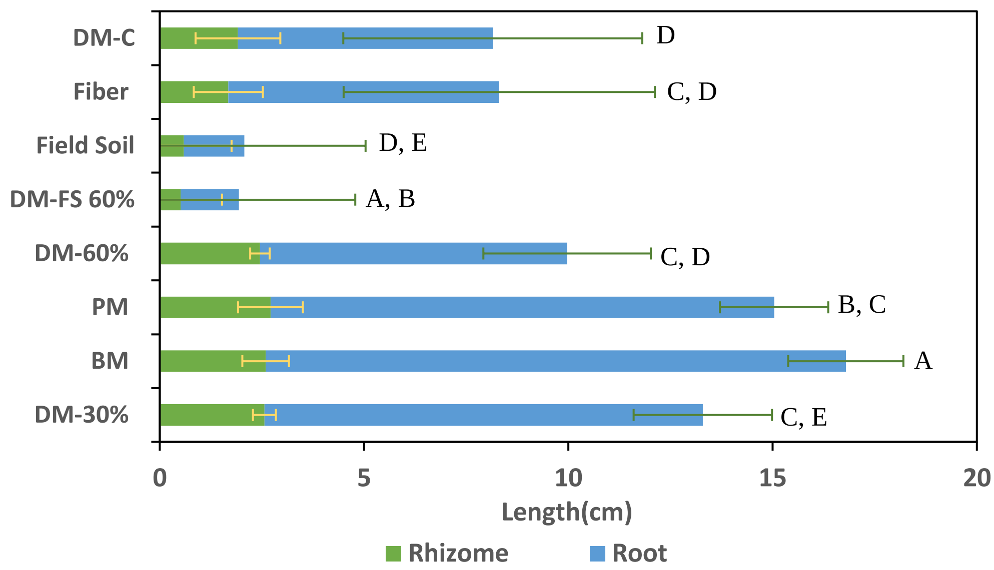

Figure 21. Mean total root length for bean plant species grown in media with the error bars representing the standard deviation of means. Means with different letters represent significant difference with other means. (α=0.05)

4.2.4 Experiment 2: Plant Biomass weight and Root Length

Mixes that performed well in the previous experiment were selected for Experiment 2 (see section 3.3.3). BM as control mix and all the other 3 are chosen from the digested manure solids. As specified before the experiment was extended to incorporate root vegetables (beet) and non-root vegetables (lettuce) along with bean to evaluate the efficiency of manure fiber and solids as a perfect replacement for peat. Beans grown in DM-60% had higher dry weight compared to all other mixes including the BM. BM and fiber almost had a same dry weight with BM edging by a small margin while the seeds grown in DM-C is much lesser than seeds grown on all other mixes (Figure 23). Statistically comparing the results notifies us that means of all the four soil mixes are not significantly different than other. Also, we should keep the fact that only 33% and 67% germination was achieved in the fiber and DM-C soil mixes (Table 4). Apart from BM which had 100% germination, DM-60% only had 50% with fiber and DM-C having equally lowest of 20% germination rate for beet. Beets grown in digested fiber solids mix yielded better average dry weight compared to all other soil mixes. Even though all the six seeds germinated in the BM mix, their average dry weight is much lesser compared to fiber. DM-60% one of the variants based on manure solids saw much lesser dry weights compared to BM and fiber whereas DM-C being the lowest of all. Statistically comparing the significance of means of plant weights, BM and DM-C are significantly different than each other ($p<0.05$). DM-60% and fiber are not Significantly different than either BM or DM-C ($p<0.05$).

For lettuce, the germination rates are quite different compared to beet (Table 4). Lettuce grown in fiber had higher biomass weight than BM which had all the 6 seeds germinated following the same trend observed in beet. DM-60% and DM-C comparatively had lower plant biomass weight than BM and fiber (Figure 23). As the germination efficiency was different across all the mixes, statistical analysis would provide meaningful observation of the results. All the means of plants grown in fiber, DM-60%, and BM are not significantly different from one another ($p<0.05$). Means of plants grown in DM-C are significantly different than fiber and not different than those grown in BM and DM-60% soil mixes ($p<0.05$).

