Effects of soil amendments on the growth of four biomass crops in Nova Scotia

By

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ABSTRACT

Biomass energy is crucial for Canada's renewable sector, but biofuel sustainability faces cost and technology challenges. To combat this, we aimed to establish a biomass production system on marginal lands using low-value crops and cost-effective biological inputs. Our objectives included assessing yield potential, comparing growth performance with and without biological inputs, and identifying optimal biological input. Using randomized block designs, we assessed four biomass crops treated with three biological inputs across two sites in Nova Scotia. The results revealed significantly higher biomass yields for switchgrass and willow treated with paper sludge in Falmouth (114% and 139% higher during establishment and 84% higher for switchgrass at Chegoggin Point by end-of-season). Consequently, switchgrass treated with paper sludge emerges as the preferred choice for grass-based biomass production. Similarly, willow treated with paper sludge demonstrated superior biomass yields for tree-based biomass production, both during establishment and end-of-season.

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1. INTRODUCTION

1.1 Global Energy Consumption

Global energy consumption has been increasing steadily over the years, and the demand for all forms of energy is continuously rising (Khanal et al., 2008). According to the International Energy Agency (IEA, 2021), the global energy demand is expected to increase by 4.5% annually through 2030 and reach 164,000 TWh by 2050, a 50% increase in global energy demand compared to 2019. Fossil fuels such as oil, gas and coal are the primary sources of energy, and their current consumption at 2009 rates will deplete the global oil reserves in 35 years, natural gas reserves in about 37 years, and coal reserves in nearly 107 years (Shafiee, S., & Topal, E., 2009). This excessive energy consumption has led to the exploited use of fossil fuels, causing global warming and climate change (Li et al., 2017).

Climate change is one of the most serious issues impacting human wellness in modern-day society. More recent developments from climate change policies have introduced advancements in the global climate observing systems that contributed to improved climate monitoring capabilities (Hartmann et al., 2013). However, even though climate change policies have significantly increased environmental awareness, the guidelines are still insufficient to make a significant difference in GHG emissions.

The burning of fossil fuels is a significant contributor to the increasing CO_2 in the atmosphere, and from a global perspective, these energy challenges result in global climate instability (Pacala, 2007). Canada is one of the top five global contributors of GHG emissions per capita (Islam et al. 2004). To mitigate this, the Canadian government has committed to reducing greenhouse gas emissions by 30% below 2005 levels by 2030 (Environment and Climate Change Canada, 2022). In addition, the 1997 Kyoto Protocol played a vital role in committing countries to use renewable energy and reduce high-carbon energy sources (Ladanai & Vinterbäck, 2009). The excessive greenhouse gas (GHG) emissions on the environment and increasing fossil fuel consumption have led to the search for sustainable and environmentally friendly energy sources (Mabee et al., 2005).

1.2 Renewable Energy Sources

Renewable energy sources like solar, wind, and biofuels have been recognized for their potential to reduce fossil fuel consumption and greenhouse gas (GHG) emissions (Pacala & Socolow, 2004). Life cycle analyses by Huo et al. (2009) demonstrate the substantial benefits of biofuels, showing potential savings of more than 88% in petroleum use and a significant reduction of 72-80% in GHG emissions compared to conventional petroleum-based fuels (Kalnes et al., 2007; Sheenan et al., 1998). Subsequently, biofuels are of interest because the fuel produced is from plants and organic wastes (Naik et al.,2010) and are the fourth largest renewable energy source (Slade et al., 2011). According to the International Energy Agency (IEA), modern bioenergy is the largest renewable energy source globally, accounting for 55% of renewable energy and over 6% of the global energy supply (IEA, 2022). In 2018, biofuels and energy from waste contributed to 2.3% of the total energy supply in 34 countries (IEA, 2020). Therefore, presuming biofuels are widely adopted in the future, they might reduce fossil fuel consumption and the world's dependence on oil and CO_2 emissions (Kitani et al., 1989).

1.3 Biomass and Biofuels

Biofuels are liquid fuels produced from biomass and are commonly used in the transport sector (Demirbas, 2007). Through fermentation and transesterification, biomass can be converted into bioethanol and biodiesel (Demirbas, 2007; Kamm et al., 2007). Most common biomass sources include wood, energy crops, plant residues, organic components of industrial wastes, algae, byproducts from plant and animal industries, and municipal solid wastes from human activities (Trinnaman & Clarke, 2004; Lainez et al., 2018). However, most biofuels produced are from plant-based biomass because plants have abundant amounts of lignocellulose (lignin, cellulose and hemicellulose) in their cell walls and which, by chemical reactions can produce biofuels like bioethanol and biodiesel (McKendry, 2002; Slade et al., 2011).

1.4 Objectives

To assess the potential of sustainably producing crop-based biomass feedstocks for the production of biofuels in Nova Scotia, a 5-year project was established with collaboration and funding from Agriculture and Agri-Food Canada (AAFC), the Nova Scotia Innovation Hub, Saint Mary's University, the Nova Scotia Federation of Agriculture, Port Hawkesbury Paper, Acadian Seaplants Ltd., ADECO BioResources Inc., and BioApplied Innovation Pathways.

The study aims to assess the effects of three locally sourced industrial byproducts or biological inputs: a liquid anaerobic digestate, a paper mill residue, and a seaweed extract on the growth characteristics of four biomass crops: switchgrass (*Panicum virgatum*), miscanthus (*Miscanthus giganteus*) and short-rotation coppiced hybrid-poplar (*Populus spp)* and willow (*Salix spp)*. In addition, plant growth characteristics, such as survival rates, moisture content, biomass yield, tissue nutrients, stem length, diameters, and volumes, were measured during the establishment year and end of the second growing season to analyze the potential effects of the biological inputs on biomass growth.

While the master's thesis presents a two-year study duration, it is important to note that the project will continue beyond this period for an additional three years, making it a comprehensive 5-year study. This extended timeframe will provide valuable insights into the long-term sustainability of the biomass production system and its potential for biofuel feedstock in the region.

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2. LITERATURE REVIEW

2.1 Need for Alternate Fuel Sources

Energy drives technological and economic development, and a country's energy choices can impact economic growth, politics, international alliances, and climate change (Chow et al., 2003). The increase in energy consumption has led to the increasing use of fossil energy, leading to climate change and eventually deterring economic development (Li et al., 2017).

The 1997 Kyoto Protocol is an important step in countries' commitment to using renewable and environmentally friendly energy sources to encourage reduced use of high-carbon energy sources (Ladanai & Vinterbäck, 2009). Based on current energy use, most energy comes from fossil fuels like petroleum, coal, and natural gas. Also note, the International Renewable Energy Agency (IRENA), in their report, stated that the global oil demand could start to decline by 2030 due to the increasing adoption of renewable energy sources and electric vehicles (IRENA 2019). In addition, burning fossil fuels significantly contributes to the rising CO_2 in the atmosphere. From a global perspective, these energy challenges result in climate instability, known as climate change. For example, in 2018, about 93% of the CO_2 emissions in the United States were from burning fossil fuels (US EPA, 2018).

2.2 Biofuels in Canada

Relative to its landmass size, Canada has one of the world's lowest populations and is ranked among the highest for greenhouse gas contributions per capita (Government of Canada 2021). According to the World Bank data from 2018, Canada's greenhouse gas emissions per capita were 16.9 metric tons of CO_2 equivalent, higher than the global average of 4.8 metric tons per capita (World Bank, 2021). To solve this, the Canadian government has agreed to bring down the emissions to 511 megatonnes of carbon dioxide equivalents (CO_2 eq) over the next decade through the Paris Agreement, relative to its 2005 level of 730 Mt CO_2 eq (Environment and Climate Change Canada, 2022). Such reductions are difficult, as more than 85% of the primary energy comes from fossil fuels (Natural Resources Canada 2017). Therefore, greener alternatives need to be developed to change greenhouse emissions significantly.

Nova Scotia lags behind in biomass energy compared to the three primary renewable energy sources (Nova Scotia Power Inc. 2019), and their energy system follows Canadian trends through its reliance on fossil fuels, with almost two-thirds of the province's electricity coming from nonrenewable sources (Nova Scotia Power Inc., 2019). Coal is the province's most prominent energy source generating around 45% of the GHGs (Nova Scotia Department of Energy, 2015). Nova Scotia is estimated to have over 400,000 hectares of marginal agricultural land, which can be used to grow purpose-grown biomass crops (Devanney 2010). Marginal lands are infertile with abiotic stresses (drought, flooding), insufficient soil nutrients, and unfit for cultivating food crops (Tóth et al., 2016). Still, most of its marginal lands are not used productively, and little research has been done to estimate their productivity.

2.3 Biofuel Sustainability

One of the main concerns about adopting biofuels as a mainstream alternative fuel source is its carbon emissions. The CO_2 released from burning biofuels equals the CO_2 absorbed by the plants during photosynthesis, and this process does not increase the net CO_2 in the atmosphere. Life cycle analysis (LCA) has often been used to assess the environmental implications of transportation fuels, particularly for comparing biofuels with their fossil counterpart (Gheewala, S. H., 2023). Life cycle analysis for biofuels will also play a key role in accessing sustainability and mitigating GHG emissions. In a study conducted by Farrell et al., 2006), biofuel production relative to fossil fuel production resulted in reduced GHGs. Also, biofuel will play a vital role in the transition to net zero carbon dioxide emissions by 2050 (IEA, 2021).

Countries like the USA, Brazil and China require billions of liters of transportation fuels per year that cannot be fulfilled from biomass crops farmed from cultivable/fertile lands. Replacing cultivable lands grown for food with biomass crops is not sustainable as it will lead to higher food prices, the "food vs fuel" debate (Runge and Senauer, 2007), deforestation and land-use change (Searchinger et al., 2008). For biofuel production to be sustainable and cost-effective, biomass crops must have a high biomass-to-energy conversion efficiency ratio, require few nutrient inputs and be grown on non-cultivable/marginal lands (Lewandowski, 2016). Adopting sustainable biomass production is essential for the transition from a fossil fuel-based economy to renewable energy (Clifton-Brown et al., 2019a).

2.4 Classes of Biofuels

Biofuels are classified into first and second-generation depending on the sources of the biomass feedstocks used to produce the biofuels and the conversion technologies to process the biomass into biofuels (Malobane et al., 2018). The first-generation biofuels are made from food crops with high lipid, sugar, and starch (e.g., corn, sugarcane, sugar beet). Hereafter, these feedstocks will be referred to as first-generation biomass crops. On the other hand, second-generation biofuels are made from non-food lignocellulosic feedstocks (e.g. forestry residues, crop residues, and municipal solid waste (Rodionova et al., 2017). Although first-generation biofuels can reduce CO2 emissions, their production process requires significant energy and resources, including fertilizers and pesticides, contributing to greenhouse gas emissions.

Additionally, using food crops for biofuel production can cause price increases and food shortages, particularly in developing countries where food security is a major concern, making first-generation biofuels unsustainable in the long term (Sims et al., 2010). Second-generation biofuels can be produced from fast-growing, high-yielding purpose-grown biomass crops (e.g. switchgrass, miscanthus, coppiced-poplar, coppiced-willow). Hereafter, these feedstocks will be referred to as second-generation biomass crops. Second-generation biomass crops can be cultivated on marginal lands and require minimal inputs, reducing first-generation biofuel's economic and environmental limitations. Some second-generation biomass crops like switchgrass, miscanthus, hybrid-poplar and willow are only grown to produce biofuels and are ideal for cultivation on most marginal lands due to their low nutrient requirements and high-water use efficiencies (Fargione et al., 2010; Heaton et al., 2008). Thus, growing second-generation biomass crops on marginal lands negates the "food versus fuel" debate and favours more sustainable biofuel production Tyner, W. E. (2008). Lignocellulosic crops such as switchgrass, miscanthus and poplar have been widely studied as potential biomass crops for biofuel production because of their low nutrient requirements and high biomass productivity (Wolf & Fiske, 2009; Hastings et al., 2008; Hansen, 1991).

2.5 Second-generation Biofuels

Biofuels derived from lignocellulosic biomass are being developed worldwide to meet multiple strategy objectives such as climate change mitigation, energy security and development of the rural economy (Nanda et al., 2015). In addition, lignocellulosic-based biofuels are potential alternatives to fossil fuels, as they are reported to reduce greenhouse gas emissions by up to 60% compared to petroleum fuel (Wolf & Fiske, 2009). Lignocellulosic biomass generally consists of three major components: cellulose, hemicellulose, and lignin. Also, there are other compounds such as resins, fats, oils and waxes. The composition of each biomass crop depends on the crop and the environmental conditions under which the crop is grown (Lemus et al., 2002).

Based on current technologies and costs, commercial lignocellulosic biofuel production still faces several challenges. One of the main factors is the availability and cost of biomass feedstocks. Since feedstocks account for a significant portion of the total production cost, the availability and cost of biomass feedstocks are critical to the commercial viability of lignocellulosic biofuels (Parrish & Fike, 2005). Also, other factors such as the efficiency of conversion technologies, the cost of enzymes and other chemicals used in the conversion process, and the overall market demand for biofuels play a major role (Parrish & Fike, 2005). Therefore, lignocellulosic crops with the highest cellulose and lower lignin content tend to produce the best biofuel yield (Fiala et al.,2018).

2.6 Perennial Biomass Crops

Two major perennial grass biomass crops grown for biofuel production in Eastern Canada are switchgrass and miscanthus (Heaton et al., 2008; Parrish & Fike, 2005). Both switchgrass and *Miscanthus spp.* are C4 warm-season perennial grasses that adjust well to various soils and climatic conditions (Sage et al., 2015). They need minimal crop inputs (e.g. fertilizers, pesticides, etc.) to grow on marginal agricultural lands (Sannigrahi et al., 2010) and have few pests or harmful diseases (McLaughlin & Adams Kszos, 2005). Switchgrass is relatively easily established from seeds, whereas miscanthus is usually planted from rhizomes (Sanderson et al., 2011). These perennial grasses can be harvested annually after establishment for up to 10 years without replanting. Such characteristics ensure that these biomass crops grown for biofuel production are well-positioned to be used as a potential low-cost and sustainable feedstock for biofuel production in eastern Canada.

2.6.1 Switchgrass

Panicum virgatum (L) of the family Poaceae is a native diploid grass (2n=18) of North America and is normally harvested annually once established (Lewandowski et al., 2003). Tolerance to heat, cold and drought has allowed it to inhabit North American areas. Switchgrass can meet both agronomic and environmental requirements to produce both forage and biofuels (Keshwani & Cheng, 2009). Switchgrass efficiently utilizes soil mineral nutrients to produce harvestable biomass with lower soil nutrient removal rates (Vogel et al., 2002). Switchgrass is also considered a vital energy crop for direct combustion and producing bioethanol or biogas (Brejda et al., 1994).

Switchgrass can be grown on marginal agricultural lands as it does not require soils with high nutrients and good physical properties (Moore et al., 2014). Schmer et al. (2008) analyzed switchgrass growth in marginal lands covering a wide range of precipitation and temperature factors. They estimated that switchgrass's annual biomass yields in marginal lands were 5.2–11.1 Mg/ha with an average estimated net energy of 60 GJ/ha, representing 540% more renewable energy produced than nonrenewable energy consumed. The study also found that the estimated average greenhouse gas (GHG) emissions of cellulosic ethanol from switchgrass were 94 percent lower than the estimated GHGs from gasoline.

In a study by Głowacka et al. (2020), switchgrass treated with anaerobic digestate showed a 37% increase in yield. However, implementing such application rates (30 m3/ha and 60 m3/ha) on a large scale, like 400,000 hectares of marginal land in Nova Scotia, requires factors like digestate availability and environmental impacts to be assessed for an economically and environmentally sustainable approach. While switchgrass generally has low fertilizer requirements, studies indicate that the response of switchgrass biomass yield to nitrogen fertilization exhibits notable variability. For instance, Haque et al. (2009) and Vogel et al. (2002) reported yield increases of 50-100%, while Guretzky et al. (2011) found a 40% improvement in biomass size and quality. Moreover, study by Wile et al. (2014), conducted in Nova Scotia, assumes significance in this context. In 2008, switchgrass exhibited markedly higher yields yielding 7.0 t per hectare, regardless of fertilizer treatment. The subsequent year, switchgrass yield declined to 4.4 t per hectare, with no substantial effect of crop type or N fertilization rate on yield observed in 2009. Chen et al. (2019) further investigated the effects of nitrogen fertilization and climatic factors on switchgrass and miscanthus yields, revealing switchgrass's better response to N fertilization but excessive N application did not increase growth. Also, they discovered that soil nitrogen uptake by switchgrass depends on the annual mean temperature and rainfall.

2.6.2 Miscanthus

Miscanthus x giganteus (2n=3x=57) is a sterile hybrid of *Miscanthus sinensis* and *Miscanthus sacchariflorus*, belonging to the family Poaceae. The genus Miscanthus commonly occurs within the grasslands of East Asia and the Pacific islands. They have C4 photosynthesis and typically grow in warm temperate and subarctic regions (Mutoh et al., 1985). Because of its low moisture and high cell wall content, miscanthus is generally regarded as a leading candidate crop for biomass production (Clifton-Brown et al., 2017). Furthermore, due to its rapid biomass accumulation rate and high nutrient and water use efficiency, miscanthus can produce increased levels of fermentable sugars that produce cellulosic ethanol (Wyman, 2007). In addition, miscanthus has shaped itself as an ideal energy crop, as they are easy to harvest and can be harvested dry (Hastings et al., 2008).

In their study, Dohleman & Long (2009) compared miscanthus and maize in terms of biomass yields. The results showed that miscanthus was 60% more productive than maize. The higher yield of miscanthus was due to its giant leaf size and the larger canopy, which allowed it to assimilate more carbon throughout the growing season.

Heaton et al. (2008) conducted the first miscanthus yield trials in the US; the tests were conducted at three locations in the Midwestern US, Illinois. The yield trials showed the highest-ever productivity in a season on record, with average harvestable yields of 30 Mg/ha with only 25 kg/ha of N fertilizer and no irrigation. Somerville et al. (2010) discuss that miscanthus has intrinsically higher water, light and nitrogen use efficiency than C3 plants. Also, its low tillage and perennial root systems increased the soil's organic carbon, preventing soil erosion. Miscanthus can mobilize its nutrients to its roots by the end of the winter; hence, harvesting during the growing season causes relatively lesser nutrient removal (Himken, M.,1997).

Lewandowski et al. (2003) conducted a multi-year study on *Miscanthus x giganteus* biomass yield in Europe. They found that the dry biomass yield ranged from 17 to 25 Mg/ha, with an average yield of 20.4 Mg/ha. The study also showed that the yield increased with the age of the crop. In the first year of cultivation, the yield was relatively low, ranging from 6.2 to 12.6 Mg/ha, but by the third year, the yield had increased to 25.8 Mg/ha.

Krzyżaniak et al. (2020) studied giant miscanthus cultivation on marginal soil with various fertilization treatments. They found that using organic fertilization alone resulted in a yield of 19.2 t/ha, significantly higher than the yield obtained with chemical fertilization (16.4 t/ha). The study also conducted a life cycle assessment which evaluated the environmental impacts of the different fertilization treatments and found that using organic fertilization had lower environmental impacts than chemical fertilization.

2.7 Coppiced Woody Biomass Crops

Woody biomass offers several advantages over herbaceous biomass. First, wood biomass is available year-round from multiple sources, so end-users do not rely on a single resource. Second, the net energy ratios associated with biofuels from woody biomass are extensive, meaning that more energy is produced than in other plant-based biomass systems (Keoleian and Volk 2005). Third, coppicing is a traditional practice of cutting back woody trees or shrubs to their base, promoting the regrowth of new stems from the stump (Knoke et al., 2005). Coppiced hybrid-poplar (*Populus x hybrid*) and willow (*Salix sp*.) are the two most common short-rotation woody biomass crops grown for biofuel production. Compared to growing full-sized trees, coppicing has several advantages, such as faster growth rates, higher wood quality, and lower harvesting costs (Rackham, 2003). SRC (short rotation coppice) is a farming method to cultivate fast-growing trees. SRCs are usually done on high-yielding woody biomass crops like poplar and willow and are harvested on a 3–5 years rotation for 15–30 years (Aylott et al., 2008).

2.7.1 Hybrid Poplar

Populus spp. (2n=38), belonging to the family Salicaceae can attain impressive heights ranging from 15–50 m, with trunks up to 2.5 m in diameter. However, regular coppicing is implemented for managed biomass production to maintain a more manageable height, allowing for efficient harvesting (Ceulemans et al., 1996).

Many fast-growing hybrid clones of Populus trees have been planted in the Northern Great Plains. These hybrids are created by crossing Cottonwood (*Populus deltoides*) and Black Poplar (*Populus nigra*) and are called *P. x euramericana* hybrids. They are hardy, male, single-trunked poplar, have rapid growth, and have fairly good disease resistance (Gilman & Watson, 1993). Hybrid-poplar is one of the fastest-growing trees in North America and is used for biofuel production (Bradshaw et al., 2000). Hybrid poplars have high productivity, even in marginal lands with low soil fertility, and a yield of 7.9–11.8 Mg/ha dry per year in the US (Sannigrahi et al., 2010). Verlinden et al. (2015) found that coppiced poplar trees were harvested at around 2 m height after three growing seasons. Despite their rapid growth, with rates of approximately 4 feet per year in height and 0.5 inches per year in diameter (Brooks, 2013; Clatterbuck, 2004), controlled coppicing ensures sustainable above-ground biomass productivity and enables repeated growth cycles for renewable biomass feedstock.

Hybrid poplars used for biomass production are developed by intra and interspecies hybridization (Isebrands and Richardson, 2014). Hybrid poplars have outstanding vegetative regenerative capabilities and high biomass multiplication rates (Aylott et al., 2008). When used for biofuel production, short-rotation crops like poplar and willow can decrease fossil fuel use and reduce CO_2 emissions (Jug et al., 1999).

Short rotation coppices of poplars are used as dedicated biomass crops because of their low nutritional and maintenance requirements. In addition, these coppices are easy to harvest and produce more yield per harvest because of their multiple branches.

According to a study by Labrecque and Teodorescu (2005), poplars and willows showcased their suitability for cultivation in marginal lands in Canada, achieving significant biomass yields during the establishment phase even in the absence of fertilization. Poplars, specifically the taxa NM6 and NM5 (*Populus maximowiczii* x *P. nigra*), attained above-ground biomass of 66 to 72 tons per hectare after their first 4-year growing cycle. Similarly, willows, including *Salix miyabeana* (SX64) and *S. sachalinensis (SX61*), produced high biomass yields of 62 to 68 tons per hectare. These findings highlight the potential of poplars and willows as promising options for biomass production in marginal lands in Canada.

Schweier et al. (2017) calculated the environmental impacts of technological and agronomic practices of hybrid-poplar SRC cultivation on marginal land in Southern Germany. The results showed that poplars grown in marginal lands had similar yields to fertile soils and reduced nitrate leaching and soil nitrous oxide emissions.

Gruenewald et al. (2007) analyzed tree species compatibility like poplar and willow in low fertile marginal lands. The compatibility was accessed based on the crop's biomass yield and biomass-to-energy conversion ratio. The results showed poplars had the highest productivity in marginal lands.

2.7.2 Willow

Salix spp (2n=28) belongs to the family Salicaceae. They are deciduous trees widely found in the north's cold and temperate regions (Karp et al., 2011). Willow has widely been domesticated for bioenergy since the seventies in North America and Europe. In North America, its production was started again in the mid-1980s (Stott, 1992; Clifton-Brown et al., 2019). Willow can be harvested within a year of growth which helps produce higher biomass yields in shorter periods (Keoleian and Volk 2005).

Zamora et al. (2014) evaluated the growth, biomass productivity, energy content, and potential ethanol yields of willow hybrids. The study was conducted in Wadena County in central

Minnesota. The researchers found that willow hybrids performed better than native willow accessions. In addition, the research shows willow hybrids have a more significant potential for biomass energy on marginal lands in central Minnesota.

Amichev et al. (2012) conducted a simulation approach for willow biomass generation in marginal lands. Around 2.12 million hectares were estimated for willow biomass generation in Saskatchewan, Canada. The simulation approach showed that willow plantations had produced the average biomass yield at a rate of 12 Mg/ha for seven consecutive harvests over 21 years. Cannell et al. (1988) investigated the light use efficiency and the leaf area changes when modifying the canopy structure for two woody biomass crops, poplar and willow. The results from the study showed willow had better results from canopy modification compared to poplar. The higher the leaf area of the plants, the more efficient will be the photosynthesis. According to the study, Canopy modification in willow could increase biomass yield (Cannell et al., 1988).

2.8 Marginal lands

Marginal lands can be defined as unproductive or unacceptable lands that are unfit for food crop production due to poor soil/land properties. Marginal lands are characterized by their limited suitability for conventional agricultural crop production. The concept of marginal land is often defined using a land suitability rating system (LSRS) in Canada, which evaluates land compatibility based on soil, climate, and landscape factors. Within this system, lands are categorized into seven distinct classes, ranging from highly suitable (class 1) to unsuitable (class 7). Intermediate classes, specifically classes 3 and 4, denote lands with moderate to severe limitations that render them marginal for specific agricultural production purposes (Agronomic Interpretation Working Group, 1995). Lands falling within classes 3 and 4 may exhibit conditions that challenge traditional agricultural practices, such as reduced fertility, poor drainage, or susceptibility to erosion (Peterson & Galbraith, 1932). However, they offer potential for sustainable biomass cultivation, optimizing resource utilization and mitigating environmental impacts. Canada has a large area of marginal land that might be suitable for energy crop cultivation. It is estimated that about 9.48 million hectares of marginal land in Canada can be utilized for lignocellulosic biomass crops (Liu et al., 2012). Using marginal land to produce cellulosic feedstocks could avoid issues raised due to replacing cultivable lands used for food for biomass production (Skevas et al., 2014). However, not all marginal lands will be suitable for planting energy crops because of environmental stresses such as drought and cold, which may be unsuitable for certain biomass crops. Hence, marginal land compatibility varies depending on the biomass crop's environmental and physiological needs (Lewis & Kelly, 2014). Lignocellulosic biomass crops grown on marginal lands can reduce groundwater contamination and greenhouse gas emissions (Hill et al., 2006). Therefore, using marginal lands to grow energy crops could be a viable option to eliminate food and environmental problems (Qin et al., 2011). Purpose-grown biomass crops like switchgrass, miscanthus, hybrid-poplar and willow can be cultivated on marginal lands due to their lower nutrient requirements and higher water use efficiencies (Fargione et al., 2010; Heaton et al., 2008).

2.9 Biological Inputs

A soil amendment is any material that would improve or maintain its physical, chemical or biological properties upon addition to the soil. Inorganic fertilizers are becoming increasingly expensive due to their high production costs and energy-intensive nature. The extensive use of inorganic fertilizers may also contributes to increasing greenhouse gas emissions (Walsh et al., 2012).

Fertilizer application is the standard way to provide essential nutrients to plants (Tandon, H.L.S, 1992). Organic fertilizers such as agricultural, organic manure and municipal waste have great potential to improve soil productivity and crop yield. However, intensive soil fertilization using mineral fertilizers has led to problems such as high cost, nitrate pollution, and soil-carbon loss (Tilman et al., 2002). To address these issues, fertilization with organic matter has been proposed as a more sustainable approach to agricultural production (Gomiero et al., 2011). However, not all farmers use organic fertilizers for various reasons, including limited availability and accessibility, higher initial costs, and lack of knowledge and training on their use (Teasdale and Mohler, 2000; Smukler et al., 2010). Thus, some farmers may hesitate to switch to organic fertilizers due to concerns about potentially lower yields or the quality of their crops.

Nutrient discharges from organic wastes vary depending upon the quality, and organic soil amendments such as paper mill residue, anaerobic digestate and seaweeds are proven to show positive effects on plant growth and are used as potential sources of nutrients (Aitken et al., 1998; Bhatnagar & Mutnuri, 2015; Rayorath et al., 2008). The application of biofertilizers could enhance the quality and yield of many biomass crops (Vessey, 2003), and more recently, there is evidence of many biological inputs like anaerobic digestates etc., improving the growth of biomass crops (Peters et al., 2017; Fei et al., 2017). Applying such biological inputs can enhance biomass production efficiency, leading to a novel approach to lower biomass feedstock's cost and sustainability.

2.9.1 Paper Mill Sludge

The pulp and paper industry is considered a large user and producer of biomass-based byproducts (Svensson & Berntsson, 2014). Paper-mill industries generate several types of sludges from primary and secondary treatment of wastes derived from virgin wood fiber sources, recycled paper products, and non-wood fibers (Camberato et al., 2011). Paper mill sludges generally have lesser metal concentrations than most municipal waste biosolids and are well within regulatory limits (Camberato et al. 1997)

Papermill sludge applications to soil may profoundly affect soil's biological, physical, and chemical properties. For example, Gagnon et al. (2001) found that adding paper sludge increased the microbial activity and the activity of several enzymes (fluorescein diacetate, acid phosphatase, arylsulfatase, and urease) 11 months after application. Also, the increase in soil organic matter from applying paper sludge depends on sludge composition, the rate, and the frequency of the complete application (Camberato et al., 2006).

Aitken et al. (1998) determined the effects of paper mill residues on crop yield and nitrogen uptake. Their study investigated the soil's moisture content and nutrient concentrations after applying the paper mill residue. The results showed that applying paper mill residues did not significantly affect crop yield. But they resulted in nitrogen immobilization in the soil, thereby decreasing nitrogen availability for the plants. Although this effect was observed for two years, soil nitrogen and crop yield were slightly higher by the third year. This effect was because the nitrogen immobilized in the ground may slowly become available after two years. Also, when applied, paper mill residues induce nitrogen and phosphorus immobilization. Aitken et al. (1998) had an issue with nitrogen immobilization. Nitrogen immobilization can inhibit the plant from N assimilation. N immobilization can be prevented by delaying the planting of crops until the residue is completely decomposed. Decomposing the residues and then applying them to the soil can have a lesser impact on nitrogen immobilization.

Increasing organic matter increases the water-holding capacity. Camberato et al. (2006) review papers based on paper mill residues on plant growth. Paper mill residues can improve water-holding capacity in soils by increasing the soil organic matter content. The organic matter in paper sludge helps to improve soil structure by promoting the formation of stable aggregates, which creates pore spaces that can hold water. In addition, the organic matter in paper sludge has a high cation exchange capacity, which allows it to attract and retain positively charged nutrient ions, such as calcium, magnesium, and potassium. These nutrient ions help to improve soil structure and water-holding capacity by promoting the formation of stable soil aggregates.

Furthermore, the organic matter in paper mill sludge can also help to reduce soil compaction, which can further improve water holding capacity by increasing the volume of pore spaces in the soil (Camberato et al. 2006). Also, to note is that studies have shown the positive effect of paper mill residues on plant growth over a 2-3-year period; they found paper sludge increased plant growth in the first year after application, however in the second and third years, the positive effects diminished (Camberato et al., 2006). The transient nature of this effect could be attributed to the fact that the organic matter in paper mill residues decomposes over time, and its beneficial effects on soil properties gradually decline (Camberato et al., 2006).

2.9.2 Anaerobic Digestate

The anaerobic digestion process, also termed biogas production or bio-methanation, was highlighted for the first time in 1776 by Alessandro Volta in his conclusion that there was “a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced” (Ahring, 2003). Since then, anaerobic digestate has been used primarily to produce biogas from manure and domestic waste (Angelidaki et al., 2003). The nutrient content of anaerobic digestates depends mainly on the nature of the feedstock, and the digestion process is rich in organic carbon and other essential nutrients for fertilizers (Alburquerque et al., 2012).

Bhatnagar et al. (2015) address using anaerobic digestate as a potential fertilizer; the study analyses the growth effects of vegetable crops fertilized with the digestate. The biogas feedstocks used in this research produced about $30m^3$ of methane per day. The study's results showed that digestate increased growth by 60% in tomatoes, 48.6% in chillies and 97% in brinjal compared to the control.

Nkoa (2014) compiled information about anaerobic digestates, their environmental effects and sustainability as fertilizers. Anaerobic digestates can contribute to sustainability by reducing fertilizer costs, nitrate pollution, and soil carbon loss. The review article stated that anaerobic digestates could be used as an organic amendment and are less harmful than aerobic digestates as aerobic digestion occurs in the presence of oxygen, which can produce nitrous oxide, a potent greenhouse gas. Additionally, aerobic digestates can contain high salts that accumulate in the soil and affect plant growth. Anaerobic digestates can improve the physical properties of soil by reducing bulk density and increasing the saturated hydraulic conductivity and moisture retention capacity (Garg et al. 2005). Thus, anaerobic digestates are much better than aerobic digestate. Also to note, anaerobic digestates contain relatively higher amounts of NH3/NH4 than other organic fertilizers, thus emitting more ammonia (Alburquerque et al., 2012; Vallejo et al., 2006).

Tambone et al. (2010) investigated the agronomic properties of anaerobic digestates by estimating the chemical, spectroscopic and biological properties. However, there are no proper guidelines for applying anaerobic digestates, as a higher dose might result in soil toxicity and pH imbalance. Nevertheless, the results from this study are comprehensive, which overall suggests from a fertilizer aspect that anaerobic digestates have high nitrogen, phosphorous and potassium concentrations. Furthermore, they are in readily available form, which can improve crop growth.

Gutser et al. (2005) compared the characteristics of 15 sources of organic soil amendments. They found that anaerobic digestates had the fifth highest fertilizer value below organic sources such as urine, poultry sludge, dried poultry droppings and bone meal. The study also shares that anaerobic digestates were interestingly ahead in fertilizer value compared to traditional sources such as cattle slurry, solid manure, sewage sludge, green manure, and bio-compost. Also, Herrmann et al. (2013) found similar results. Anaerobic digestates produced by the co-digestion of animal sludge and maize have a relatively higher nitrogen fertilizer value of 30% than cattle and pig sludge. In addition, researchers have shown that anaerobic digestates have similar or greater crop performance than corresponding undigested animal manures and slurries, demonstrating their high fertilizer value and efficacy (Bachmann et al., 2011; Möller et al., 2015; Chantigny et al., 2007).

Haraldsen et al. (2011) investigated the effects of liquid anaerobic digestates on barley. They found that anaerobic digestates performed the same as the mineral NPK fertilizer Fullgjødsel®, which led the authors to recommend the digestate for cereal production.

2.9.3 Seaweed (*Ascophyllum nodosum*) Extract

In agriculture and horticulture, seaweed has been used as animal food, soil conditioner, manure, and liquid extracts as growth promoters and crop protectants against pests and diseases. The predominant species in the North Atlantic Ocean used for making biostimulating extracts is *Ascophyllum nodosum*, belonging to the brown algae family Phaeophyceae. Seaweed extracts are made from storm-cast or freshly cut seaweed. (Verkleij, 1992). *Ascophyllum nodosum* extracts are a common component in commercial formulations, and their application has been proven to significantly increase yield, biometric characteristics, and the quality of several crops (Abel-Mawgoud, 2010; Mattner et al., 2013; Ali et al., 2016). *Ascophyllum nodosum* is a brown alga that grows in marine environments like shallow coasts and backwaters. They are predominantly found in the rocky intertidal zones of the Atlantic shores of Nova Scotia and New Brunswick, Canada (Ugarte et al.,2006). Di Stasio et al. (2018) did an investigation using tomato plants grown in a greenhouse at the experimental station of the University of Naples, Italy. The main goal of this research was to analyze the effects of *A. nodosum* on the tomato crop exposed to increased salinity and nutritional deficiency. Results from the study prove that plants had improved water relations under stress treatment and several fruit quality traits. In addition, the seaweed extract also increased the ions content required for adaptation to salinity. Fei et al. (2017) investigate the effects of three beneficial soil microbes (*Azospirillum brasilense, Penicillium bilaii* and *Variovorax paradoxus)* and *Ascophyllum nodosum* extracts on the growth of three clones of hybrid-poplars and two cultivars of switchgrass grown under greenhouse conditions and on marginal land. This experiment explored the potential enhancement to yield and productivity of the biomass crops by applying the beneficial soil microbes and the *A.nodosum* extract. Also, the results from this study show that the application of the seaweed extract only had a slight increase in crop growth compared to the control in poplar, while there was no effect in switchgrass.

Sabir et al. (2014) investigated grapevine’s growth, nutrient accumulation, yield, and quality responses to applying *A.nodosum* extract over two years. Although the extract did not increase vine yields, it increased leaf chlorophyll concentration. In addition, the study found that the minerals in algae alone did not lead to increased growth reactions. However, various biologically active compounds present in seaweed extracts were identified as beneficial to help plants cope with different abiotic stresses, such as salinity, drought, and extreme temperatures. The study further suggests that while the minerals in seaweed extracts may not be enough to promote plant growth, they can aid plants in overcoming abiotic stress when used in combination with nutrient fertilizers.

3. MATERIALS AND METHODS

3.1 Site Characterization

A total of seven sites were established across Nova Scotia to test the growth potential of four biomass crops on marginal agricultural lands (Fig.3.1.1). Two of these sites, located at the Cann Farm Chegoggin Point, NS (43°51'22.2"N 66°10'06.7"W), and the Corradini Farm, Falmouth, NS (45.006338, -64.164868), are the focus for this thesis research.

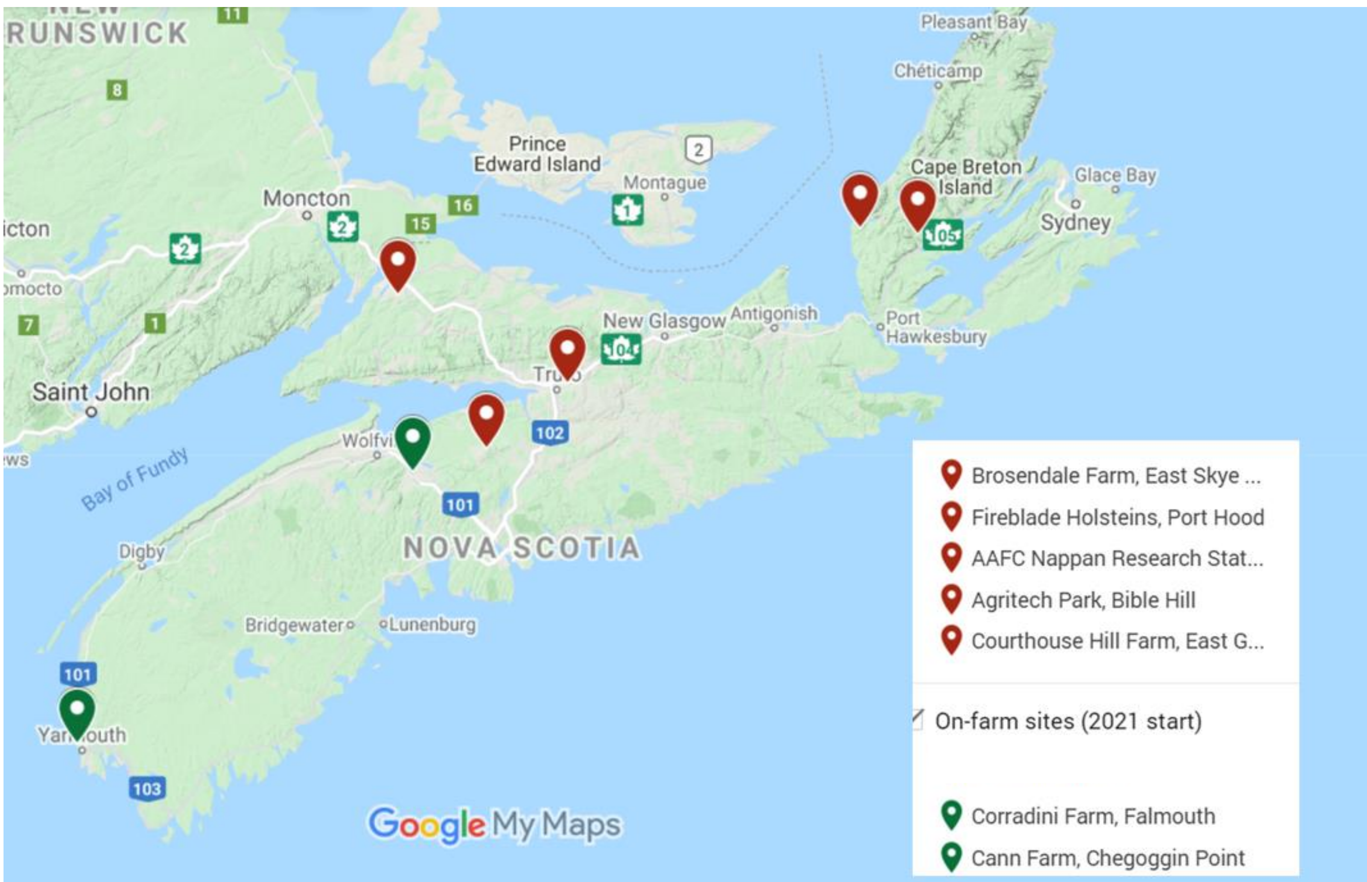


Figure 3.1.1 Location of the seven research sites in Nova Scotia testing biomass crops. Five sites were established in 2019 (red markers), and two sites in 2021 (green markers). The image was created in Google Maps™.

The Chegoggin site (Fig.3.1.2) is situated along the sea facing the Gulf of Maine. The site's total area was approximately 1.03 acres with a total area of 4165 m^2 (Fig.3.1.3).

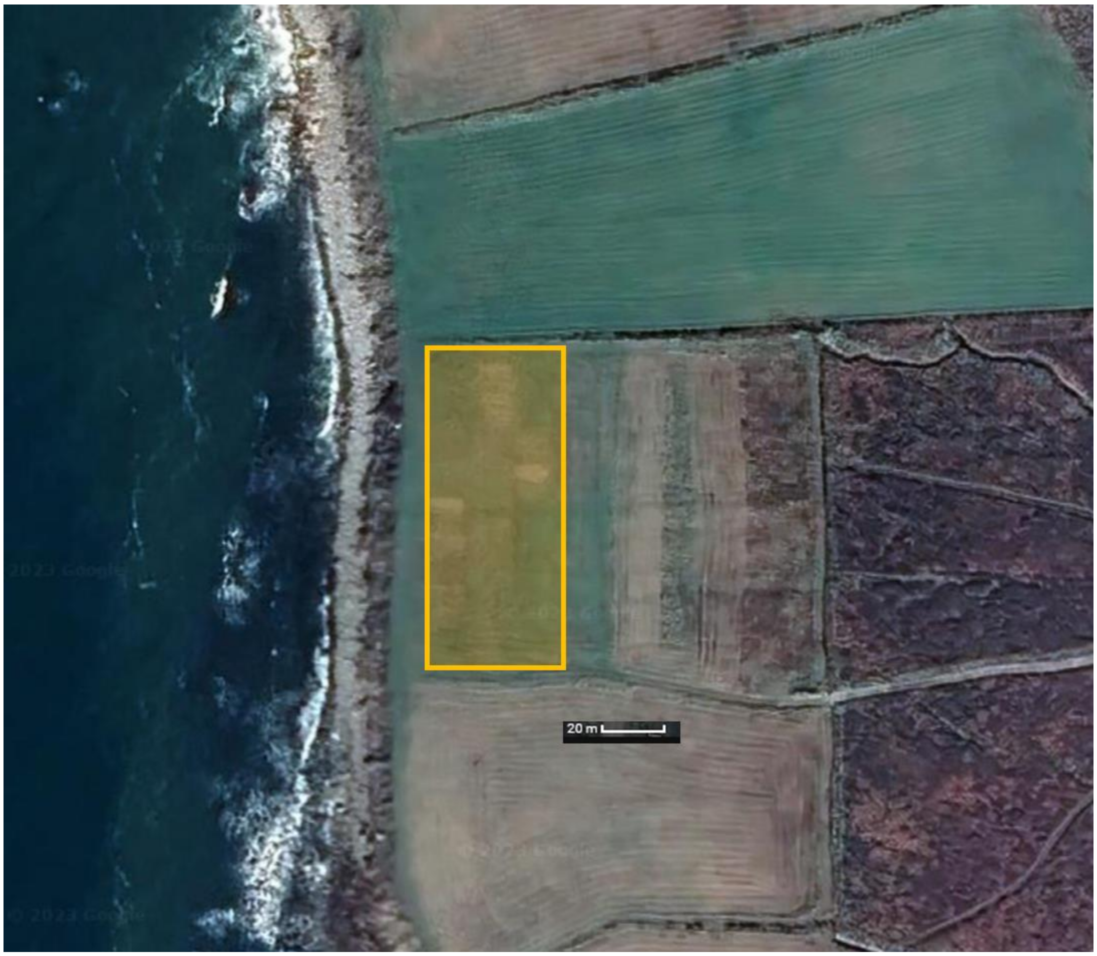


Figure 3.1.2 Location of Chegoggin Point site with plot area highlighted. The image was created in Google Maps™.

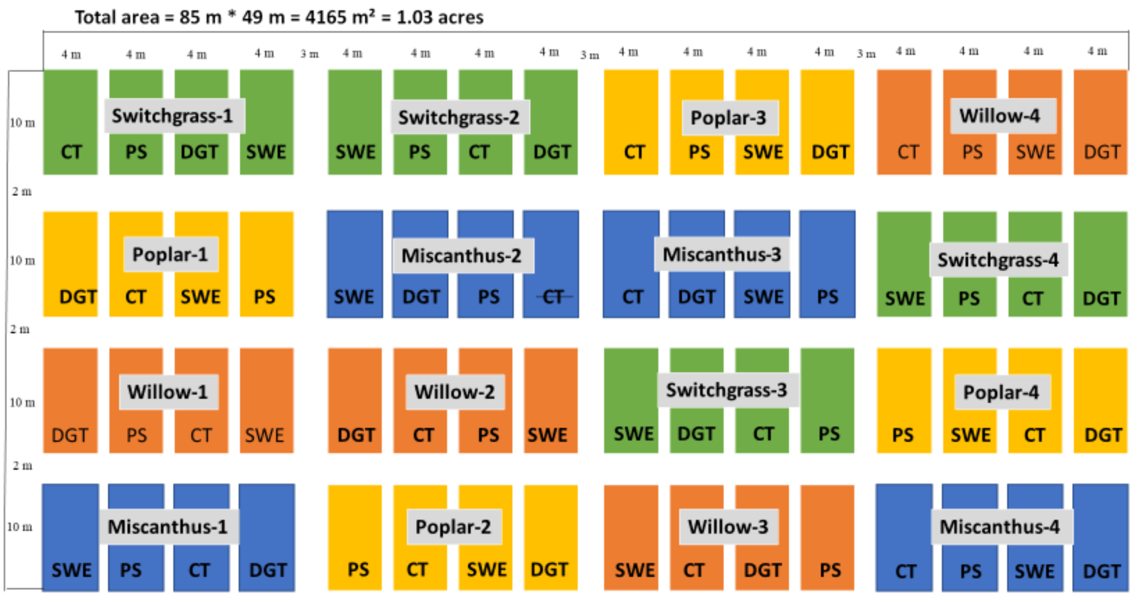


Figure 3.1.3 Plot design and layout for the Chegoggin Point site. Soil amendment treatments: CT – Control; PS- Paper Sludge; DGT- Digestate; SWE- Seaweed.

The Falmouth site (Fig.3.1.4) is located downslope from a highway (NS-101), with farmlands and a willow plantation nearby. At Falmouth, after initial site analysis, the border space was too narrow and lacked space around the perimeter. Thus, the normal distance between the plots (3 m) was reduced to 2 m to allow more space around the borders. After modifications, the final layout was measured to be 0.93 acres with 3772 m^2 (Fig.3.1.5).