Figure 22. Seeds Germinating from Different soil media (from left to right) – DM-60%, Fiber, DM-C and BM

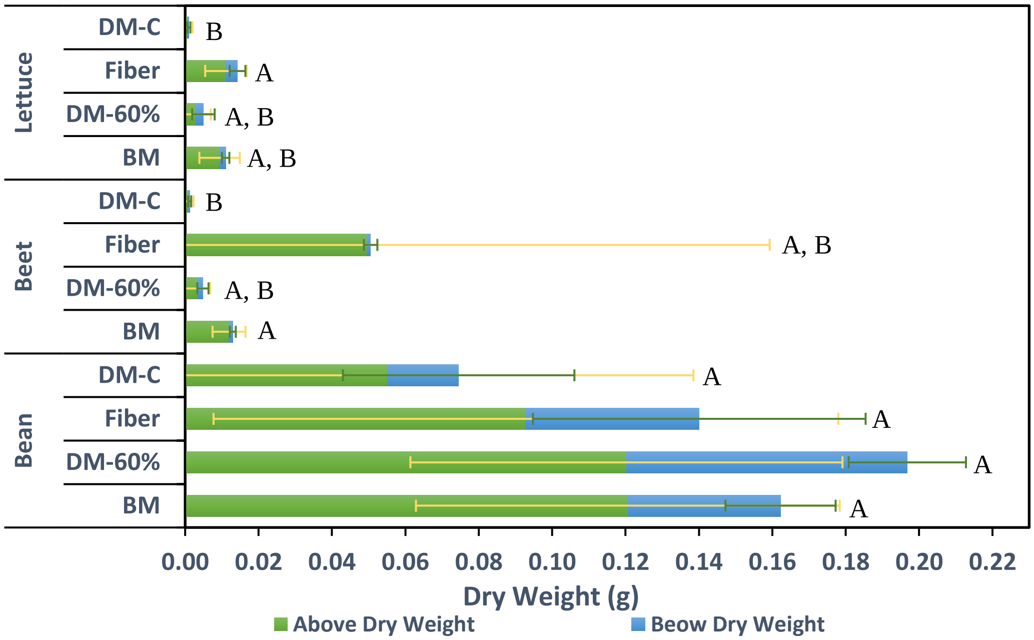

Figure 23. Mean total dry weight for bean, beet and lettuce plant species grown in media with the error bars representing the standard deviation of means. Means with different letters represent significant difference with other means. (α=0.05)

Root Lengths (Figure 25) of beans grown in BM had larger lengths compared to those grown in DM-60% which was quite opposite in case of the weight. Root lengths of plants grown in DM-60% and fiber are almost equal while the DM-C being the lowest of all four soil mixes.

Figure 24. Bean, Beet, and Lettuce Grown in all the Soil media (left to right) - DM-60%, Fiber, DM-C and BM

The same trend has followed in beets also with BM having the largest of root length compared to all other succeeded by DM-60% media mix. The root lengths of plants grown in the fiber and DM-C are almost equal and also for the first time a positive result has been evident out of the DM-C mix. Statistically comparing all the means gives us the surprise result of all not being significantly different than one another ($p<0.05$).

For lettuce, the same trend as shown in the biomass weight was apparently visible as the root length of lettuce grown in fiber and BM are almost equal. Also, the DM-60% and DM-C showed similar drift with almost same lengths. While statistically comparing all the means of root lengths are not significantly different than one another.