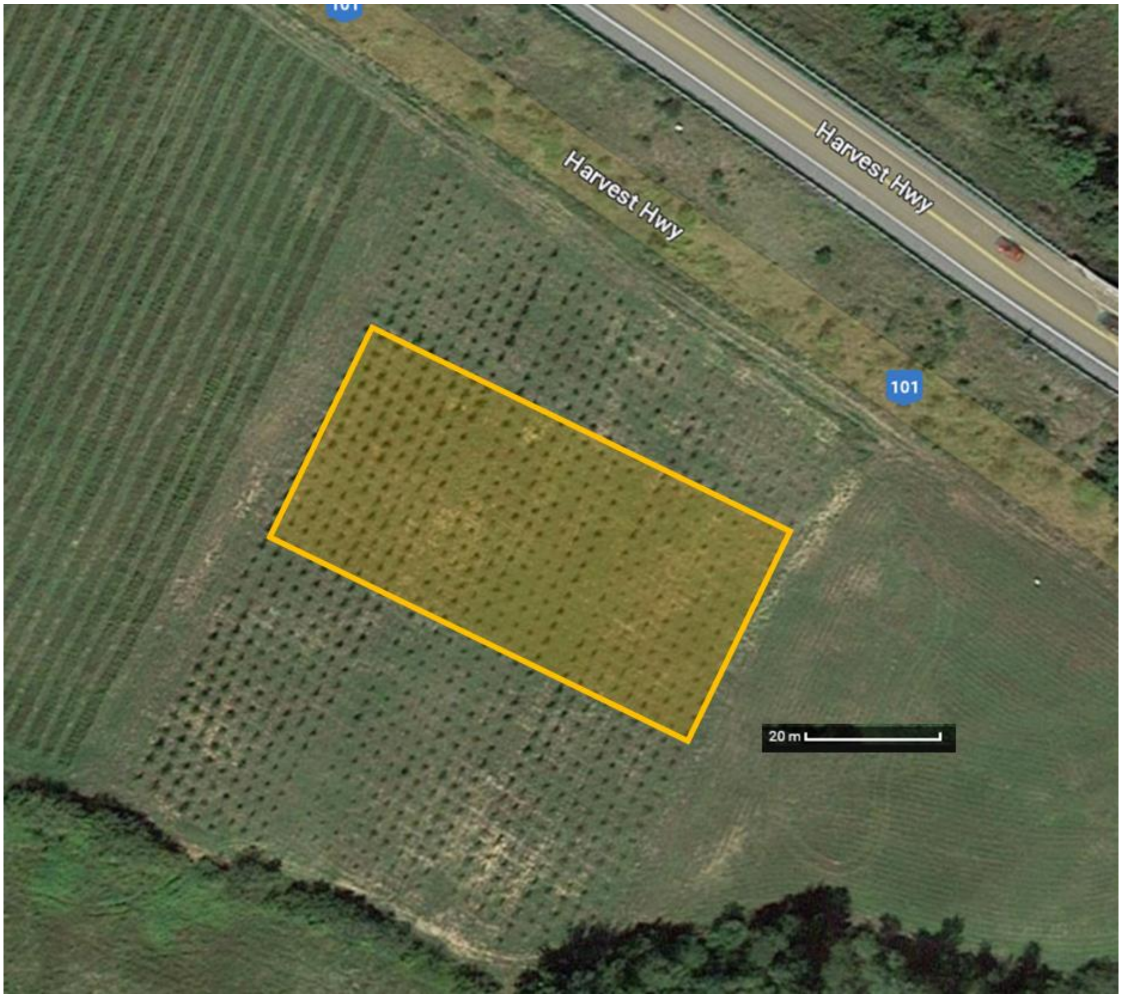


Figure 3.1.4 Location of Falmouth site, with plot area, highlighted. The image was created in Google Maps™.

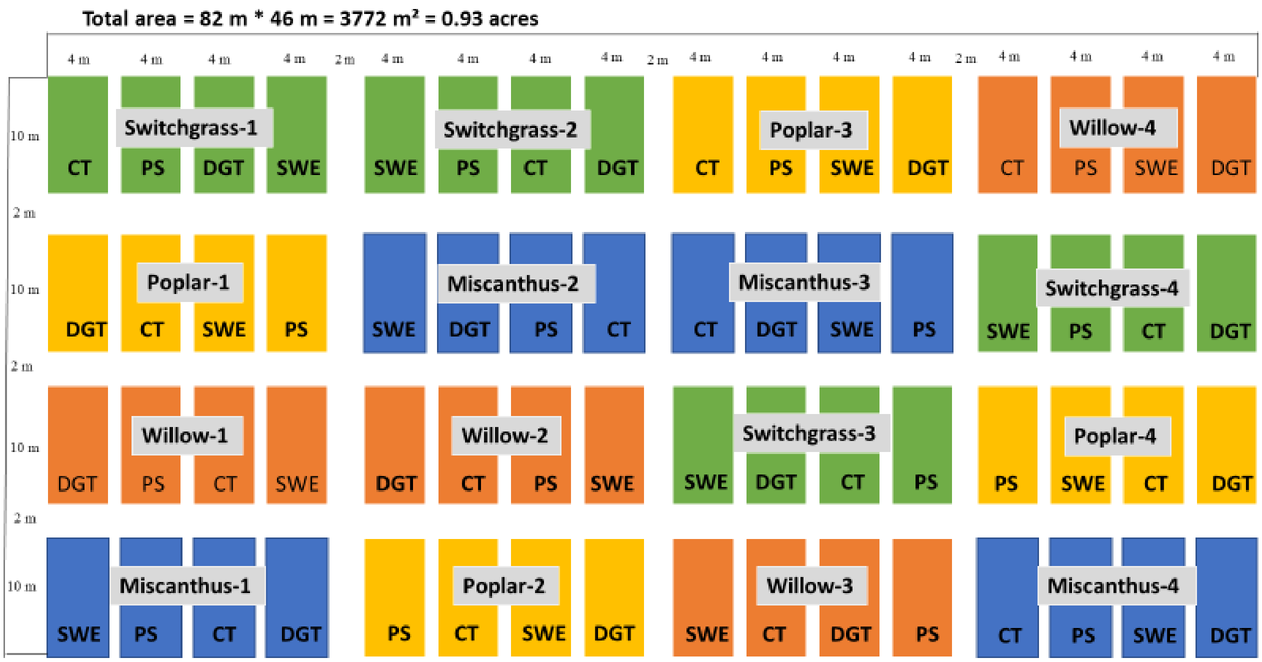


Figure 3.1.5 Modified layout for the Falmouth site with 2m between subplots instead of 3m. Soil amendment treatments: CT – Control; PS- Paper Sludge; DGT- Digestate; SWE- Seaweed.

Table 3.1.1 Site characteristics for the Falmouth and Chegoggin Point sites.

Characteristics	**Chegoggin Point**	**Falmouth**
Classification	Rego Gleysol	Orthic Sombric Brunisol
Soil series	Deerfield	Cumberland
CLI:	3P – 5W	3TW
Previous 5-year cropping history	Unimproved hay field	Short-rotation coppiced willow

The Canada Land Inventory (CLI) provided by the Canadian Soil Information Service determined the soil series and classification shown in Table 3.1.1 (Canadian Soil Information Service, 2021). The initial assessment helped define the soil profile, series, parent material, drainage, and water table. Hilchey et al. (1960) was used to identify the soil horizons, pH, colour, and soil characteristics. In the site characterization for the Chegoggin Point and Falmouth sites, the CLI (Canada Land Inventory) values were indicated as Chegoggin Point 3P – 5W and Falmouth 3TW. The CLI values represent land capability classifications and land use suitability ratings based on a specific coding system used in the Canada Land Inventory assessment. The code "3P – 5W" for Chegoggin Point signifies that the land is classified as having a moderate agricultural capability (Class 3), which comes with moderately severe limitations that restrict the range of crops or require special conservation practices. The subclass "P" indicates the presence of stoniness in the soil, while "5W" points to woodland and very severe limitations that restrict the land's capability for producing perennial forage crops, although improvement practices are feasible, and “W” indicates excess water conditions. Similarly, the code "3TW" for Falmouth indicates a moderate agricultural capability (Class 3) with adverse topography “T” and excess water conditions “W” (Canadian Soil Information Service, 2021). The soil at the Chegoggin Point site is a fine-textured sandy loam with a moderate quantity of rocks. The soil at Falmouth was sandy with a mixture of rocks, silt, and clay. The soil limitations at both sites were stoniness and poor drainage, especially in Falmouth. The soil samples from both sites weighing 1kg from a 0-15cm depth were collected and were analyzed for soil nutrients.

HOBO ® data recorders (H21-USB) were installed on both sites shortly after field establishment, with moisture sensors (S-SMx -M005) and a temperature sensor (S-TMB M0xx) located 15 cm below the soil surface. Soil temperature and moisture data were collected.

3.2 Planting Materials

Figure 3.2.1 Planting materials used for the study (clockwise from left), switchgrass seeds (A), miscanthus rhizomes (B), poplar cuttings (C) and willow cuttings (D).

Switchgrass (*Panicum virgatum* cv Cave-in-Rock) (Fig.3.2.1A) were sourced from Ferme Norac, Inc., St-Timothée, QC. Miscanthus (*Miscanthus* x *giganteus)* rhizomes of the variety 'Nagara' were obtained from the Miscanthus nursery at the AAFC Nappan research farm (Fig.3.2.1B). Hybrid-poplar cuttings (*Populus nigra* × *P. maximowiczii* clone NM-6) were sourced from Dr. Derek Sidders, Canadian Wood Fiber Centre, Natural Resources Canada, Edmonton, AB. (Fig.3.2.1C) Willow cuttings (*Salix miyabeana* cv SX67) were sourced from Agro Énergie, Inc., St-Roch de l'Achigan, QC (Fig.3.2.1D).

3.3 Biological/Soil Amendments

Figure 3.3.1 The soil amendments (left) of anaerobic digestate (A, B), papermill sludge (C), and seaweed extract solution (D).

The soil amendments used in this study were sourced from different places throughout NS. The anaerobic digestate was obtained from a biogas production facility sourced from T.E. Boyle Farm & Forestry Limited, Tracadie, NS (Fig. 3.3.1A, B). The paper mill "sludge" (Fig.3.3.1C) is a wood fiber residue obtained as a byproduct of the Port Hawkesbury Paper mill in Port Hawkesbury, NS. The seaweed *(Ascophyllum nodosum)* extract, Stella Maris™ (Fig.3.3.1D), was obtained from Acadian Seaplants Ltd., Dartmouth, NS.

3.4 Planting

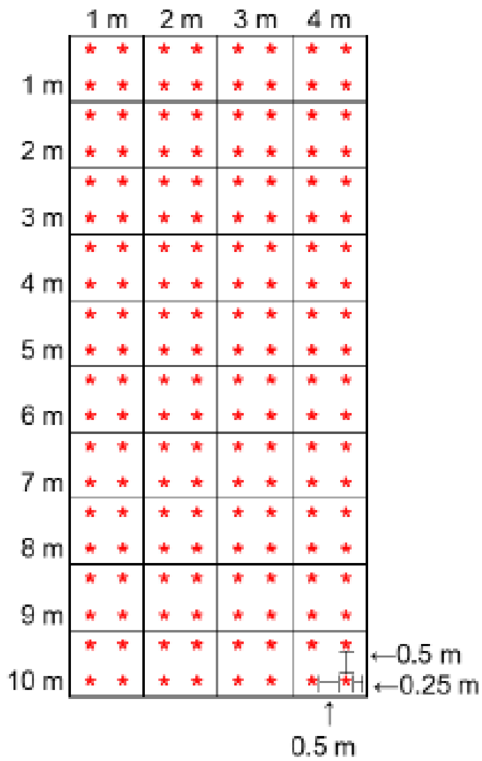


Figure 3.4.1 Planting design for switchgrass subplots (160 spots/site).

The planting was done manually from June 30, 2021, to July 7, 2021, at the Chegoggin Point site and from July 31 to August 9, at the Falmouth site. The Falmouth site was prepared by removing the pre-existing willow plantation with heavy machinery; both sites were ploughed and tilled to prepare the soil for planting. A rotary tiller was used to break up any remaining clumps of soil. Switchgrass seeds were pretreated at 4 ºC for five days in both sites before sowing to break potential dormancy. The seeds were hand sown into “seeding circles” on the soil surface of 0.25m diameter with a total of 160 circles/subplot (Fig.3.4.1). These seeding circles were used to attempt to have a relatively even distribution of the switchgrass while still enabling the application of the soil amendments and the biostimulant (see below). There were 20 rows (each 4 m in length) of these seeding circles, with eight circles per row within each subplot, and each circle was approximately 0.25 m in diameter (~500 cm2). There were approximately 0.5 m between the center of each seeding circle within and between rows providing a relatively even distribution of plants within each subplot. For each seeding circle, 1 g of seeds (~500 seeds/seeding circle) were sown. The sowing was planned before a rainy day to aid the germination.

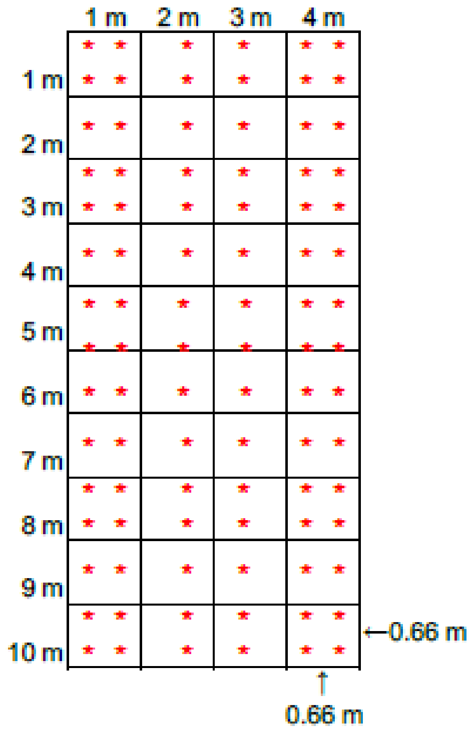


Figure 3.4.2 Planting design of Miscanthus subplots (90 plants/plot)

For miscanthus, the planting was done by rhizomes collected from a previously established site (Nappan). The rhizomes were stored in a cold environment between harvesting and planting. The rhizomes were then trimmed such that there was at least one growing bud per rhizome, and then they were planted with buds facing upward in 4-5 inches-deep holes. A spacing of 0.66m between rhizomes was used, and with 90 rhizomes/subplot (Fig.3.4.2).

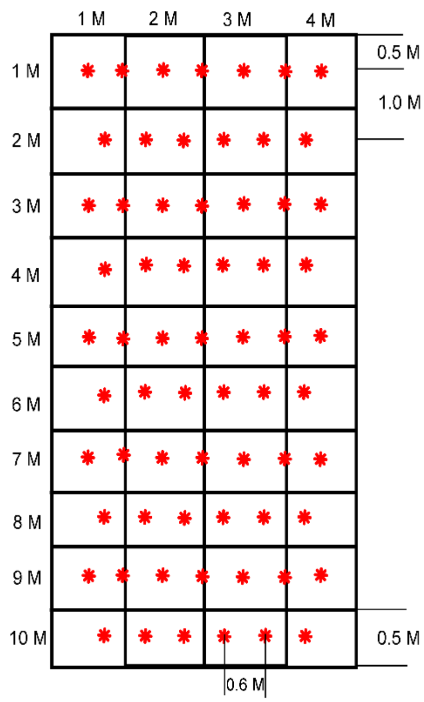


Figure 3.4.3 Planting design of poplar and willow (65 cuttings)

Poplar and willow cuttings were planted in each subplot following the single design. In this method, the cuttings were planted 1 m between rows and 0.6 m between cuttings within each row for a total of 65 cuttings/subplot (Fig 3.4.3). The cuttings were approximately 20-30 cm long and stored in cold temperatures before planting to prevent budding. The cuttings were soaked in water the day before planting to enhance the establishment. In the Chegoggin Point site, the rocks beneath the topsoil, and their compactness, made it difficult to plant the cuttings. Thus, holes were poked by beating with a hammer on a sharp metal rod. While at Falmouth, simply pushing the cuttings into the soil was sufficient. The cuttings were planted in such a way that there’s at least 10cm of stem above the ground.

Figure 3.4.4 Crop emergence two weeks after planting at the Chegoggin Point site (from left switchgrass(A), miscanthus(B), poplar(C) and willow).

Figure 3.4.5 Crop emergence two weeks after planting at the Falmouth site (from left switchgrass(A), miscanthus(B), poplar(C) and willow).

Two weeks after planting at both sites, switchgrass had germinated in all the seeding circles, and the trees had new leaves (Fig 3.4.5 &3.4.6). However, only 5% of the miscanthus rhizomes have had their shoots emerge at both sites.

3.4.1 Miscanthus replanting (2022)

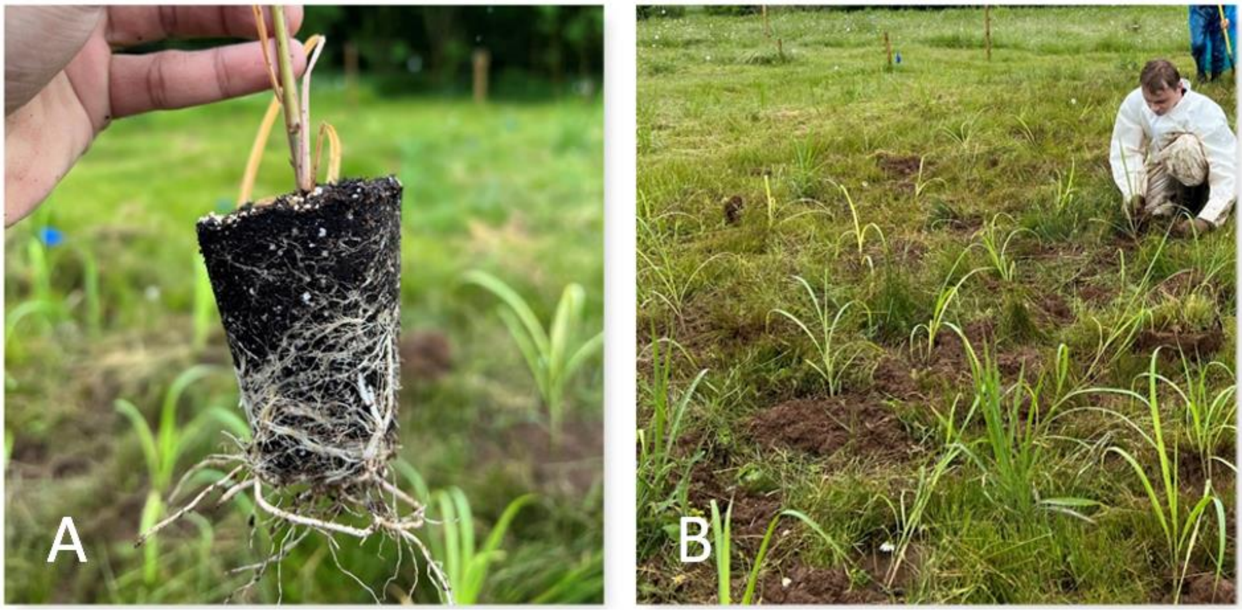


Figure 3.4.1.1 Miscanthus plantlets just prior to planting (A) and control plot during replanting (B).

After the winter of 2021-22, it became apparent that miscanthus had failed to establish at the Chegoggin Point site, with survival rates of less than 1% and less than 25% survival at the Falmouth site. To investigate the reasons for this failure, the miscanthus plots were replanted with tissue-cultured plantlets (Fig.3.4.1.1A) instead of rhizomes on June 13-14, 2022, at the Falmouth site and on June 23, 2022, at the Chegoggin Point site. Notably, the tissue-cultured plantlets were only used in the control plots (Fig.3.4.1.1B) as part of the evaluation process. Replanting was done to determine if the failure of the miscanthus to establish itself in 2021 was due to poor-quality rhizomes or some other edaphic or environmental factors. Miscanthus plantlets were generated via in vitro tissue culture (Fei et al. 2019) from dormant buds isolated from Miscanthus × giganteus cv. Nagara was collected from mature plants growing at the Agriculture and Agri-Food Canada (AAFC) research farm in Nappan, NS. The tissue-cultured plantlets were planted at a density of 90 plants per subplot, with a spacing of 0.66 m between plants. Each plantlet was carefully placed in a hole, ensuring that the roots were entirely covered with soil, and the hole was then gently pressed down to secure the plantlet in place. After replanting, most of the plantlets emerged within 14 days.

3.5 Soil Amendments Applications

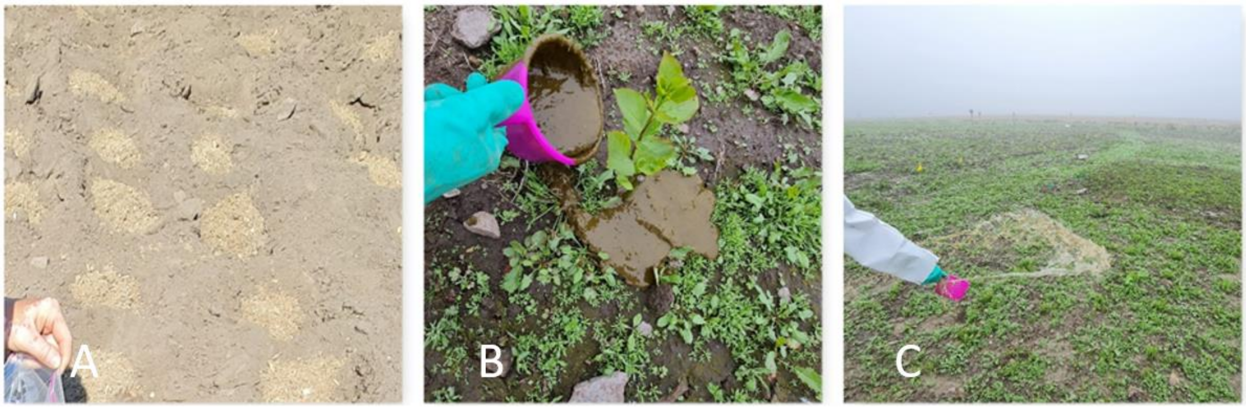


Figure 3.5.1 The biological inputs (clockwise from left) of paper mill sludge within pre-dug holes, digestate application around a poplar cutting applied and seaweed extract sprayed onto the switchgrass subplot.

The paper mill sludge application was applied just before planting. First, the paper mill sludge was delivered to the sites from the Port Hawkesbury Paper mill in large 1000 L bulk bags. Then, it was moved to the respective treatment plots using hand carts. The paper mill sludge application was made by digging holes with shovels where planting materials (seeds, rhizomes, or tree cuttings) were planted (Fig.3.5.1A). The hole size was determined based on the type of plant materials to be planted; a 2 L hole for the switchgrass seeds, a 3 L hole for miscanthus rhizomes; and a 5 L for the tree cuttings. After application, the holes were top-filled with soil until they had a uniform surface. The paper mill sludge treatment was completed the same day as planting for the Chegoggin Point site. However, due to heavy rains, the paper-sludge application at the Falmouth site took three days. The application rates of paper sludge for each crop were as follows: 1280 liters for switchgrass, 1260 liters for miscanthus and 1300 liters for poplar and willow. The combined application rates for all four crops resulted in an overall equivalent application rate of 12,047 kg/ha.

The anaerobic digestate and seaweed extract treatments were applied six weeks after planting at both sites. First, the poplar and willow subplots were treated with the digestate by manually pouring 1L of the digestate around each tree cutting (Fig 3.5.1B). The same technique was followed for miscanthus by applying 0.72 L per plant. This way, approximately 65 L was applied per subplot for both the trees and miscanthus. For switchgrass, 65 L of the anaerobic digestate was also applied per subplot. Still, it was diluted 50:50 with water before application and manually broadcasted as evenly as possible onto each subplot (Fig.3.5.1C). Hence, in all crops, the application rate of the anaerobic digestate was 65 L/subplot, equivalent to 16,250 L/ha.

A seaweed extract solution was prepared by diluting Stella Maris™ *A. nodosum* extract (Acadian Seaplants Ltd., Dartmouth, NS) with water (1 L of extract per 1000 L of water). This solution was applied in the same manner as the anaerobic digestate to each crop and again at 65 L/subplot. Given that the seaweed extract solution is based upon a 1:1000 dilution of Stella Maris™ aquatic plant extract with water, the application rate of the actual *A. nodosum* extract was equivalent to a rate of 16.25 L/ha. The anaerobic digestate and seaweed extract were applied for the second time after the initial establishment year growing phase. For the second application, the digestate and seaweed extract treatments were applied to one-half of each subplot using a split-plot design. The digestate and seaweed-treated subplots were divided into halves (2 x 10 m) for the new application. The application rates were the same as the first application.

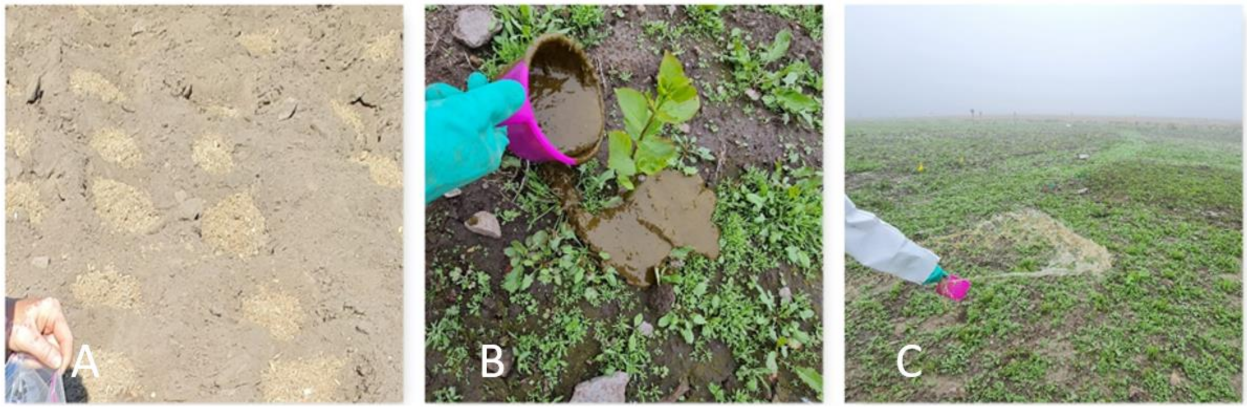


Figure 3.5.2 The biological inputs (clockwise from left) of paper mill sludge within pre-dug holes, digestate application around a poplar cutting applied and seaweed extract sprayed onto the switchgrass subplot.

3.6 Second Amendment Application (2022)

The second application was made to observe the real benefits of the digestate and seaweed as they could not be fully utilized during the initial establishment phase of the plants. By applying the treatments a second time, it was possible to assess the reactions of the plants to the digestate and seaweed after they had completed their establishment year and to understand their potential long-term benefits. A second application of the digestate and seaweed extract was made roughly 11 months after the first treatment. The treatments occurred on July 5th, 2022, at the Falmouth site and between the 6th and 7th of July at Chegoggin Point. The second application was done using a split-plot design, in which the second application is made to one-half of each subplot (i.e., 2 x 10m). The application rates to the split plots were identical to the first application to the subplots.

3.7 Miscanthus Shoot Tissue Nutrient Concentrations (2021)

Samples of miscanthus shoot tissue from the end-of-season harvest from the Falmouth site in the establishment year (2021) were analyzed by the Nova Scotia Department of

Agriculture Analytical Laboratory in Truro, NS, for nutrient content. The sample collection was done in November 2021, roughly eight weeks after planting.

3.8 Soil Analysis

Soil cores were taken from each subplot during the establishment year and end-season data collection from both sites. A tubular soil sampler (5 cm in diameter) was used to collect cores to a depth of 15 cm from each sub-plot and split-plot. Six cores were collected from each subplot to analyze nutrient and heavy metal content. The cores were taken randomly around switchgrass and miscanthus plots. For poplar and willow plots, cores will be taken in an alternating pattern between trees, between rows, and between double rows. Soil cores were also randomly collected outside the plots to obtain a control sample. Following collection, the soil cores were combined per treatment, divided into two replicates, and put into labeled bags based on their crop and treatment type. These samples were sent to the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS, for the compositional analysis of nutrients and AGAT Laboratories, Dartmouth, NS, for heavy metal analysis.

3.9 Weeding

The first weeding was done six months after the establishment year data collection on 8th and 9th June 2022 at the Falmouth site and 20th and 21st June 2022 at the Chegoggin Point site. The second weeding was done roughly after an additional four weeks on 18th July 2022 at the Falmouth site and on 20th July 2022 at the Chegoggin Point site. At both Falmouth and Chegoggin Point sites, weeding operations were carefully carried out to ensure the crop plants were not damaged in the process. During the first weeding, hand weeding was done within for all crops to avoid potential damage to the developing crops.

Handheld brush cutters were used for the second weeding to maintain weed height at approximately 3 to 10 cm for miscanthus, poplar, and willow. Due to their dense growth and tightly packed nature, selective weeding within switchgrass subplots was challenging. To overcome this, a careful approach was employed during the weeding process. The weeding for switchgrass involved manually trimming the entire plot to the height of the switchgrass itself (7-10cm). This method ensured that only the taller weeds, those higher than the switchgrass, were trimmed. This allowed to remove taller weeds without compromising the switchgrass growth. By selectively trimming only the taller weeds, the switchgrass crop could continue to thrive and flourish with minimal disturbance. No weedicides or herbicides were used for environmentally friendly and sustainability in a biomass crop production system. All weeding operations were done carefully to ensure that the crop plants were not damaged during the process. The pathways around the subplots were mowed to approximately 8 cm using a gasoline-powered, self-propelled brush cutter (model BC2601HM, Billy Goat Industries Inc., Kansas City, MO, USA) with a 0.66 m cutting blade (Fig 3.8.1A). Within the tree subplots, weed height was controlled to approximately 3 to 10 cm using handheld brush cutters (PROYAMA 42.7cc Extreme Duty 2-Cycle Gas Brush Cutter, Yema M&E Equipment Co. Ltd., Shenzhen, CN) (Fig. 3.8.1B).

Figure 3.9.1 A self-propelled brush cutter used to mow weeded around subplots (A) and handheld brush cutters used to control weeds within the tree subplots (B).

3.10 Data Collection

In 2021, biomass from the subplots was sampled approximately 13 weeks after planting on 1st November 2021 at the Falmouth site and approximately 18 weeks from 8th and 9th November 2021 at the Chegoggin Point site. In 2022, during the end of the growing season, data was collected approximately 64 weeks after planting on 28th and 31st October 2022 at the Falmouth site and approximately 69 weeks from 24th and 25th October 2022 24-10-2022 at the Chegoggin Point site (details below). In all cases, samples were collected from each subplot from each replicate, giving a sample size (n) of four for each crop/soil amendment combination.

3.10.1 Establishment Year (2021)

The data collection for the establishment year included the biomass yield and the post-winter survival rates. All sampling procedures were done using random sampling methods (details below).

3.10.1.1 Switchgrass:

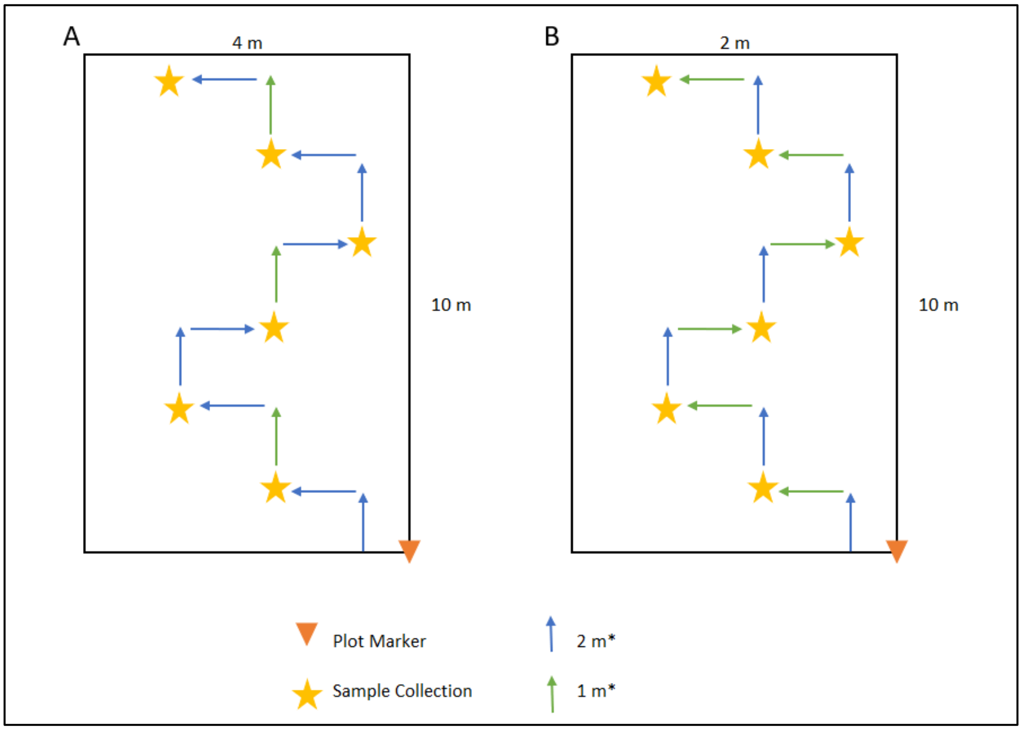


Figure 3.10.1.1.1 Sampling pattern used in each switchgrass subplot. The sampler entered the subplot near the plot marker on the bottom right corner of the plot and followed the patterns marked by the arrows. Each blue arrow represents approximately 2 m, and the green arrow represents approximately 1 m. Sampling quadrats were placed approximately where each star is indicated in the diagram.

Switchgrass biomass subsamples were collected using 0.25 m^2 quadrat from six positions within each subplot of biomass collected from six locations within each subplot following the pattern outlined in (Figure 3.9.1.1.1). All biomass within each quadrat was clipped 5 cm above ground level and collected (Fig.3.9.1.1.2). The fresh weight of the combined six biomass subsamples was weighed in the field using a Denver Instrument PK-352 laboratory scale (Denver Instrument; Bohemia, NY) and recorded. A sub-sample (75 – 100 g) was then taken from the pooled sample and placed into a labelled bag to determine the water content. The biomass sub-samples were dried in an oven and lasted for 3 to 4 days, during which the samples were kept in the oven at a temperature of 70°C. Based on the subsample's water content, the sample's dry weight was calculated and used to estimate the yield of each crop/soil amendment combination in kg/ha. All switchgrass subplots were mowed 10-15 cm in height following sample collection to simulate a fall harvest.

Figure 3.10.1.1.2 The 0.25 m2 quadrant used to sample the switchgrass.

3.10.1.2 Miscanthus

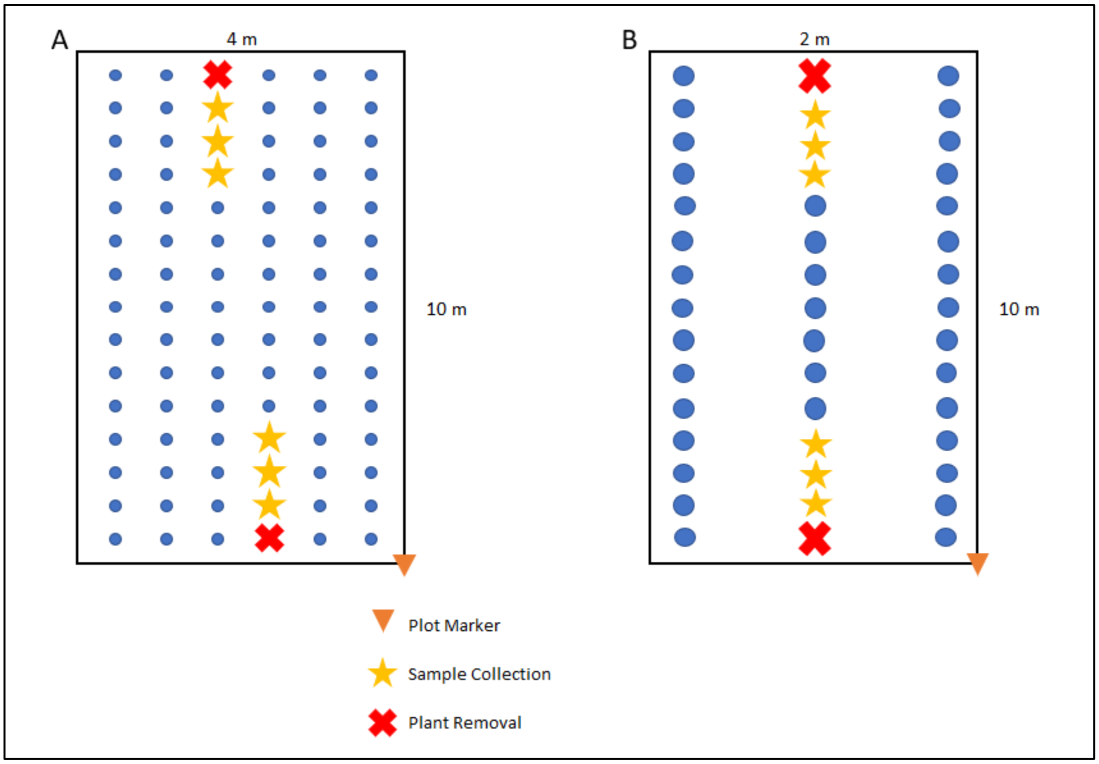


Figure 3.10.1.2.1 Sampling pattern used in each Miscanthus subplot (A). The blue dots represent the location where rhizomes were planted. The stars indicate the location where plant counts were collected. The red X's represent plants clipped from the edge of the subplots to enable access to plants to be sampled.

Miscanthus biomass subsamples were collected from six randomly selected plants from each subplot using the sampling pattern depicted in Figure 3.18. Plants were approximately cut 5 cm above ground level, the subsamples combined, the fresh weight of the combined subsamples were measured in the field, and a subsample of the combined sample was taken for determination of water content of the biomass in the lab as was done for switchgrass (see section 3.9.1.1). After samples were ground using a sample grinder, the aliquots of the dried tissues were sent to the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS, to analyze the nutrient concentrations. The analysis was done using TruSepec CN Carbon Nitrogen Determinator (Leco Corporation; St. Joseph, MI) for nitrogen and a Varian 72ES ICP-OES Spectrometer (Analytical West Inc.; Corona, CA) for the remaining nutrients (P, K, Ca, Mg, Fe, Zn). The resulting nutrient concentrations were then converted into nutrient yield per hectare by multiplying with the dry weight and plant count data to obtain nutrient yield per hectare. All miscanthus plots were mowed following sample collection to simulate a fall harvest.

The survival rate of the miscanthus subplots was determined seven months after planting. The survival rate in this context represents the proportion of miscanthus plants that developed from the planted rhizomes. The survival rate was determined by counting the total number of living plants relative to the number of rhizomes planted (i.e., 90) in each subplot.

Figure 3.10.1.2.2 Examples show the miscanthus plants grown from rhizomes in 2021 after two months of growth in the Falmouth site**.**

3.10.1.3 Poplar and Willow:

Survival rates were assessed in the poplar and willow subplots just before sample collection. The survival rate was determined for each subplot by counting the total number of living plants relative to the original number of cuttings planted (i.e., 65). Also, ten random plants were selected throughout the sub-plots before entering the field.

For measurements of stem biomass accumulation in the establishment year, just before coppicing, eight randomly selected plants were cut 5 cm above the ground, leaves were removed from the stems, and the stems were placed in labelled perforated-plastic bags (Fig.3.9.1.3.1). Back in the lab, the samples were then dried at 70 º C for 3 to 4 days to determine water content and dry weight of the samples. These data were used to calculate biomass yields in kg/ha (see below).

Figure 3.10.1.3.1 Example of sampled willow stems from a subplot and the perforated plastic bags in which the samples were transported back to the lab.

3.10.2 End of Season (2022)

The data collection for the end of the season included the grasses biomass yields, the tree's average stem length and diameter, the tree's total stem length, and total stem volume.

3.10.2.1 Fall 2022 Switchgrass and Miscanthus Biomass Yield

Switchgrass and miscanthus aboveground biomass were sampled on 24th October 2022 in the Chegoggin Point site and on 28th October 2022 in the Falmouth site, which was 15-16 weeks after the second amendment application and 11 months after the establishment year data collection. Six samples were collected from each subplot with a 0.25 m2 quadrat for switchgrass. The sampling process was the same process done during the establishment year (2021) data collection. The first sampling was done for switchgrass; the fresh weight of the six switchgrass samples for every treatment per subplot was collected and weighed in the field (upon placement in a tared bucket) and recorded. Subsequently, a sub-sample (75 – 100 g) was weighed from the pooled sample, placed into a labelled bag, taken back to the lab, and oven-dried for 3 to 4 days at 70 ºC. Once all the switchgrass samples were collected, the plots were mowed to simulate a fall harvest. For miscanthus, samples were collected by cutting all biomass from each plant 5 cm above ground level. The fresh weight of the six biomass samples was weighed in tared buckets in the field and recorded, then placed in labeled plastic bags. Samples were then dried in the lab using a hot air oven for 3 to 4 days at 70 ºC and subsequently weighed to calculate dry biomass yield. The biomass collected and dried in the lab was ground using a sample grinder for further nutrient analysis. The dry weights of these samples per subplot were converted into dry weight per hectare before statistical analysis (see details below). All miscanthus was mowed following the sample collection to stimulate a fall harvest.

The miscanthus at the Chegoggin Point site failed to emerge even by the end season (emergence was less than 1%); thus, sampling was not possible.

Figure 3.10.2.1.1 Grass sampling using shows the (from left) 0.25 m2 quadrants at the Chegoggin Point site (A). Harvesting aboveground biomass of miscanthus (B). A biomass sampled being weighed at the site (C) and drying of the sub-samples in the drying oven in the lab.

3.10.2.2 Trees Primary Stem Length and Diameter, Fall 2022

Each tree within each sub-plot was numbered from left to right, top to bottom. The trees were then selected for sampling using a random number generator for each sub-plot and split plot (Fig.3.9.2.2.1)

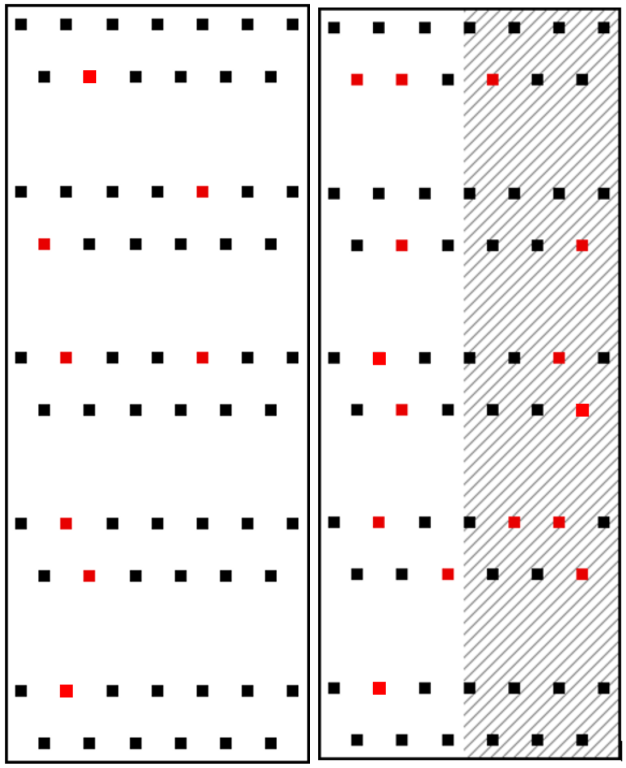


Figure 3.10.2.2.1 Randomized selection patterns for poplar and willow sub-plots on the left and split plots on the right sampled tree locations indicated in red.

The stem lengths were measured from 5cm from the base of the primary stem (i.e. the originally planted cutting) to its tip, and the base diameters were measured 5 cm above the base of the stem from eight randomly selected trees.

Figure 3.10.2.2.2 Measuring trees stem length (A) was measured using a measuring tape, and stem diameters were measured using a vernier caliper (B).

A total of 8 stems were selected, and the stem length and diameter were measured using a measuring tape (Fig.3.9.2.4.1(A)) and caliper (Fig.3.9.2.4.1(B)), respectively. To measure the primary stem length and diameter, all stems on each tree were first measured individually, and their lengths and diameters were recorded. These measurements were summed to obtain the total length and diameter for each tree. The primary stem length and diameter for each subplot were calculated by adding the lengths and diameters of all the trees in that subplot and then dividing the sum by the number of trees present.

3.10.2.3 Trees Total Stem Length, Fall 2022

A total of 8 stems were sampled using the same random sample generator, and all the stem lengths, including the secondary and tertiary stems, were measured. The total stem length was obtained by combining the length of all stems on each tree.

3.10.2.4 Trees Total Stem Volume

Using the measured primary stem lengths and diameters, the total stem volume (TSV) of the individual plant was estimated using the formula:

$$TSV = [SV_1 = (\pi r^2{}_1 \times L_1)/3] + [SV_2 = (\pi r^2{}_2 \times L_2)/3] + \ldots [SV_x = (\pi r^2{}_x \times L_x)/3]$$

In which TSV is the sum of the volume of individual stems [$SV(_{1\,..\,x})$] as calculated from the area of the individual stem at its base [$\pi r^2(_{1\,..\,x})$] multiplied by the length of the individual stem [$L(_{1\,..\,x})$]. This formula assumes each stem is a cone with the diameter of the stem decreasing from its base to the tip of the stem; as such, it is an estimate of stem volume and not a true measurement of stem volume.

3.11 Statistical Analysis

To statistically analyze the influence of a single factor on a response variable (e.g. treatment on crop dry weight), a one-way analysis of variance with a Tukey-Kramer post-hoc test would be typically employed. In cases where the ANOVA assumptions of homoscedasticity and normality of the data were not met, a generalized linear model (GLM) was used in conjunction with ANOVA (Agresti 2007). Unlike linear regression, GLM can best suit the distribution of the data instead of satisfying the assumptions by transforming the data (Fox, 2008). A gamma distribution with the log-link function was used, as the datasets had positive skewness.

The experimental design follows a randomized block design. Each block consists of four 10 m x 4 m plots dedicated to each crop species under investigation. The design is replicated four times, resulting in a total of 16 plots at each site so that each crop/soil amendment combination has four replicates (n=4).

Similarly, a two-way ANOVA was used to estimate a pairwise comparison of two independent variables on a single dependent variable. This method was used for a comparative study between poplar and willow datasets. By doing this, it is possible to understand how the growth characteristics of the plants are affected by the soil amendments and how this effect varies across different crop types.

All the analysis was done using the R programming language (R version 4.2.2) with the "car" (Fox et al.2020), "multcomp" (Hothorn et al. 2020), and the data visualization using "ggplot and "dplyr" functions (Wickam et al. 2020).

3.12 Soil Baseline Nutrients (2021)

Table 3.12.1 Chemical analysis of site soil samples. These samples were collected during site establishment in 2021.

	Chegoggin Point	Falmouth
Nitrogen (%)	0.37	0.20
pH	5.15	5.71
Buffer pH	7.5	7.72
Organic matter (%)	6.23	4.33
P_2O_5 (kg/ha)	77.6	59
K_2O (kg/ha)	170.6	154.6

Calcium (kg/ha)	989	2100
Magnesium (kg/ha)	483.6	265.3
Sodium (kg/ha)	335.3	118
Sulfur (kg/ha)	45	30.6
Aluminum (ppm)	958	893.6
Copper (ppm)	0.36	1.96
Iron (ppm)	424	257.33
Manganese (ppm)	8.3	108.67
Zinc (ppm)	1.84	3.18

3.13 Soil Baseline Nutrients (2022)

Table 3.13.1 Chemical analysis of site soil samples. These samples were collected during end-of-season data collection in 2022.

	Chegoggin Point	Falmouth
Nitrogen (%)	0.31	0.19
pH	5.58	5.99
Buffer pH	7.57	7.78
Organic matter (%)	5.35	3.85
P_2O_5 (kg/ha)	60	33
K_2O (kg/ha)	156	134
Calcium (kg/ha)	992.5	2126
Magnesium (kg/ha)	438	268.5

Sodium (kg/ha)	222.5	92
Sulfur (kg/ha)	47	22.5
Aluminum (ppm)	1042	768.5
Copper (ppm)	0.245	2.615
Iron (ppm)	457	227
Manganese (ppm)	12	54
Zinc (ppm)	1.29	0.8

3.14 Weather data (2021)

The weather data were obtained from the Falmouth Dyke (INOVASCO40) and Chegoggin Point weather stations. The Falmouth Dyke is an underground weather station located about 1 km from the Falmouth site, and the nearest weather station to the Chegoggin Point site was the Environment and Climate Change Canada (ECCC) station, which is about 6 km from the site.