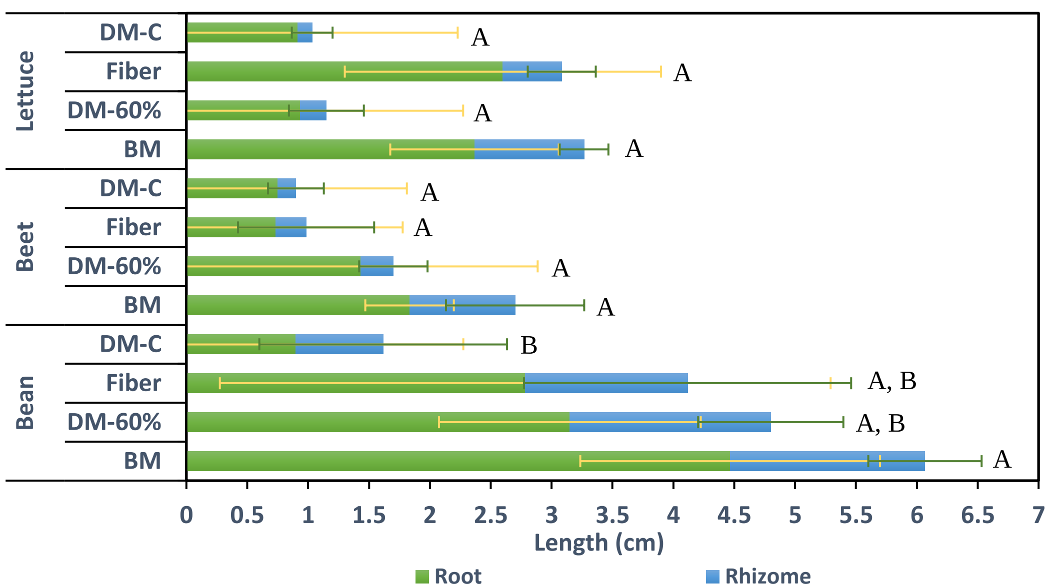

Figure 25. Mean total root length for bean, beet and lettuce plant species grown in media with the error bars representing the standard deviation of means. Means with different letters represent significant difference with other means. (α=0.05)

4.3 Experiment 2: Time required for Germination in all the media

One of the important objective of the 2nd experiment is to evaluate the media based on the time required to germinate. Table 7 represents the time taken by plant seeds in different media to germinate. As expected BM was the first soil media in which plants started to germinate after a week of planting seeds. On the next day i.e., 8th day after planting, most of the plant seeds in the BM germinated while all the bean seeds with some lettuce were germinated in the DM-60% media. The main fiber component took extra 2 days compared to BM, some bean and lettuce germinated on day 10. DM-C was so slow and was the last media in each plant type to germinate. Fiber which is a constituent of the DM-60% was slow in the process compared to its parent material. All the bean seeds in the DM-60% germinated compared to 4 in the fiber. 5 lettuce seeds did germinate at the end compared to just 2 in the DM-60% mix. Only 2 bean, beet and lettuce seeds were germinated in the DM-C media. Based on this result, both DM-60% and fiber mix seems to be fairly equal in their performance as the media. Even though the germination efficiency was lower in the fiber mix, the plant shoot weight and root lengths were not significantly different than BM and DM-60% mixes. Also, this demonstrates the fact that, even the DM mix can be substituted as peat replacement product without separating fiber from it. Further intensive research on different plants with different conditions would make things clear on whether DM can be substituted as peat replacement product.

Table 7. Time taken by seed to germinate in each media – numbers indicate days after initial planting

Plant	**Soils Amendments**											
	DM-60%			**Fiber**			**DM-C**			**BM**		
Lettuce		8		10	9	9	12			11	7	8
		8		10		9	15			11	9	11
Beet	8	10			15	7		15		7	8	8
	9							16		7	8	8
Bean	8	8	8	9	9				9	7	8	8
	8	8	8	10	17				10	8	8	8

4.4 Discussion

Much previous research result shows that the fiber can be used as a potential replacement for peat in the container plant production, especially in the nursery and floriculture crops. The objective of this research is to broaden the applications of the digested fiber as container media to edible crops so that much more reduction in GHG emissions, bio-solids wastage, and cost reduction could be achieved. Article by (Johnson et al., 2006) explains that topdressing the turf with cow manure increases the soil quality which adds up to the discussion of digested and well-composted cow manure has the potential to be used as soil media. Physical and chemical analysis of fiber and fiber-containing mixes performed by (Macconnell et al., 2010) and the results obtained in our experiment seems to be similar with copper being the only exception among all the nutrients. Analysis of DM-30%, DM-60%, DM-FS was not carried out as these mixes are made up of perlite and wood chips which do not have any impact on the characteristics of the DM.