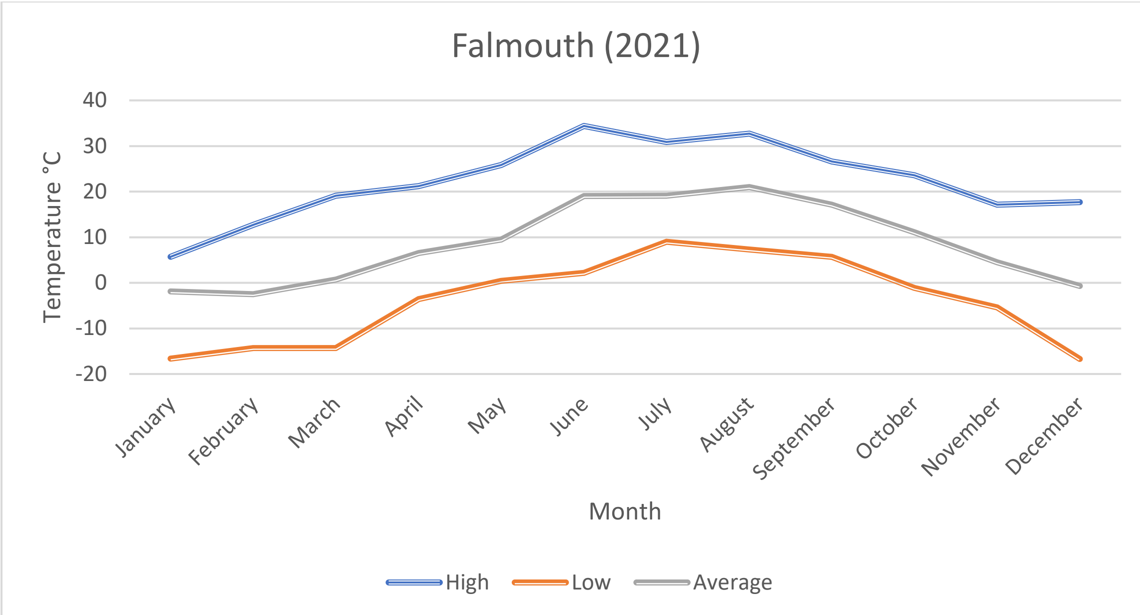


Figure 3.14.1 Monthly minimum, maximum and average temperature conditions at the Falmouth Dyke weather station during 2021.

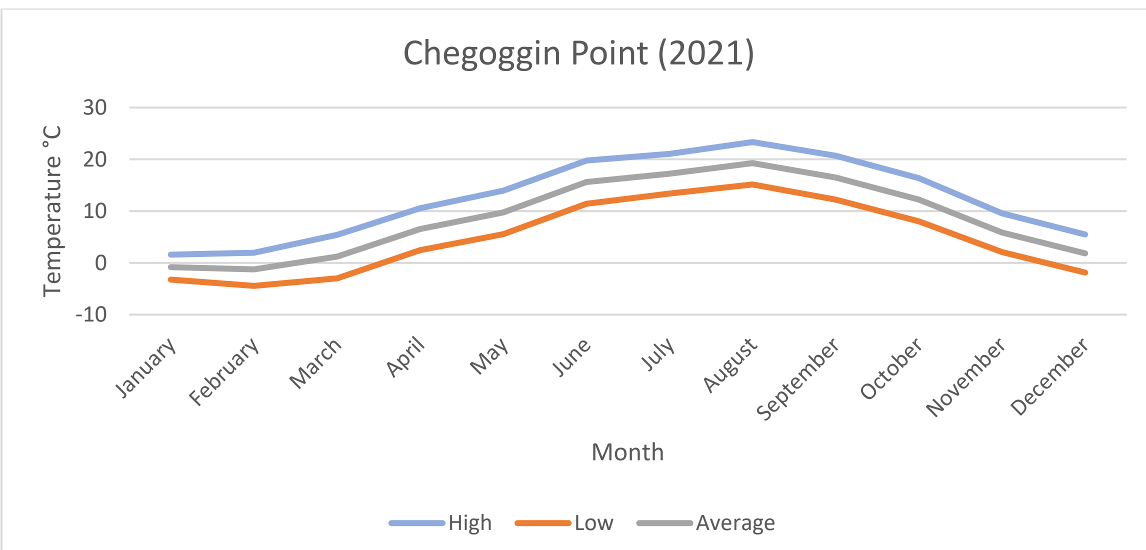


Figure 3.14.2 Monthly minimum, maximum and average temperature conditions at the Chegoggin Point home weather station during 2021.

The 2021 maximum daily temperature around the Falmouth station occurred in June, averaging 34.4 °C, with the lowest in February at -16.7 °C (Fig. 3.12.1). The Chegoggin Point home station had a maximum temperature in August at 28.3 °C, while the coldest was in March at -12.7 °C (Fig. 3.12.2).

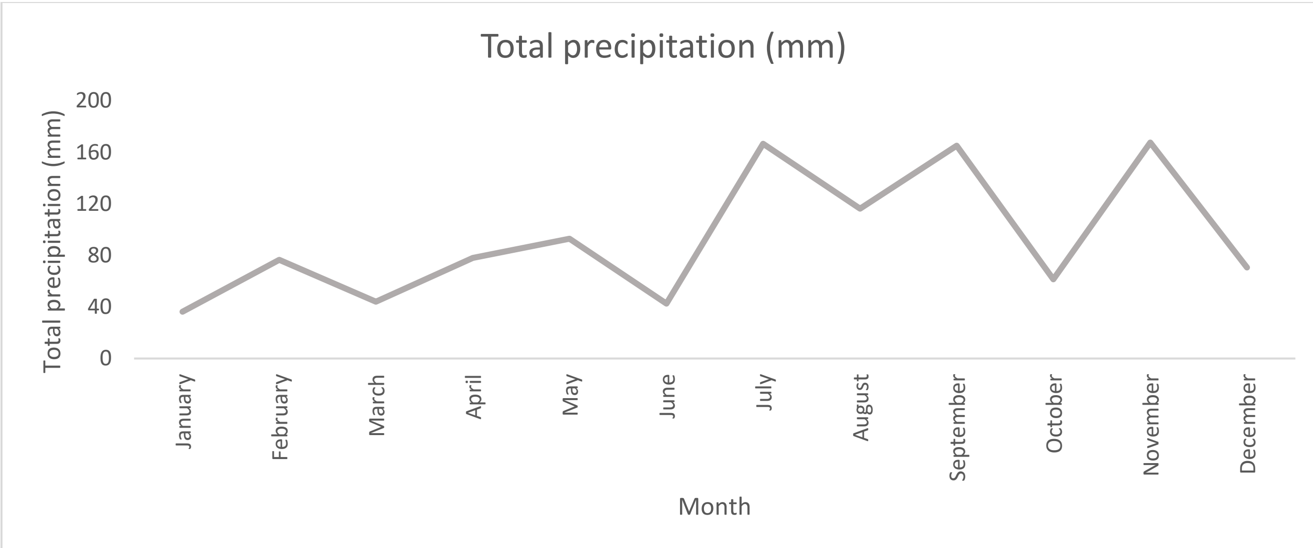


Figure 3.14.3 Monthly precipitation (mm) at the Falmouth Dyke weather station during 2021.

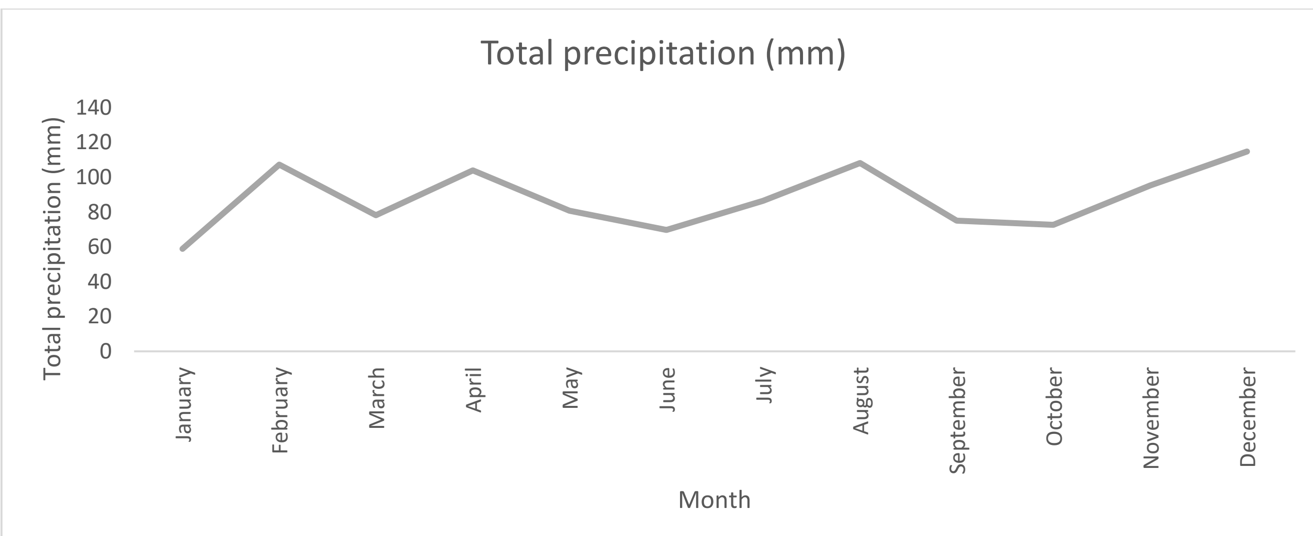


Figure 3.14.4 Monthly precipitation (mm) at the Chegoggin Point home weather station during 2021.

3.15 Weather data (2022)

The weather data for 2022 were also obtained from the Falmouth Dyke (INOVASCO40) and Chegoggin Point weather stations. The Falmouth Dyke is an underground weather station located about 1 km from the Falmouth site, and the nearest weather station to the Chegoggin Point site was the Environment and Climate Change Canada (ECCC) station, which is about 6 km from the site.

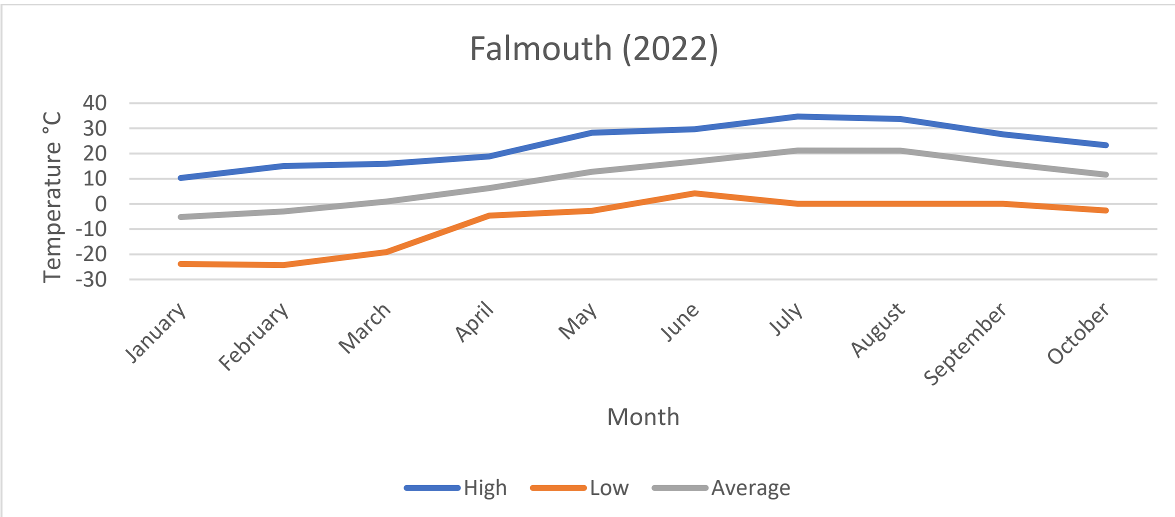


Figure 3.15.1 Monthly minimum, maximum and average temperature conditions at the Falmouth Dyke weather station during 2022.

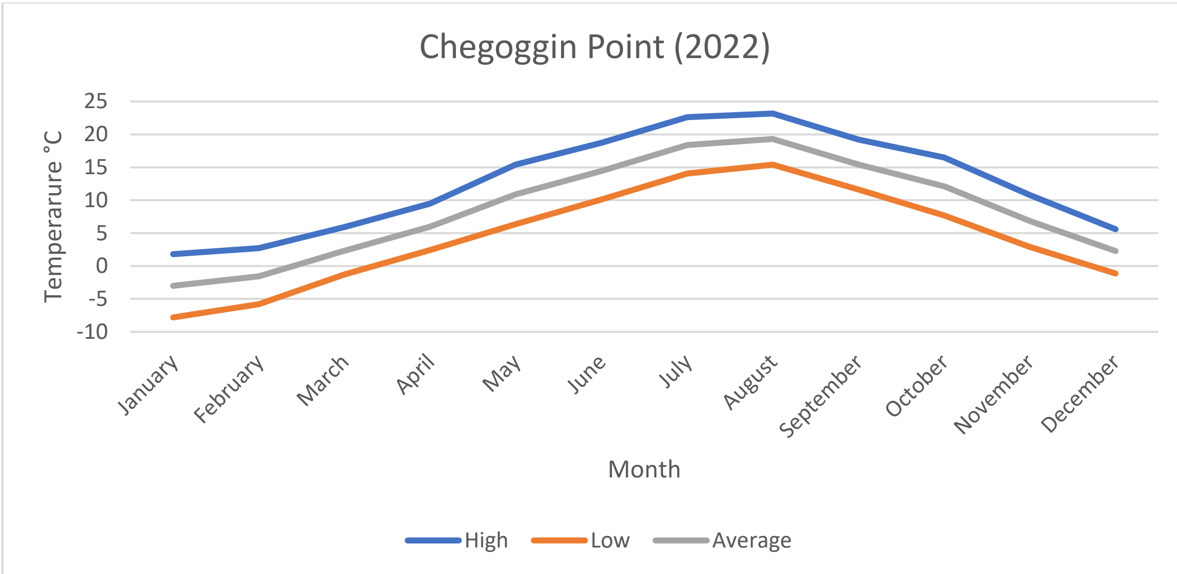


Figure 3.15.2 Monthly minimum, maximum and average temperature conditions at the Chegoggin Point home weather station during 2022.

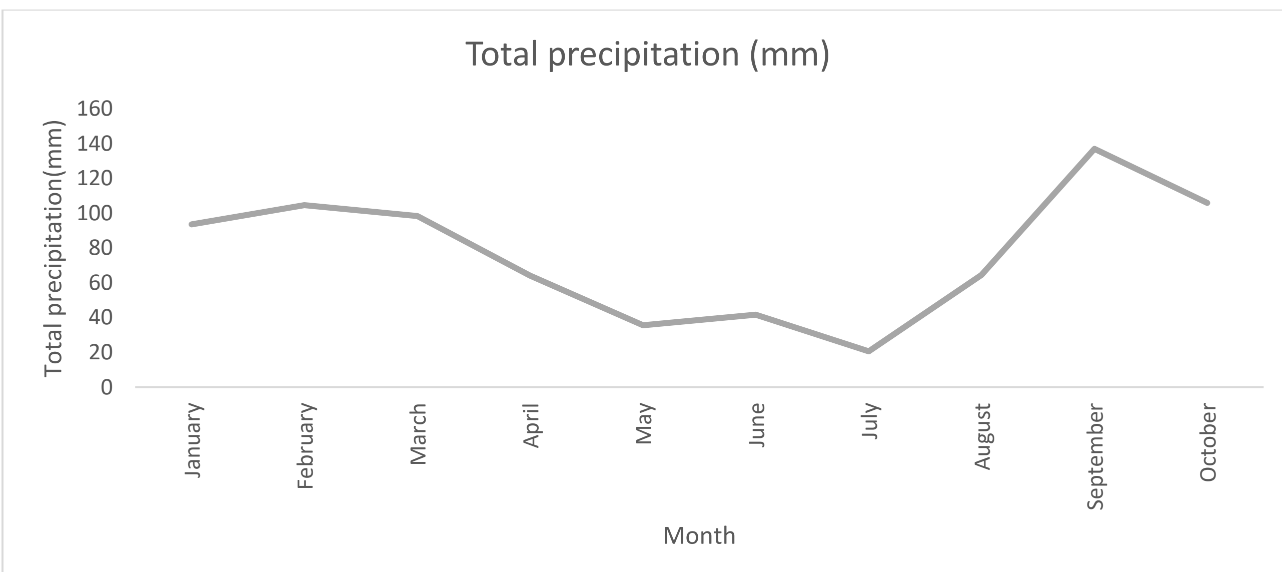


Figure 3.15.3 Monthly precipitation (mm) at the Falmouth Dyke weather station during 2022.

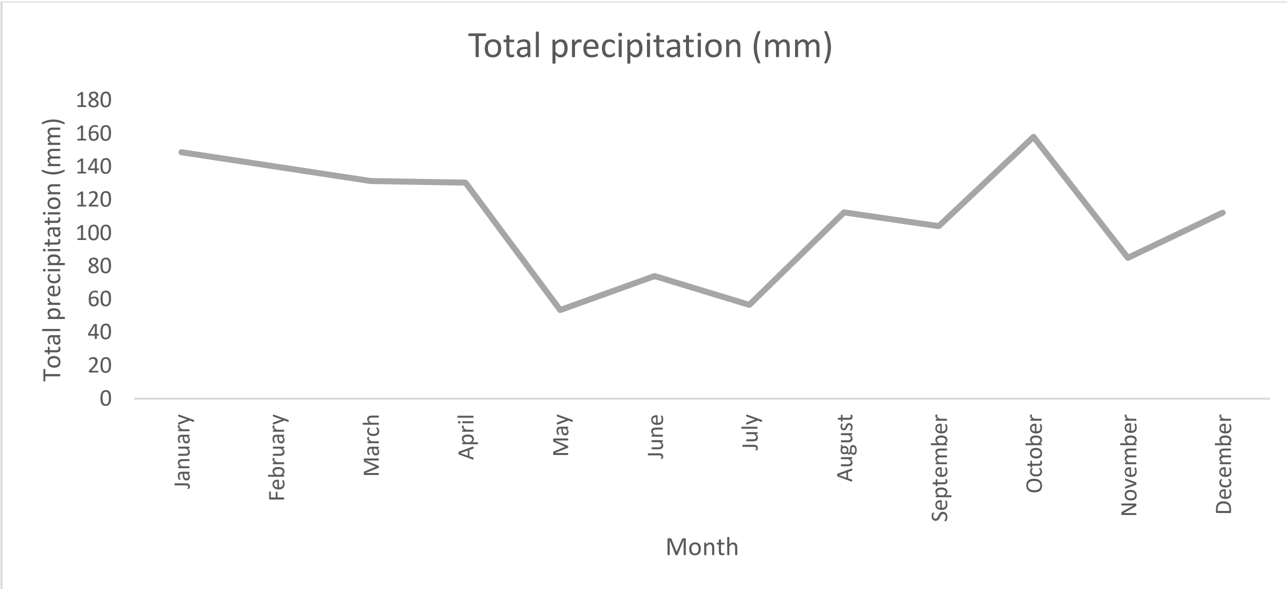


Figure 3.15.4 Monthly precipitation (mm) at the Chegoggin Point home weather station during 2022.

The 2022 maximum daily temperature around the Falmouth station occurred in July, averaging 34.7 °C, with the lowest in February at -24.3 °C (Fig.3.13.1). The Chegoggin Point home station had a maximum temperature in August at 23 °C, while the coldest was in January at -7.8 °C (Fig.3.13.2). Unfortunately, the weather data for the Falmouth Dyke (INOVASCO40) was not operational for November and December due to technical difficulties.

3.16 Digestate nutrient concentrations (2021)

Anaerobic digestate samples were taken during the 2021 treatment application. The samples were then dried and analyzed.

Table 3.16.1 Chemical analysis of anaerobic digestate samples taken in Falmouth and Chegoggin Point. The de-watered solid fraction (dry matter) of the liquid digestate is expressed as a percentage of the wet weight from the sample. Nutrient concentrations are expressed as a percentage of parts per million (ppm) of the dry matter fractions of the liquid digestate.

	Digestate (Chegoggin Point)	Digestate (Falmouth)
Dry matter (%)	11.16	10.23
Nitrogen (%)	2.23	2.17
Calcium (%)	1.595	1.567
Potassium (%)	2.638	2.836
Magnesium (%)	0.606	0.623
Phosphorous (%)	0.659	0.642
Sodium (%)	4.785	5.150
Boron (ppm)	33.91	30.38
Copper (ppm)	94.06	90.61
Iron (ppm)	3277.51	3094.26
Manganese (ppm)	257.74	249.36
Zinc (ppm)	110.60	104.38

3.17 Digestate nutrient concentrations (2022)

The anaerobic digestate samples taken for the 2022 second application were sampled for nutritional analysis.

Table 3.17.1 Chemical analysis of anaerobic digestate samples taken in Falmouth and Chegoggin Point. The de-watered solid fraction (dry matter) of the liquid digestate is expressed as a percentage of the wet weight from the sample. Nutrient concentrations are expressed as a percentage of parts per million (ppm) of the dry matter fraction of the liquid digestate.

	Digestate (Chegoggin Point)	Digestate (Falmouth)
Dry matter (%)	11.24	11.27
Nitrogen (%)	0.32	0.32
Calcium (%)	0.192	0.186
Potassium (%)	0.345	0.339
Magnesium (%)	0.066	0.063
Phosphorous (%)	0.074	0.071
Sodium (%)	0.653	0.662
Boron (ppm)	3.90	3.75
Copper (ppm)	7.18	6.77
Iron (ppm)	312.85	297.27
Manganese (ppm)	30.50	29.07
Zinc (ppm)	11.93	10.88

3.18 Soil moisture and temperature data (2021-2022)

A HOBO® Micro Station equipped with moisture and temperature sensors was installed at a depth of 15cm to measure the soil conditions. They were installed just outside the edge of each site. The hobo collected data on an hourly basis. However, due to technical issues, soil temperatures at the Chegoggin Point sites after May 2022 are not available.

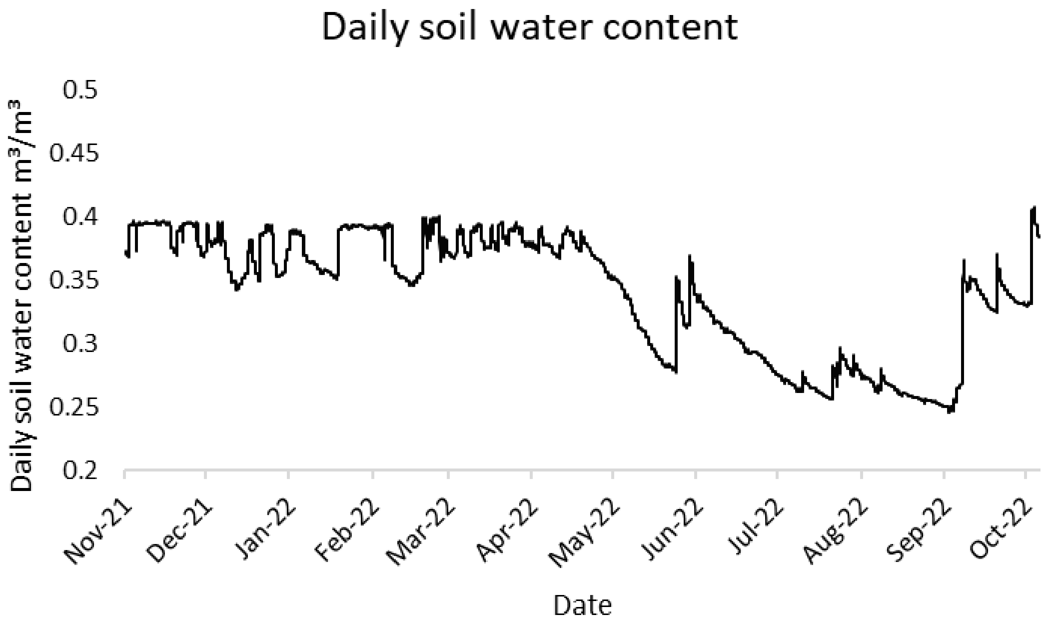


Figure 3.18.1 Daily water content (m3/m3) of soil at the Falmouth site from November 2021 to October 2022.

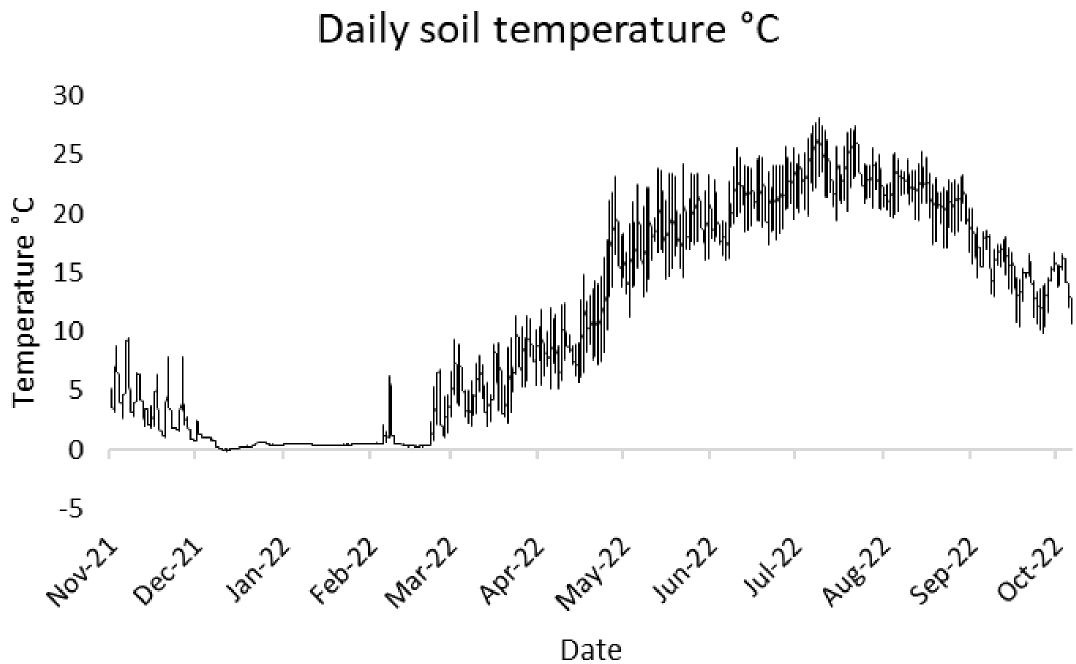


Figure 3.18.2 Daily temperature (°C) of soil at the Falmouth site from November 2021 to October 2022.

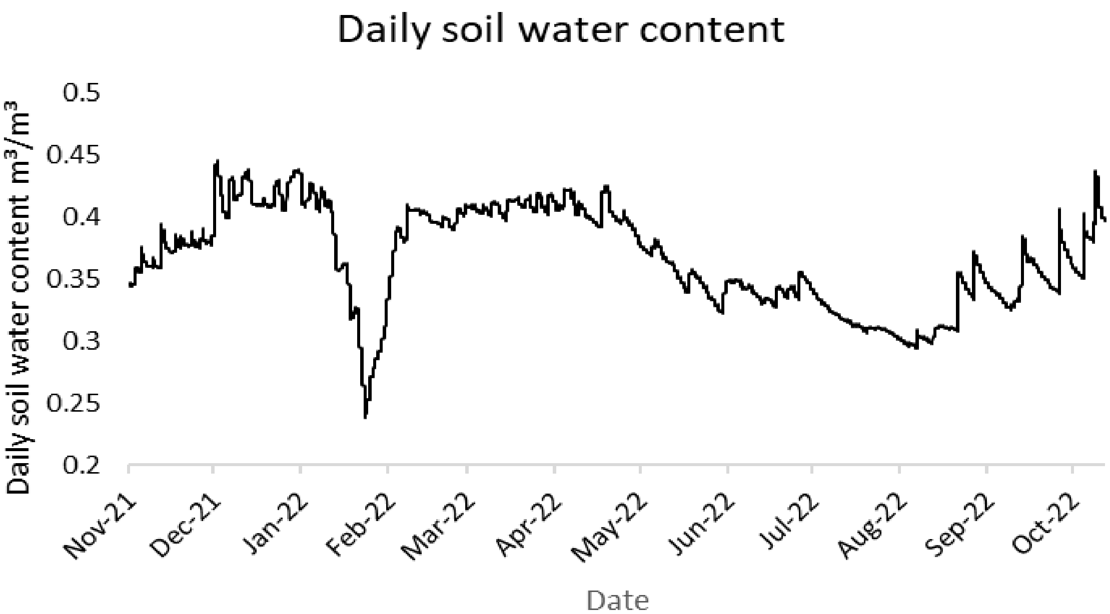


Figure 3.18.3 Daily water content (m3/m3) of soil at the Chegoggin Point site from November 2021 to October 2022.

At the Falmouth site, the highest soil temperatures occurred in July 2022 (28°C), and the lowest daily soil temperatures occurred in December 2022 (-0.2°C) (Fig.3.16.2). The temperature data collected exhibited a distinct pattern, with the warmest temperatures occurring during the months of June to September, followed by a cooler period from October to May.

The daily soil moisture data from the Falmouth site shows that soil moisture was highest in October 2022 (0.4074 m^3/m^3) and the lowest in September 2022 (0.246 m^3/m^3) (Fig.3.16.1). The soil moisture data for the Chegoggin Point site showed the highest in December 2021 (0.4451 m^3/m^3), and the lowest was recorded in February 2022 at 0.2379 (m^3/m^3) (Fig.3.16.3).

4. RESULTS

The study focused on evaluating the potential of these locally sourced soil amendments to enhance the establishment and end of season yields of the crops on marginal lands. During the establishment year in 2021, data were collected on plant-growth parameters, including biomass yield, tissue nutrient contents (only for miscanthus), and survival rates. In the subsequent year, 2022, the final outcomes were assessed, growth parameters such as biomass yield for grasses, primary stem length and diameter for trees, total stem lengths, and stem volume. This two-year data collection process provided insights into the impact of the studied soil amendments on the growth and development of the biomass crops.

4.1 Coppiced Hybrid-Poplar and Coppiced Willow Survival Rates (2022)

Effects of soil treatments on the survival rates of the tree species were measured at both sites in June 2022, approximately 10 months after planting in the establishment year in 2021 (Figs. 4.1.1 and 4.1.2). The survival rate captures both the success rate of the initial establishment of the tree crops in 2021 plus their ability to survive their first over-wintering period (i.e., the winter of 2021-22). The survival rate was calculated by counting the number of living coppiced trees divided by the total number of cuttings planted per subplot (i.e., 65 cuttings/subplot).

The survival rates from both tree species were excellent (near 100%) in all treatments at the Falmouth site except for the coppiced hybrid-poplar treated with paper mill sludge, still having a very good survival but statistically significantly lower survival rate of 85% (Fig.4.1.1).

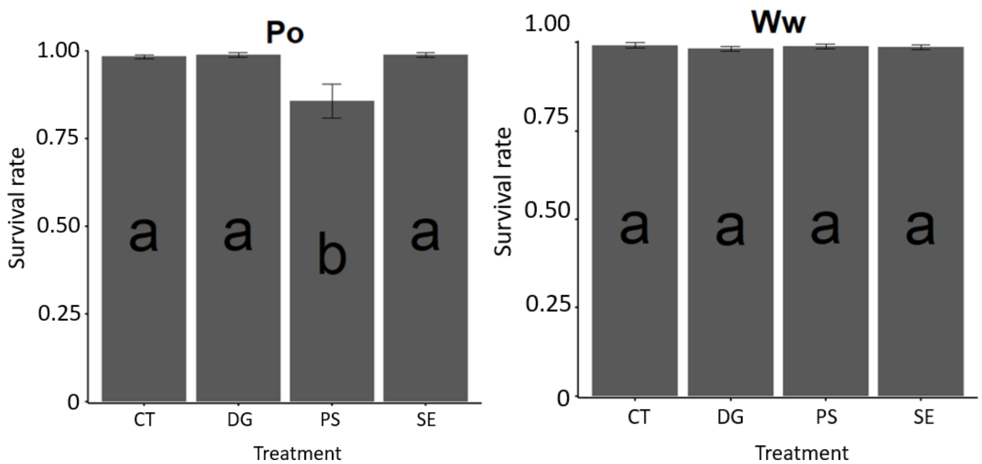


Figure 4.1.1 Survival rates of coppiced hybrid-poplar (Po) and coppiced willow (Ww) grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Falmouth site in June 2022. Within each t ree species, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

At the Chegoggin Point site, the coppiced hybrid-poplar treated with the paper mill sludge had a survival rate of 52%, significantly lower than the control plants at 83% (Fig. 4.1.2). The anaerobic digestate and seaweed extract treated coppiced hybrid poplar had similar survival rates to the controls. The paper mill sludge-treated plants in willow had the lowest survival rate at 74%, but this was not significantly different from the other treatments (the survival rate was 85% for the control).

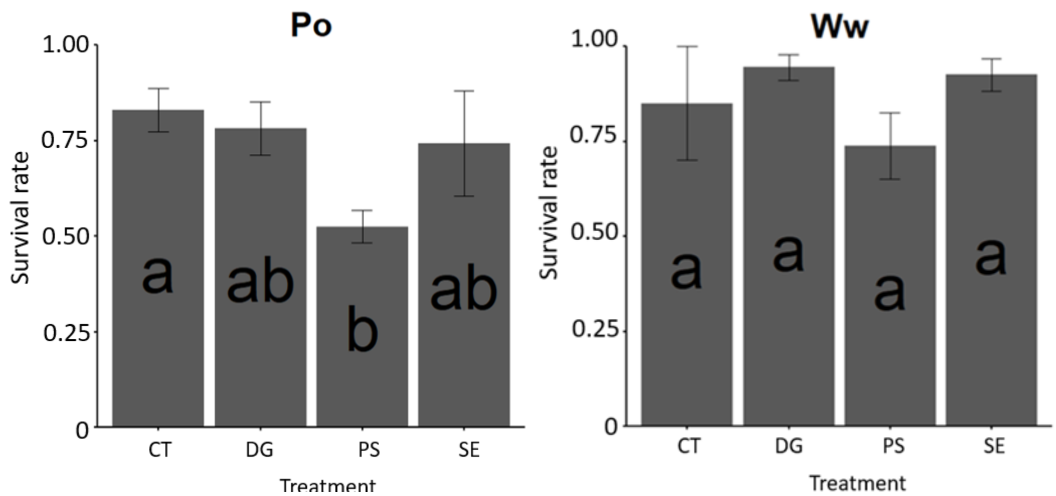


Figure 4.1.2 Survival rates of coppiced hybrid-poplar (Po) and coppiced willow (Ww) grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Chegoggin Point site in June 2022. Within each tree species, treatments labelled with the same letter are not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard errors.

4.2 Miscanthus Survival Rates, 2022

The survival rate for miscanthus was measured in June 2022, approximately 10 months after planting in 2021. Only survival rates for the Falmouth site could be calculated due to the failure of the miscanthus to emerge at the Chegoggin Point site (i.e., the survival rate for miscanthus at Chegoggin Point is less than 1%). The survival rate was calculated by counting the number of live plants and dividing by the total number of plants per subplot (90 trees/subplot).

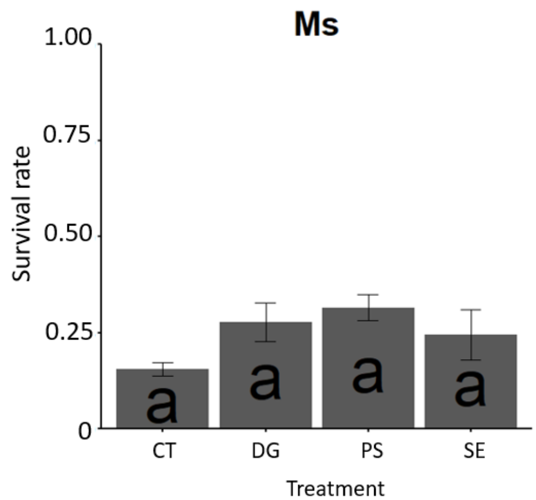


Figure 4.2.1 Survival rates of miscanthus grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), and paper mill sludge (PS)) at the Falmouth site in June 2022. Treatments labelled with the same letter are not significantly different (n = 4; α = 0.05). Error bars represent standard errors.

4.3 Miscanthus Replanting Survival Rates, 2022

The miscanthus was replanted with tissue-cultured plantlets on June 13 -14, 2022, at the Falmouth site and on June 23, 2022, at the Chegoggin Point site, still only in the control plots. Replanting was done to determine if the failure of the miscanthus to establish itself in 2021 was due to poor-quality rhizomes or some other edaphic or environmental factors. Replanting was conducted for the control plots. Subsequently, the assessment of plant emergence was during the end-of-season data collection, which was approximately four months after the replanting. During this assessment, all the plantlets exhibited a 100% emergence success rate in both sites.

4.4 Switchgrass Moisture Content (2022)

The moisture content of switchgrass subsamples at both the Falmouth and Chegoggin Point sites was measured to determine if soil amendment treatments had any effects on this parameter and to enable the conversion of fresh weight (FW) yields to dry weight (DW) yields. The percent moisture content was calculated using the formula (FW – DW) ÷ FW × 100.

There were no significant effects of soil amendment treatments on the moisture content of switchgrass at either site (Fig. 4.4.1).

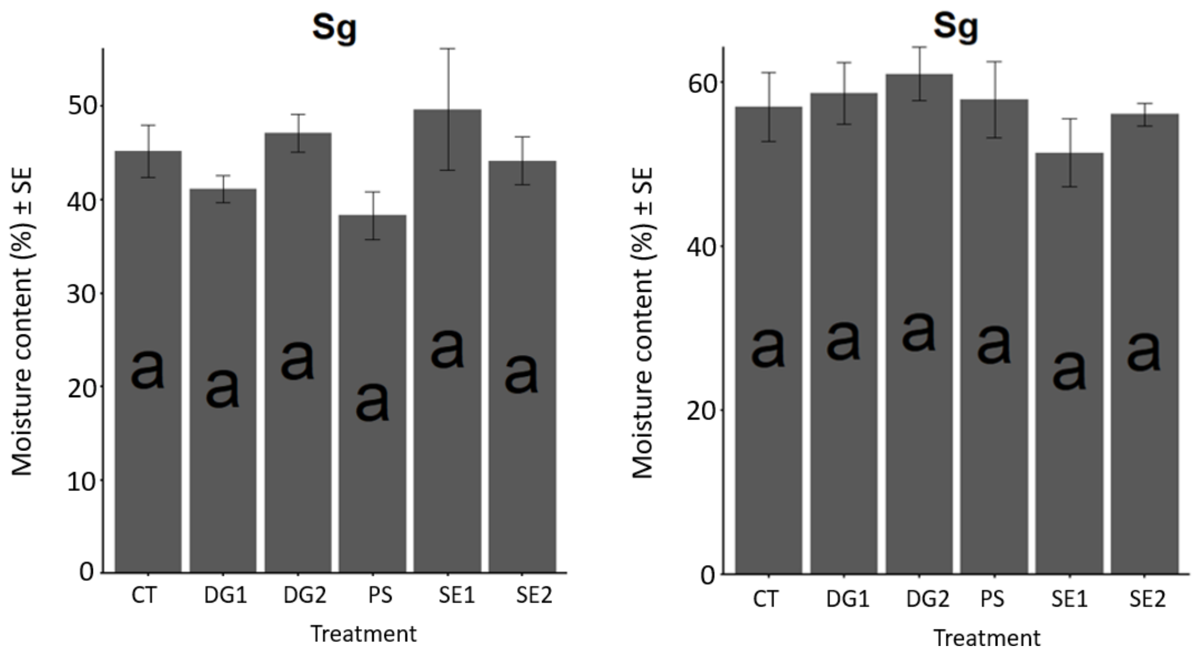


Figure 4.4.1 The moisture content (%) of switchgrass at the Falmouth (left) and Chegoggin Point (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.5 Miscanthus Moisture Content (2022)

The moisture content of Miscanthus subsamples at the Falmouth sites was measured to determine if soil amendment treatments had any effects on this parameter and to enable the conversion of fresh weight (FW) yields to dry weight (DW) yields. The percent moisture content was calculated using the formula (FW – DW) ÷ FW × 100.

There were no significant effects of soil amendments treatments on the moisture content of Miscanthus at the site (Fig. 4.5.1).

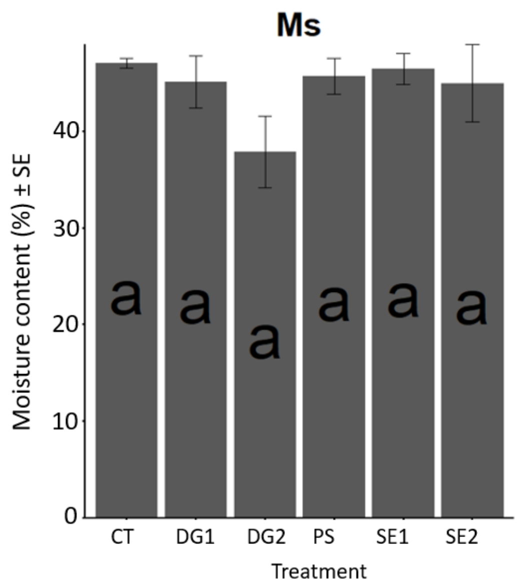


Figure 4.5.1 The moisture content (%) of switchgrass at the Falmouth site as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.6 Biomass Yield (2021)

The harvesting of all four energy crops aboveground biomass occurred in November 2021, around 17 weeks after planting. First, fresh biomass samples were weighed, and then subsamples were dried to determine water and dry weight. The resulting dry weights of these samples per subplot (in kg) were divided by the subplot area (40 m^2) and multiplied by 10000

m^2/ha to convert the dry weight to kg/ha. The dry weight per hectare was then analyzed using analysis of variance through a normal or gamma model.

The aboveground biomass yield for miscanthus in the Chegoggin Point site was not possible, as the rhizome emergence percentage was less than 1%. The failure of the miscanthus emergence might be due to the excessive salt concentration of the soil, which is discussed further in the discussion section.

After conducting the one-way analysis of variance and post-hoc tests of the data for the Falmouth, it was found that switchgrass and coppiced-willow crops grown in subplots treated with paper mill sludge (PS) had significantly higher yields compared to all the other treatments (114 % and 139 % higher than the control treatments, respectively). Although the average dry weights of miscanthus and coppiced-hybrid-poplar treated with paper mill sludge were numerically the highest among the soil amendment treatments, they were not statistically significantly different from the other treatments. The other two treatments, anaerobic digestate and seaweed extract, resulted in similar yields within crops and did not significantly differ from the control treatments (Fig. 4.6.1).

The one-way analysis of variance and post-hoc tests of the biomass data from the Chegoggin Point site indicated there were no significant differences among the soil amendment treatments (Fig. 4.6.2). Although dry weight yields of the switchgrass and coppiced willow crops were numerically the highest, they were not statistically significantly different from the other treatments. Likewise, the digestate and seaweed extract performed similarly within each crop, except in coppiced hybrid-poplar, where the anaerobic digestate treatment had numerically, but not statistically significantly, higher dry weight yields than in the seaweed extract treatments.

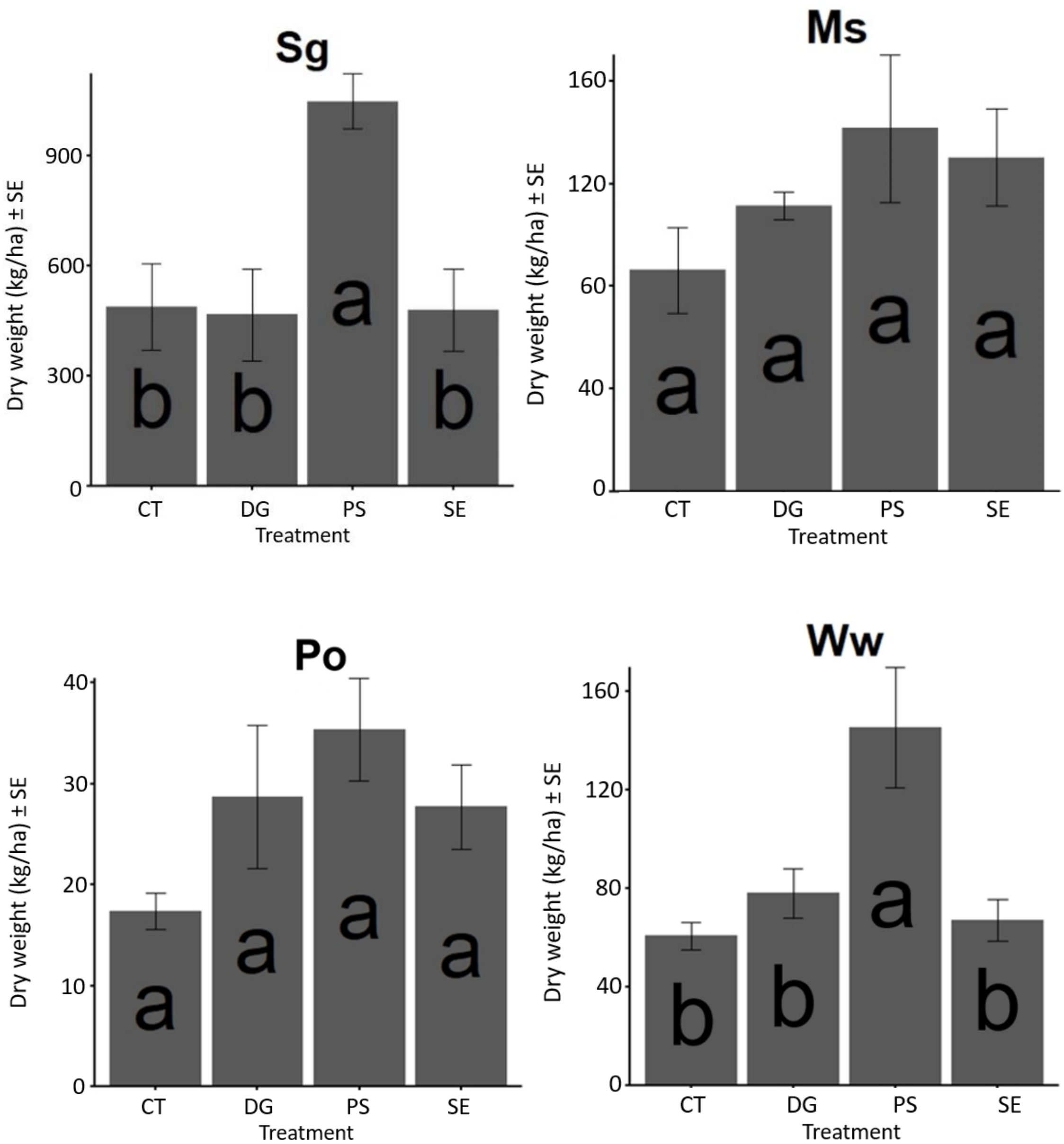


Figure 4.6.1 Aboveground biomass yield of four crops (switchgrass (Sg), miscanthus (Ms), coppiced hybrid-poplar (Po) and coppiced willow (Ww)) grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Falmouth site in the establishment year (2021). Within each tree, species treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

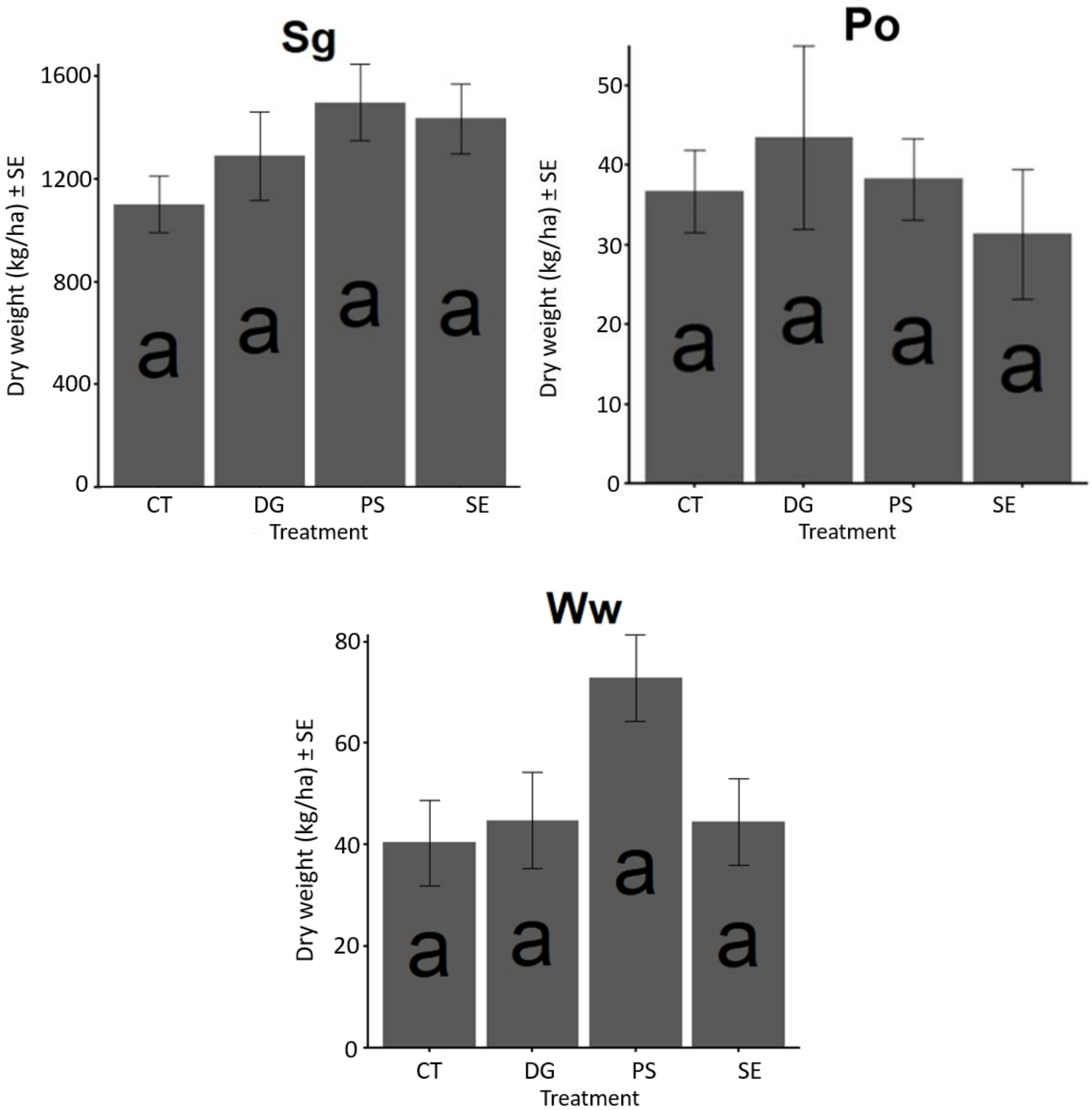


Figure 4.6.2 Aboveground biomass yield of three crops (switchgrass (Sg), coppiced hybrid-poplar (Po), and coppiced willow (Ww)) grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Chegoggin Point site in the establishment year (2021). Treatments labelled with the same letter are not significantly different from each other (n = 4; $\alpha = 0.05$). Error bars represent standard errors.