4.4.1 Bulk Density, Porosity, pH and Electrical Conductivity – impact on Soil Media

The bulk density of the soil is an important parameter as it is responsible for the air and water movement. The recommended range is 0.09 to 1.50 g/cm^3 (Bunt, 1988) based on the results of experiments on the different soil types. The bulk density of fiber mix is at 0.58 g/cm^3 which is within the recommended range. This should have led to the optimum availability of the water and airspace which in turn should have led to good root surface growth. Root lengths of the bean plant grown in fiber, DM-30%, DM-60% and DM-C are significantly different than those grown in BM, however, the root lengths are not different among DM mixes and fiber. BM having a much lesser bulk density at 0.11 g/cm^3 might have had more pore space and water availability for the easier growth of the plants. BM and peat values in this research study are same as of those presented in various published studies by (Lamont, 2015; Lamont & Elliott, 2016a; Li et al., 2009) whereas reported fiber values are in the range of 0.40 to 0.43 g/cm^3 (Macconnell et al., 2010) which is quite lesser than our value (0.58 g/cm^3) however it is well within the recommended range.

Porosity extends from 50% in mineral soils to 90% in certain peat (Bunt, 1988). Depending upon the plant type, the optimum porosity differs from either 10% to even 60-70% (Grable, 1966). Having higher porosity would give the media a very good water retention and aeration needed for the plant growth (Bunt, 1988). However, sometimes it might have a negative impact on the plant growth as high porosities might make media to not to able to hold the water passing through making it low water holding capacity soil (Huddleston, Kling, Thompson, & Troeh, 1984). Result in this study reveals that the porosity of DM, BM was not different and was in same range while fiber had slightly lower porosity than these two. On observing it is seen that all the soil media had more than 50%, which demonstrates the fact that all these soil media could have received a similar amount of air and water throughout the growth period.

pH as known plays an important role in laying out the micronutrients available to the plant growth. If its higher than neutral then, micronutrients might become unavailable to the plants. Experiments carried out by researchers with other substrates combined with fiber all have accounted for maintaining the pH (Lamont & Elliott, 2016a; MacConnell & Collins, 2009) with elemental Sulphur and gypsum. The recommended range of pH for container plant production is 5 to 5.50 (Bunt, 1988) and this has been proved in many other experiments. Cattle manure compost with woods chips (Sandefur, 2017) had pH at 6.5 which is slightly less than neutral and also DM. pH of our soil mix with fiber is at 7.80 which is higher than the recommended range however, we have got favorable results. This proves that experiments with above-mentioned agents could make the media much more promising for plants. EC of the fiber mix was in range with the cited literature (see section 4.2) which represent the fact that the soil media were non-saline. DM and peat had higher soil EC which should have led to saline soil, however, the shoot biomass weight and root lengths of a plant grown in both the media were not significantly different than those grown in fiber.

4.4.2 Nitrogen, Phosphorous, Potassium, and ash – impact on the Soil Media

Main nutrients such as nitrogen, phosphorous and potassium are very important for plant growth and it had to be in optimal amounts where more or lesser amounts could cause diverse effects on the growth. Nitrogen in the form of ammonia and nitrate-nitrogen are important for plant germination and growth as discussed in the literature (e.g. Silber & Bar-Tal, 2008)(Bunt, 1988). The fiber mix had a nitrogen content of 18.22 g/kg which is in series with an experiment carried out by (Krucker et al., 2010) using chrysanthemum plant and also with (Wang et al., 2016) using strawberry as a plant for growth trail. Being in the same range with these two it was different than the experiment carried out by (Lamont & Elliott, 2016b) which had nitrogen at 3.9% of total dry weight compared to 1.8% in this experiment. This nitrogen content was higher in fiber mix than the experiments conducted with other substrate sources such as guar, jantar, wheat straw and rice hull (Mustafa et al., 2016) which was found at 10 g/kg compared to 18.22 g/kg and another experiment with yard waste (Beeson, 1996) and composted municipal solid waste (Ozores-Hampton, Monica, A. Obreza, Thomas, Hochmuth, 1998) had a total N at 1.2% and 0.76% which is lesser compared to 1.8%.

Both these comparisons support that anaerobically digested dairy fiber is a better soil media component compared to other media such as yard waste, municipal solid waste, guar, jantar, rice hull, wheat straw. The TN content present in fiber soil mix in this experiment is 1.8% whereas fiber solids obtained another from leach bed reactor system had TN at 1.28% (Liao et al., 2010) which is quite present in the same range. Aerobic composting of high solids cattle manure with wood chips through MSAD reactor in the previous experiment by Dr. Sharvelle (Sandefur, 2017) had total nitrogen value at 0.66% which is much less than the amount present in our experiment substrate (1.02%) whereas the BM used in this experiment had nitrogen content at 0.62% which is same range.