4.7 Biomass Yield, Grasses (2022) – Switchgrass and Miscanthus

Analysis of these data indicated that, in both grass crops at the Falmouth site, none of the soil amendment treatments resulted in significant differences in yield compared to the control treatments (Fig. 4.7.1). However, it is interesting to note that, although not significantly different, the yield of switchgrass and miscanthus treated with the pulp mill sludge had yields 29 % and 132 % greater, respectively, than the control treatments. It is also interesting to note that the switchgrass treated with either one or two applications of the seaweed extract had the lowest yields and were statistically lower than the yield of the pulp mill sludge-treated switchgrass. Overall, the switchgrass yields were much higher than the miscanthus yields; this is not surprising given the miscanthus's poor establishment/survival rates (see section 4.2).

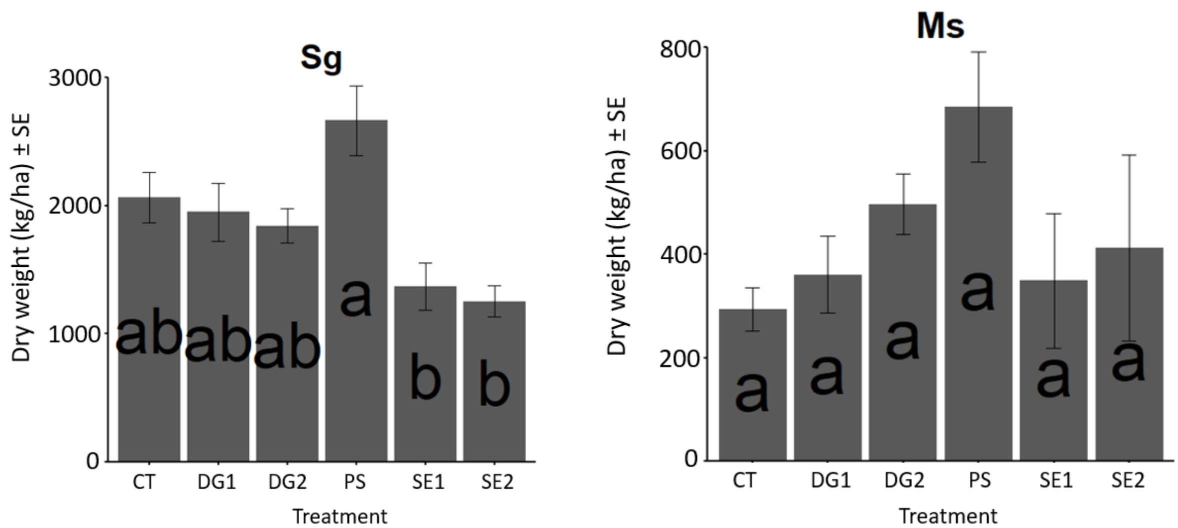


Figure 4.7.1 Aboveground dry weight (kg/ha) of switchgrass (Sg) and miscanthus (Ms) as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season at the Falmouth site. Within each crop, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

Yield data was only available for switchgrass at the Chegoggin Point site in 2021 (Fig. 4.7.2) due to the failure of the miscanthus rhizomes to emerge in the establishment year (2021) at this site.

A one-way ANOVA of the switchgrass data indicated that both the single and double applications of the anaerobic digestate and the paper mill sludge application resulted in increases in yield compared to the untreated control by 70 %, 66 % and 84 %, respectively. The paper mill sludge had the highest yield (4033.5 kg/ha) of all the soil amendment treatments.

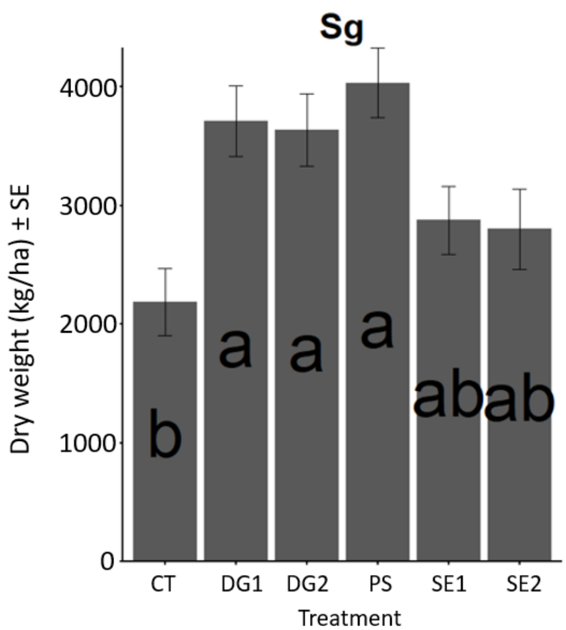


Figure 4.7.2 Aboveground dry weight (kg/ha) of switchgrass (Sg) as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season at the Chegoggin Point site. Within each crop, treatments labelled with the same letter are not significantly different from each other (n = 4; $\alpha = 0.05$). Error bars represent standard errors.

4.8 Poplar Primary Stem Length (2022)

No significant differences were found in the average stem lengths of coppiced hybrid-poplar among the soil amendment treatments at either site (Fig. 4.8.1). Although not significantly different, average stem lengths in the double application of anaerobic digestate treatment were 26 % greater than the control at the Falmouth site. The paper mill sludge treatment was 44 % greater than the control at the Chegoggin Point site.

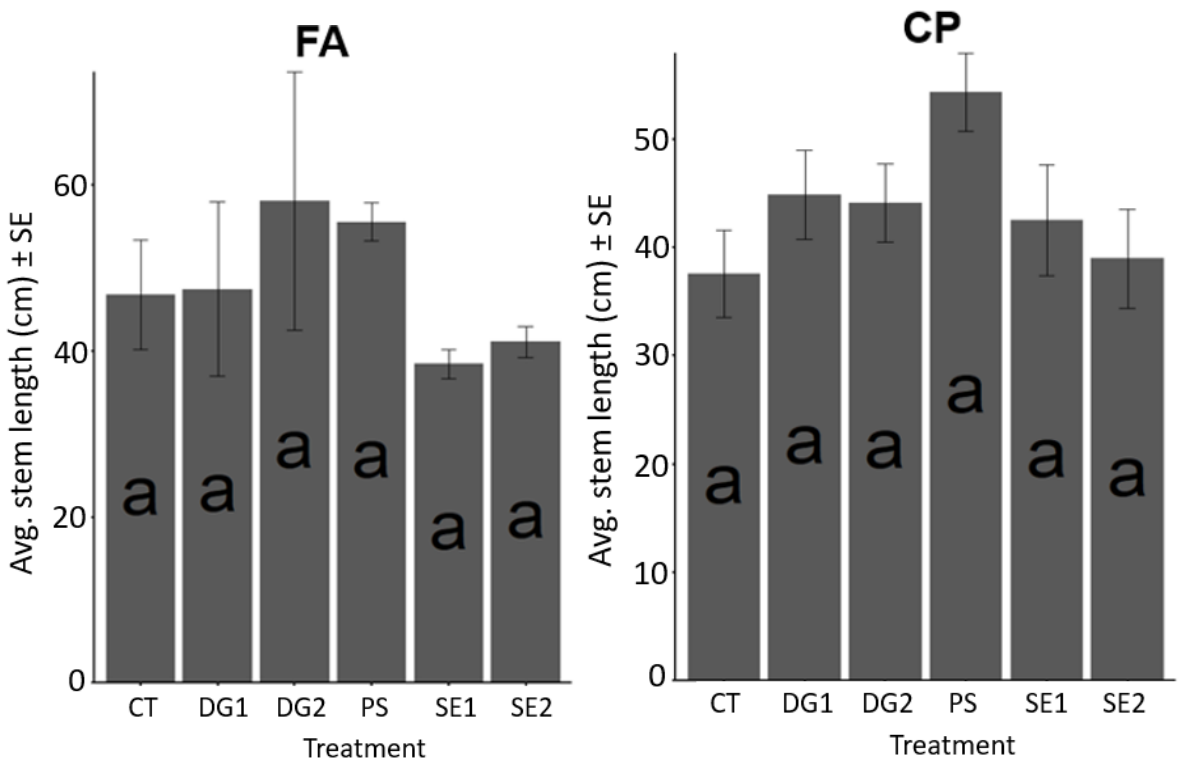


Figure 4.8.1 Primary stem lengths (cm) of coppiced hybrid-poplar at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.9 Willow Primary Stem Length (2022)

No significant differences were found in the average stem lengths of coppiced willow among the soil amendment treatments at either site (Fig. 4.9.1). Although not significantly different, average stem lengths in the double application of anaerobic digestate treatment were 67 % greater than the control at the Falmouth site. The paper mill sludge treatment was 20 % greater than the control at the Chegoggin Point site.

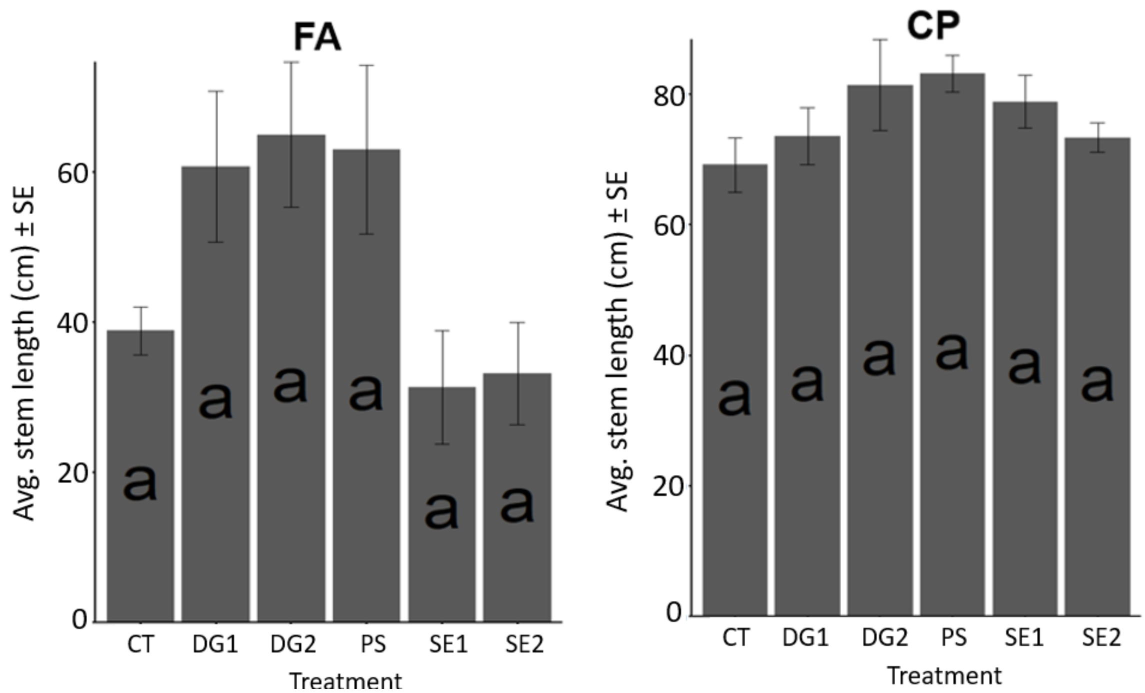


Figure 4.9.1 Primary stem lengths (cm) of coppiced willow at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.10 Poplar Primary Stem Diameter (2022)

No significant differences in coppiced hybrid-poplar average stem diameters were found among soil amendment treatments at the Falmouth site, with the highest average diameter found in the second digestate treatment subplots (5.2 mm). However, at the Chegoggin Point site, the paper mill sludge treatment had a significantly high average stem diameter (5.7 mm) than the control treatment (by 36 %) and then the double application of seaweed extract (by 12 %) (Fig.4.10.1)

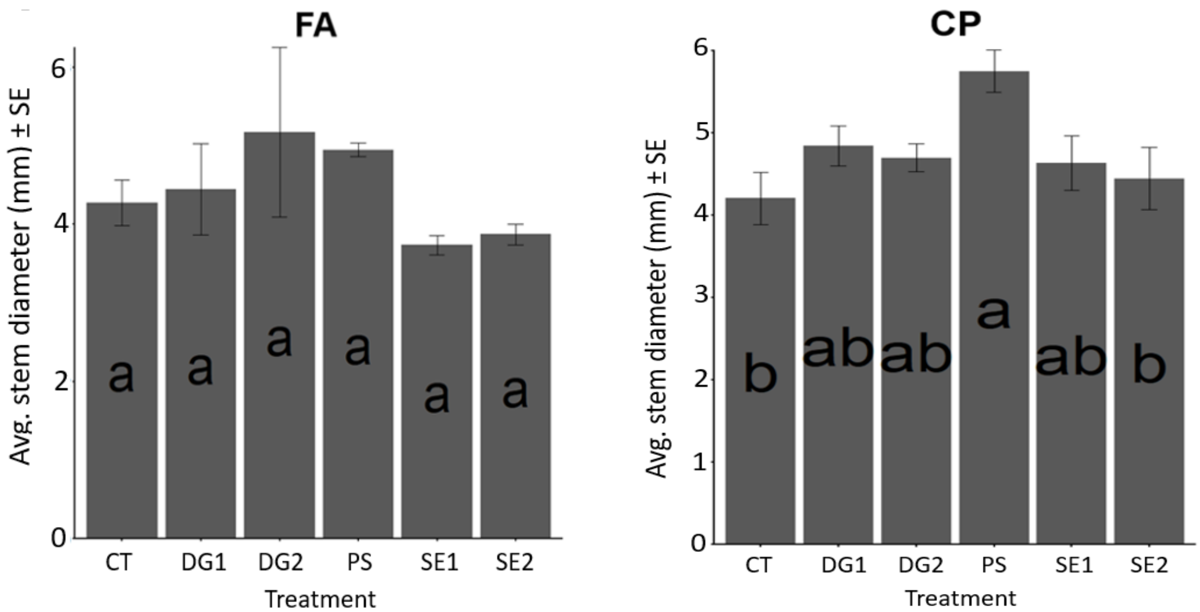


Figure 4.10.1 Primary stem diameter (mm) of coppiced hybrid-poplar at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

4.11 Willow Primary Stem Diameter (2022)

There were no significant effects of soil amendment treatments on the primary stem diameters of willow trees at the Falmouth site (Fig. 4.11.1). Although the average stem diameter of the willow treated with the double application of the anaerobic digestate was 33% greater than the control, this increase was not significantly different. However, at the Chegoggin Point site, the double application of the anaerobic digestate resulted in a statistically significant increase in average stem diameter of 20 % compared to the control treatment.

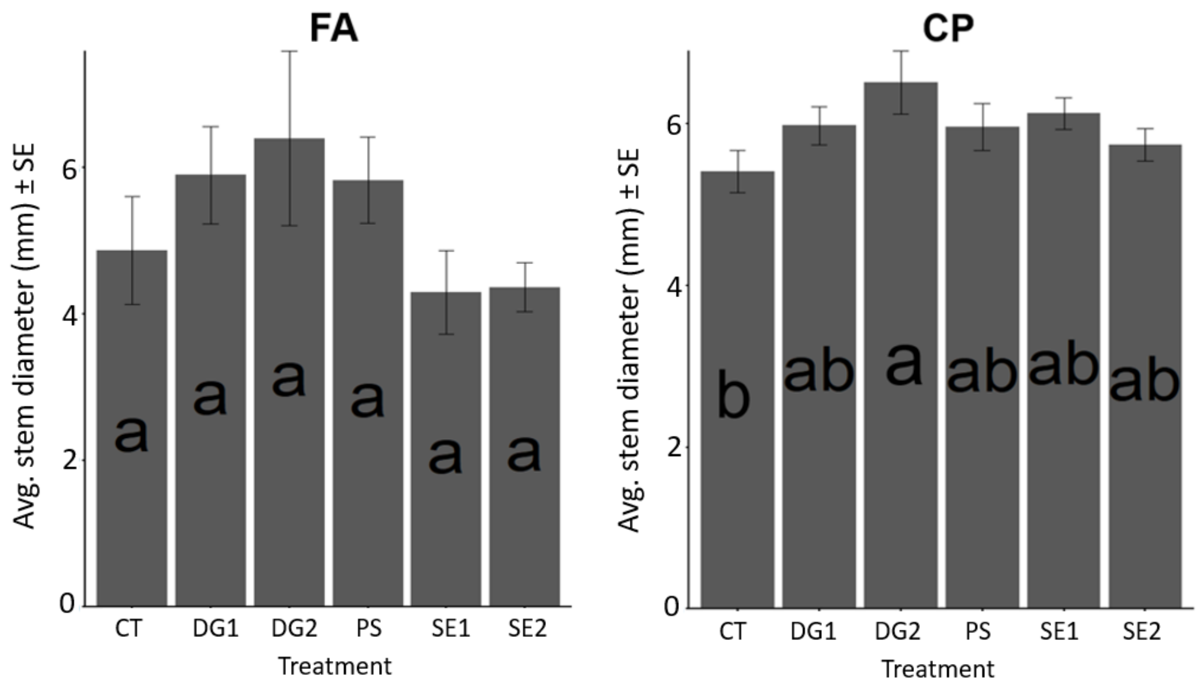


Figure 4.11.1 Primary stem diameter (mm) of coppiced willow at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.12 Poplar Total Stem Length (2022)

There were no significant differences in the total stem length of the coppiced hybrid-poplar among the soil amendment treatments at either of the two sites (Fig. 4.12.1). Although not significantly different from the controls, the highest total stem length was found in the treatment with two applications of anaerobic digestate treatment (464.5 cm; 24 % greater than the control treatment) at the Falmouth site, and the paper mill sludge treatment had the highest total stem length (434.5 cm; 44 % greater than the control treatment) at the Chegoggin Point site.

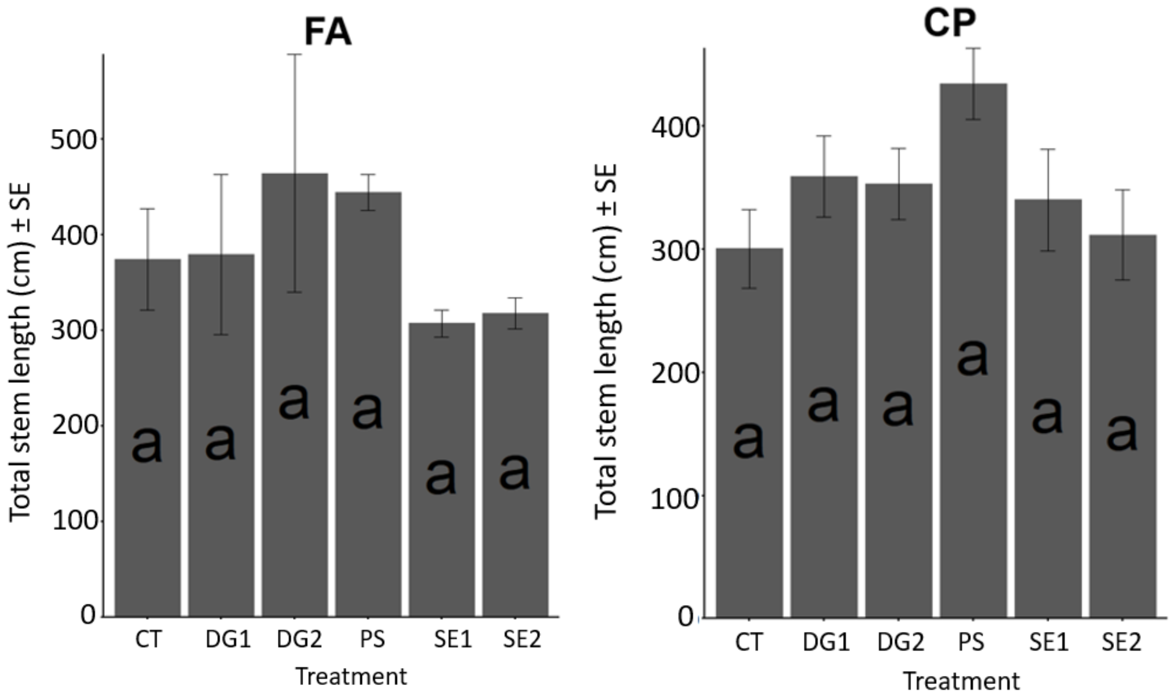


Figure 4.12.1 Total stem length (cm) of coppiced hybrid-poplar at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

4.13 Willow Total Stem Length (2022)

There were no significant differences in total stem length in coppiced willow trees among the soil amendment treatments at either site (Fig. 4.13.1). The highest total stem lengths (520.4 cm) were in the willow trees treated with two applications of the anaerobic digestate at the Falmouth site and in the subplots treated with the paper mill sludge (664 cm) at the Chegoggin Point site.