Phosphorous and Potassium, both are mainly responsible for energy and metabolism processes occurs within the cell. Phosphorous deficiency leads upper leaves to turn dark green while lower leaves changes to yellow and potassium deficiency lead to mottling of foliage and pale leaf margins (Bunt, 1988). TK normally present at 3-4% in mineral soil and 0.4% in natural peat (Bunt, 1988) while in our fiber mix it is in series with peat at 0.32%. DM (0.4%) and peat (0.32%) also had the same amount of nutrient content as peat whereas BM had very low value at 0.07% compared to all the other soil mixes. Normally plants require 3-4% of potassium for good growth (Bunt, 1988). Composting experiment with high solids cattle manure had TK of about 0.69% (Sandefur, 2017) which is slightly higher than the amount present in the DM this experiment but way less than the recommended range.

The experiment with herbaceous perennials and petunias by (Lamont & Elliott, 2016a; Macconnell et al., 2010) has shown the amount of potassium in their experiment ranging at 2.3% and 0.46% respectively while the experiment with chrysanthemum with dairy fiber (Krucker et al., 2010) has 9 g/kg potassium compared to 16.67 g/kg in this fiber mix. As the amount of the plant available potassium was not in optimum range matching some of the other experiments but neither upper dark green or lower pale-yellow leaves were observed (see Figure 18, 19 & 24). Having low amounts of potassium compared to all other BM had shown amazing results than other mixes and it should be mainly because of the commercial treatment it has undergone. Phosphorous present in our fiber mix was 1.09 g/kg which is in the same range as the experiment with fiber as plant media carried by (Lamont, 2015) present at 1.12 g/kg. Also, the test with petunia (Liao et al., 2010) had the phosphorous at 0.69 g/kg which is quite low compared to above experimental results. Phosphorous present in DM (0.73 g/kg) and peat (0.549 g/kg) was quite close to testing results of petunia. Previous results from Dr. Sharvelle experiment (Sandefur, 2017) had phosphorous in the recommended range @0.49% but it differed from the manure used in this experiment (0.73%) which demonstrates that the material is in same range with sphagnum peat. Adequate phosphorous i.e., 0.3-0.6% (Bunt, 1988) was available to the plant for healthy growth so no visible deficiency was observed in both the conducted experiments.

Ash content is the representation of non-volatile solids and its impact on minerals and nutrients availability. Sphagnum peat moss or commercially available peat usually contains a very low amount of ash content ranging from as low as 2% to 50%. But on the contrary ash content in treated manure would be in the range of 80 to 90%. This is mainly due to the presence of more inorganic material in the treated manure where the organic carbon is volatilized on the digesters. Higher ash content leads to a reduction of potassium, chlorine levels in the soil media which leads to a reduction in the amount needed for germination and growth (Bakker & Elbersen, 2005).

Also, it produces higher residues of material as it is mainly composed of inert materials which in turn leads to more management cost and cause a negative impact on human perceptions (Auvermann, 2011). Sphagnum peat moss has the very low amount of ash content which nullifies the above-mentioned deficiencies making it suitable for public use. In our experiment, DM having ash content at 82.8% with high pH might have caused potassium deficiency and phytotoxicity with increased amounts of sulfur and chlorine in the soil media (Bakker & Elbersen, 2005).

4.4.3 Micro Nutrient's impact on Soil Media

Copper found in fiber was higher than cited literature values. This might have happened due to high pH as it plays an important role in controlling copper availability and movement. At high pH of 7.8, it might have hindered the movement of ions responsible for the reaction which then results in low energy release affecting the growth potential.

Iron in fiber was greater than peat and BM while half of it was observed in digested manure. Iron present in all the soil mixes were much higher than the literature values which represents immobilization of the nutrient in the media. It is also in series with the fact that container having small volume would be tough for free movement of the nutrients and much more porosity is needed.

Zinc and Manganese both present in adequate amounts needed for the plant growth in fiber mix according to values reported by (Macconnell et al., 2010) and (Lamont & Elliott, 2016b). However, zinc values reported in this experiment for BM and peat was 7.1 mg/kg and 6.0 mg/kg which is very low compared to all the other values. DM's zinc content was in series with the literature values. For Manganese same trend was followed for DM, BM, and peat with very low values pointing at 34, 42 and 57 mg/kg respectively which is much lesser than those cited literature values. As the pH is very high in our mix of fiber and DM which leads to decrease in the amount of plant available Manganese which might lead to deficiency, however, no visible deficiency was detected throughout the growing period.

High C/N ratio would release more nitrogen which is very good for shoot growth during germination period and does not support root growth as well (Bunt, 1988). This could be directly related to the experiment results where good above and below growth was found in the soil mix having BM in both the experiments and for peat in the first experiment. Even though the C/N ratio was lower than the reported values, the growth of the plants in the DM and fiber was not statistically different than the BM and peat ($p>0.05$).

4.4.4 Nutrients impact on Plant Shoot and Root Growth

Dry weights of the shoot and root were measured to compare the growth quality of all the soil mixes. In the first experiment, based on the total weight of the plant DM-60%, fiber and DM-C had higher mean plant dry weight compared to the commercially available soils BM and peat. Bean plant grown in fiber soil mix in this experiment had a shoot weight of 1.33g over a growth period of 3 months while petunia grown in fiber media in the experiment by (Liao et al., 2010) had shoot weight at 3.5g, however, the growth period was not mentioned. This might be because of higher available ammonia and nitrate nitrogen compared to the amount present in BM and peat as they are mainly responsible for plant growth and photosynthesis. Recommended ranges for ammonia-nitrogen to nitrate-nitrogen is 1:1 (Bunt, 1988), however, in this experiment, no such ratio is attained in any of the soil mixes including the commercially available mixes. This should have induced ammonia toxicity and reduced rates of photosynthesis and absorption of water by roots, however, it seems that it might not have happened during the experiment. As marketed soils, the BM and peat did not have the right ratio which could have led to stunted plant growth, however, they had produced plants with weights statistically not different to those grown in digested soil mixes. DM-FS 60% and field soil did not perform as expected as they did not have the optimum amount of nutrients required healthy plant growth as depicted by the results of their chemical properties. Also, only 1 of 6 seeds planted germinated which clearly depicts that every nutrient needed for the plant was completely missing and proves that the soil needs to be modified by adding nutrients and other solutions to bring to the feasible condition. Plant available Potassium and Phosphorous were present in right amount that is needed for the plant intake (Refer Figure 15 and 16) as reported in the book media and mixes for container grown plants (Bunt, 1988).

In the second experiment, a bean is grown in BM, DM-60% and fiber mixes had higher plant dry weight and germination efficiency while DM-C, which produced very good results in the first trial did not perform as expected. Having very low ammonia and nitrate-nitrogen ratio, BM has produced plants with better quality compared to plants grown in all other soil mixes. This shows that addition of some nutrients to BM in order to maintain the soil quality has been done before marketing it which makes this soil, currently a better performing mix. Despite all those numbers and comparisons, the beans grown in all the four soil mixes are not significantly different than one another ($p>0.05$). Beets grown in these mixes had mixed results where BM outperformed all by germinating all 6 seeds planted. The fiber had better total dry weight measured however only 2 out of 6 had sprouted whereas DM-60% and DM-C showed average results. This might have happened due to having high pH, high nitrogen content and low level of micronutrients which could have made the soil conditions different for a beet to grow as usual. Also, boron plays an important role in supplying nutrients for plants that are essential for cell growth and differentiation. Mixes with high ammonium-nitrogen content have shown boron deficiency (Bunt, 1988) in the past and DM-60% & DM-C are rightly lined in this condition of having high nitrogen content which might have had an impact on the plant germination. Molybdenum responsible for the reduction of nitrate-nitrogen to ammonia-nitrogen (Bunt, 1988) was not present in adequate amounts. If present in right amount it would have reduced more available nitrate-nitrogen to ammonium-nitrogen making its ratio as 1 which could have improved the conditions. The same pattern was noticed in the lettuce growth as in Beet where BM performed well along with fiber. Lettuce seeds are more sensitive, and they require nutrients in the right proportion for growth, as in this case was considered as not available making it difficult for them to germinate. Also, due to high pH and salinity in case of DM, the availability of both these nutrients might have become scarce and so the amount needed was not available leading to poor germination compared to BM. Besides keeping all these facts apart, for beet and lettuce plants grown in fiber and DM60%, its mean plant weights were not significantly different than to those grown in BM. The results obtained through two experiment shows that the fiber can be substituted as plant media.

Even though these experiments are carried out without adding extra nutrients, pH adjustment or other modifications to the mixes they had shown same or even better results at times compared to commercially available BM. If all those adjustments were done to fiber media mix, then they could have performed even better than BM which can be demonstrated by conducting much more extensive future research experiments. Throughout these experiments, DM-60% and fiber performed equally good (Refer Fig 17 and Fig 23) which suggest that digested fiber can be a successful peat replacement product.

Economically viable options of producing & marketing fibers and also about the operation of digesters in a small scale farms were also deeply discussed by various articles (Pelaez-Samaniego et al., 2017), (Klavon et al., 2013) and (C. Bishop et al., 2010). They showed the way for all the feasible options available for the installation and operation of the AD in small-scale farms.

CHAPTER – 5: CONCLUSION

Peat being a successful plant growth media over the past few decades has become sustainably questionable due to its disruption to the natural environment, peatlands and high emissions of GHG. However, peas have been an economically effective media for all the horticulture and nursery industries and also produced very good quality plants over the years. However, the above concern has led to a search for some other material that could substitute peat well. Peat with its very well-defined structure would adapt to its environmental conditions rapidly. Many materials such as sewage sludge, rice hull, coconut coir, municipal compost, potato waste etc., have been studied however failed to produce good results over a long duration. However, the anaerobic digestion of cow manure yields a fibrous material termed as anaerobically digested manure fiber, which has same physicochemical properties to be a successful plant media replacing peat.

Research studies have been conducted over the past decade with the plants from floriculture and horticulture industries and it has produced fantastic results making itself as a viable replacement to peat. However, the testing of this fiber material with edible crops were not performed that much and so, in this research study we have expanded the objective of testing the manure fiber solids as plant growth media for edible species. Three different plant seeds were chosen in the form of bean, beet, and lettuce all from different plant species family. As expected the physio-chemical properties were similar to peat with the exception of being short on some micronutrients.

In the first experiment, Bean grew in fiber and DM mixes had more dry weight compared to commercially available BM and peat. While in the second experiment same trend was seen in the case of bean but beet and lettuce performed poorly in the DM-C soil. Even statistical analyses of both the experimental results showed that the mean weight of plants grown in fiber and DM-60% were not statistically different than those grown in BM. Main consequences were found in the presence of higher ammonia and nitrate-nitrogen ratio which could have led to ammonia toxicity which in turn reduces the plant growth rates and water absorption by roots. Also, this has led to the increase in the pH of the media where it would reduce certain micronutrients such as copper, boron, molybdenum to cause a deficiency in the soil. Lettuce and Beet are sensitive to these micronutrients which have to lead to a reduction in their growth. Potassium and Phosphorous were found in right proportions however the increase in pH could have caused its deficiency and might have affected plant growth. Mostly all the previous experiments were carried out by adjusting the pH and amending the soil with extra nutrients. However, in this experiment as a first step, we have not done any such amendments.

Also, many differences exist in installing the anaerobic systems in the small-scale digesters systems which are a source of these bio-solids, as they are not economically viable. However, many studies have revealed that installation is possible by adopting certain measures such as collecting tipping fees, cost sharing, producing and marketing these digested fibers. They can form a steady revenue stream for all those small-scale systems. Installing these systems also helps in reducing bio-solids disposal, GHG emission, enables carbon sequestration and peatland restoration which in turn blooms the biodiversity and water regulation in the downstream.

The two experiments have shown us that the ADDF has similar physiocochemical properties as of peat and the growth trails have also shown that quality of the plant grown is good compared to the commercially available soils. A little refinement is needed to be done for growing more sensitive plant species in these media. Also, DM which is parent material to fiber has shown statistically similar results in terms compared to plants grown in fiber mix. This demonstrates the fact even DM has the potential to be a plant growth media which nullifies the job of separating the fiber from DM. Further intensive research could only reveal the exact nature of DM. However, these results have demonstrated us the fact that anaerobically digested manure fibers can be used a successful plant growth media replacing environmentally unsustainable peat.

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