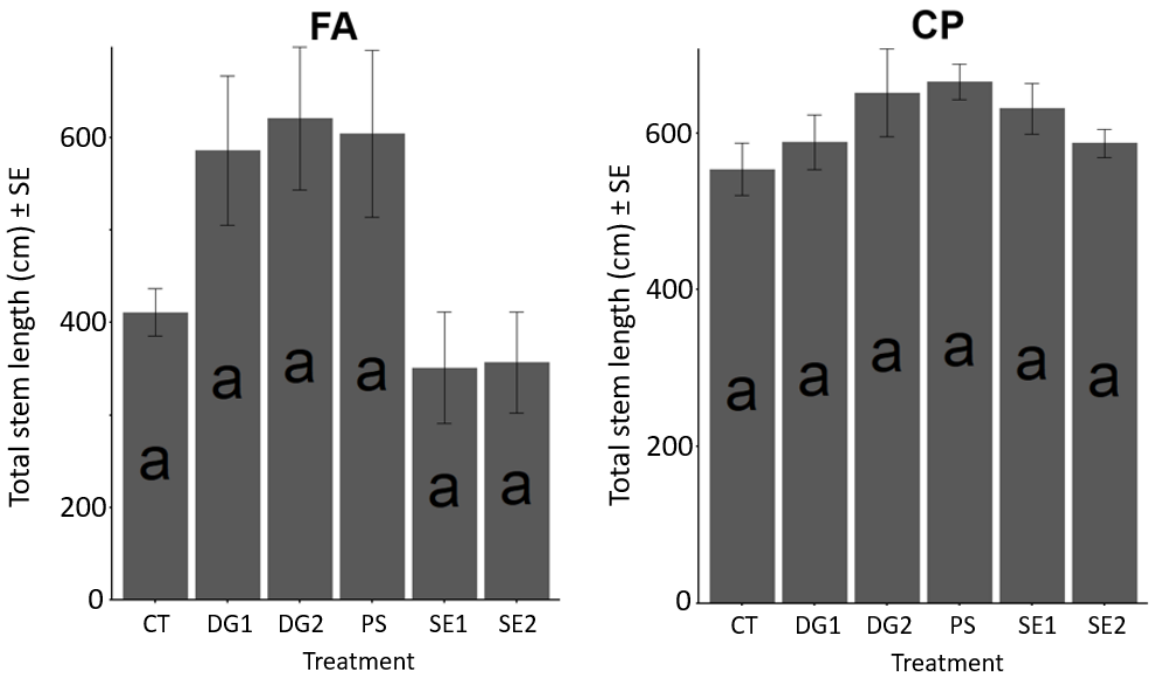


Figure 4.13.1 Total stem length (cm) of coppiced willow at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.14 Poplar Stem Volume (2022)

Using the primary stem length (see section 4.8) and diameter (see section 4.10) of all secondary and tertiary stems on randomly selected coppiced hybrid-poplar trees (eight 8 trees per subplot) total stem volume (TSV) per tree was estimated.

There were no significant differences in TSV of coppiced hybrid-poplar trees among the soil amendment treatments at the Falmouth site (Fig. 4.14.1). Although the TSV of trees treated with the double application of the anaerobic digestate was 215 % greater than the control treatment, the increase was not statistically significant. No significant differences were found for poplar TSV at the Chegoggin Point site, but the double application of anaerobic digestate had the highest total stem volume (74.68 cm3; 51 % higher than the control).

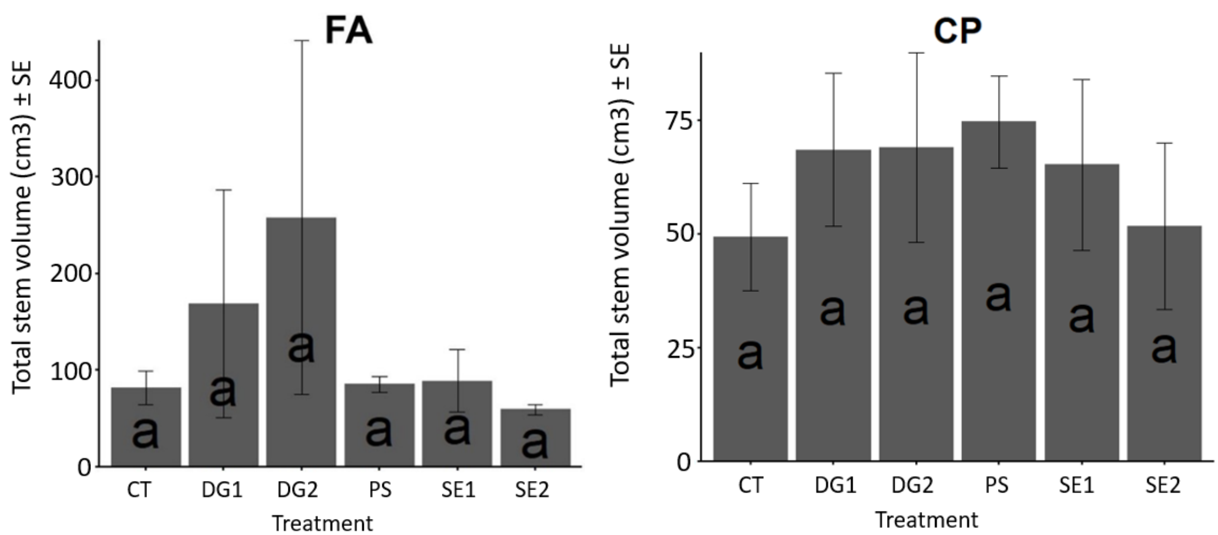


Figure 4.14.1 Total stem volume per subplot (cm3) of coppiced hybrid-poplar at the Falmouth (FA) (left) and Chegoggin Point (CP) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

4.15 Willow Stem Volume (2022)

Using the primary stem length (see section 4.9) and diameter (see section 4.11) of all secondary and tertiary stems on randomly selected coppiced willow trees (eight trees per subplot), a total stem volume (TSV) per tree was estimated.

At the Falmouth site, the coppiced willow treated with the double application of anaerobic digestate had the highest TSV (346.3 cm^3) and was significantly greater than the control and two seaweed extract treatments (Fig. 4.15.1). The TSV of the willow treated with the double application of anaerobic digestate was also 243 % higher than the control treatment, but this was not statistically significantly different. No significant differences were found for willow TSV at the Chegoggin Point site, but again the double application of anaerobic digestate had the highest total stem volume (377 cm^3; 111 % higher than the control).

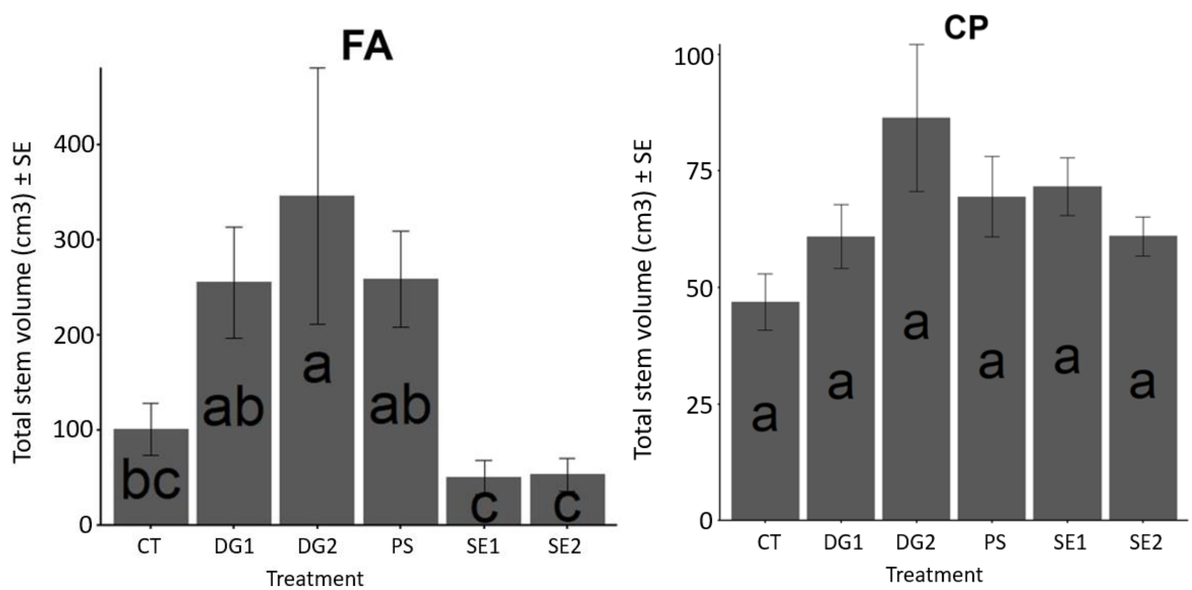
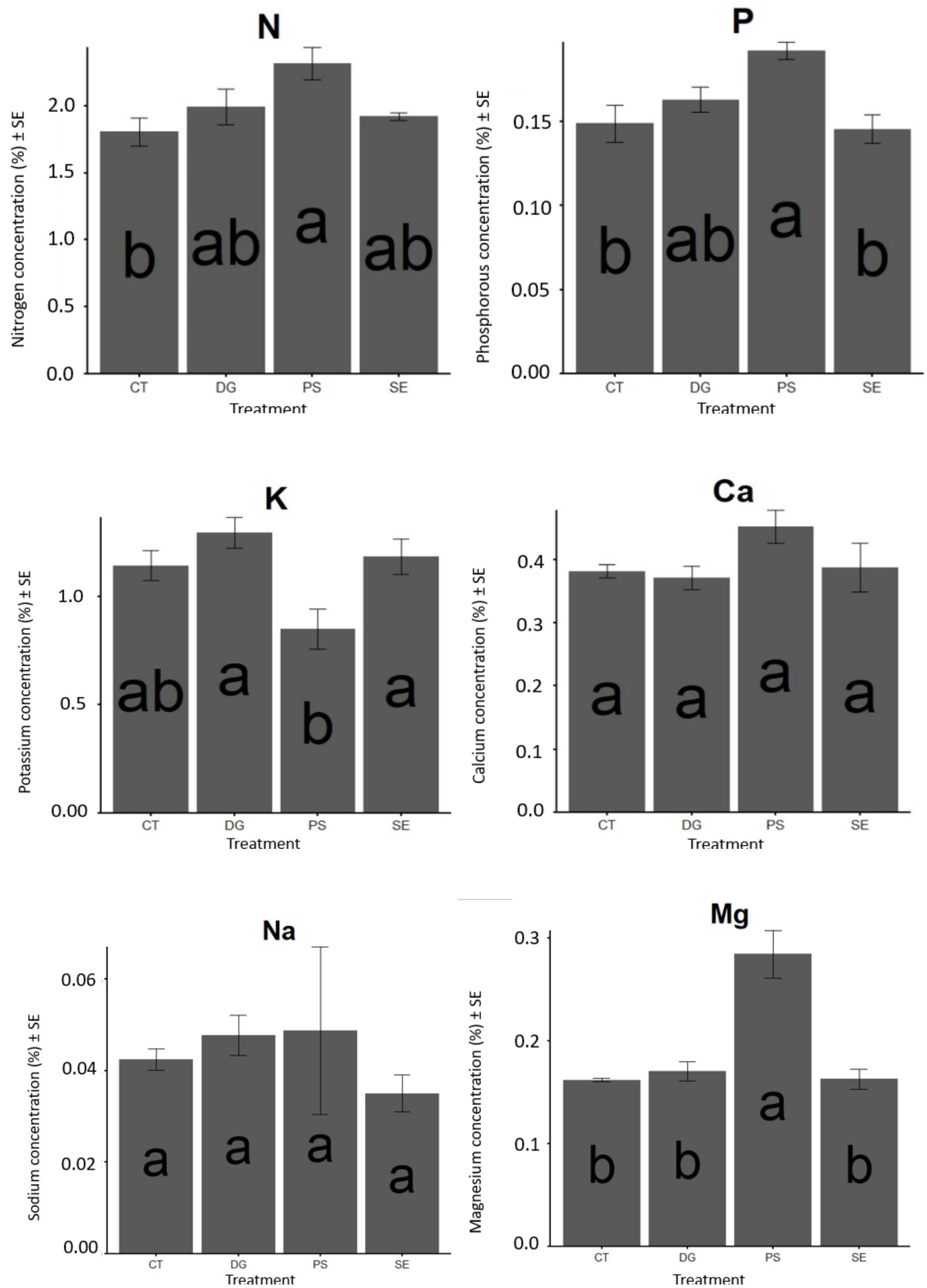


Figure 4.15.1 Total stem volume per subplot (cm3) of coppiced willow at the Falmouth (FA) (left) and Chegoggin Point (FA) (right) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.16 Miscanthus Shoot Tissue Nutrient Concentrations (2021)

A one-way analysis of variance for miscanthus shoot tissue nutrient concentrations showed that the paper mill sludge treatment resulted in significantly higher concentrations compared to the control (p-values <0.05) for nitrogen by 28%, phosphorous by 29%, magnesium by 75% and manganese by 101% (Fig. 4.16.1). There were no significant effects of soil amendment treatments on tissue nutrient concentrations for calcium, sodium, iron, and zinc.



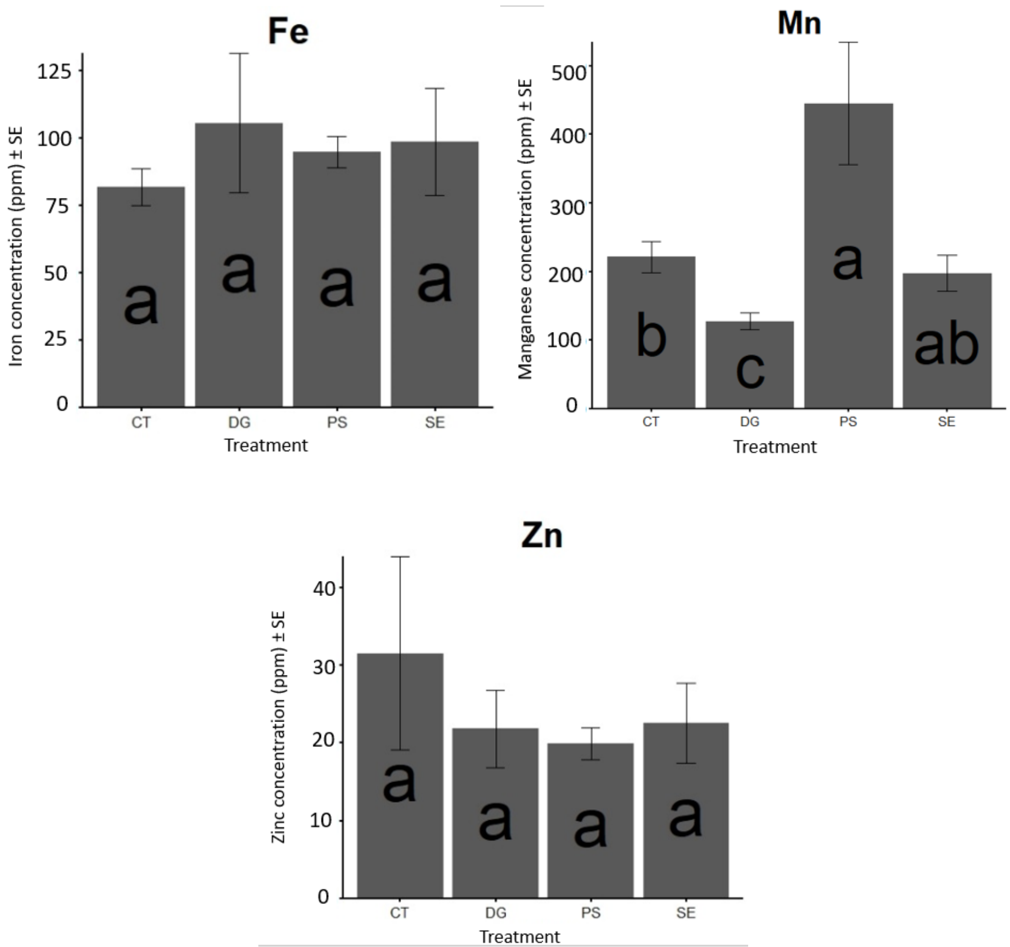
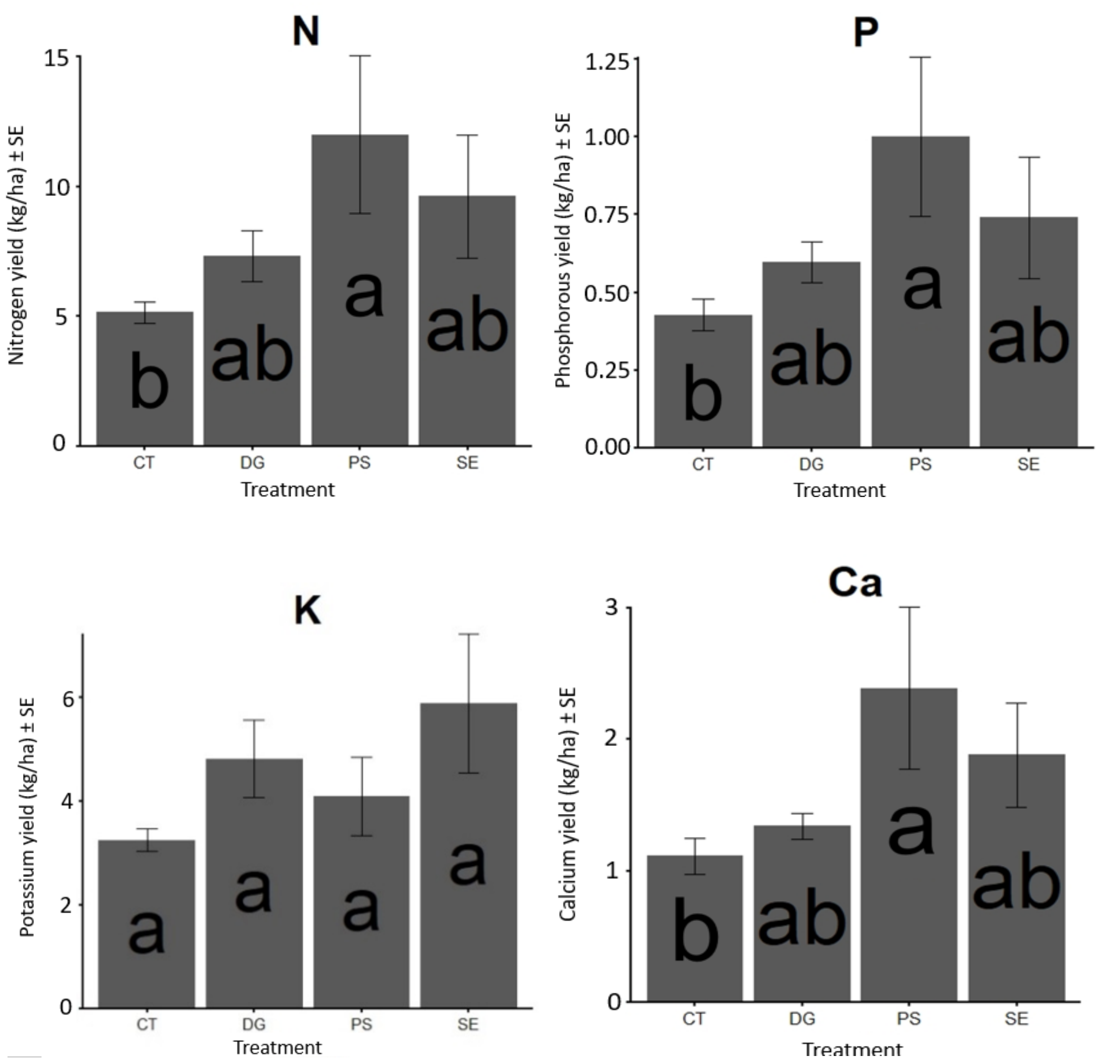
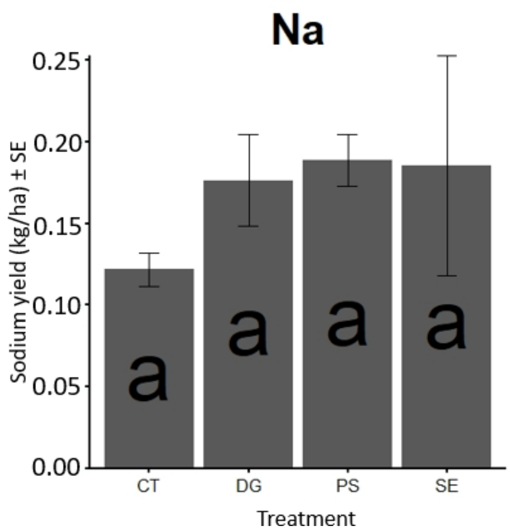


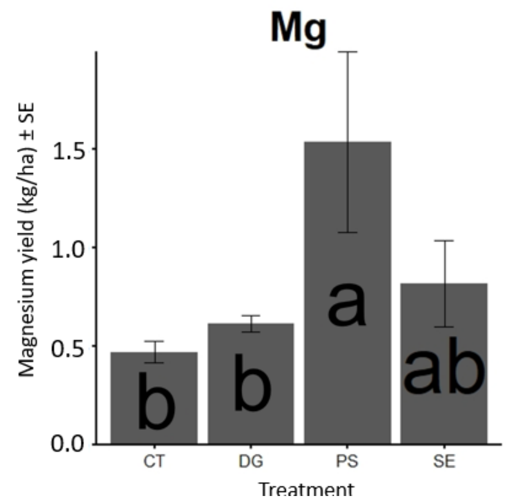
Figure 4.16.1 Shoot tissue nutrient concentrations for miscanthus grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Falmouth site in 2021. Treatments labelled with the same letter are not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard errors.

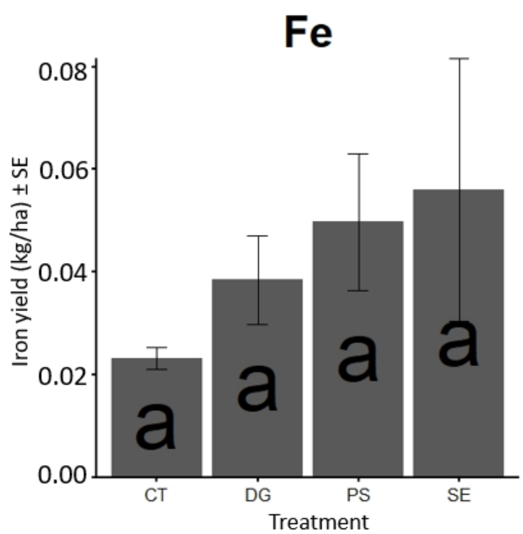
4.17 Miscanthus Shoot Nutrient Yields (2021)

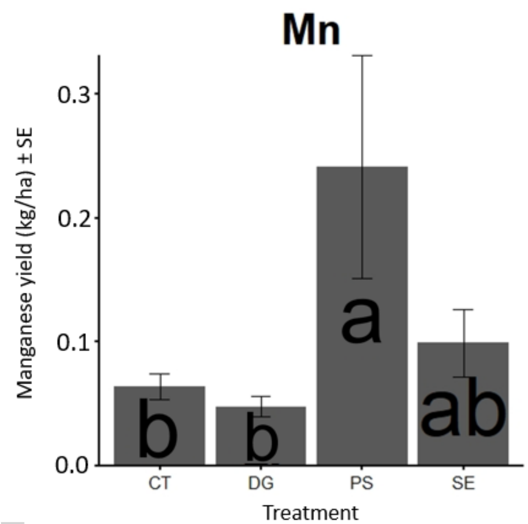
Miscanthus tissue nutrient concentrations (see section 4.16.1) from the 2021 fall harvest at the Falmouth site were converted into shoot nutrient yields (kg/ha) (Fig. 4.17.1). A one-way analysis of variance for these nutrient yields indicates that the paper mill sludge treatment resulted in significantly higher nutrient yields compared to the control (p-values <0.05) for nitrogen by 113%, phosphorous by 133%, calcium by 114%, magnesium by 226% and manganese by 276%. There were no significant differences in nutrient yields among soil amendment treatments for potassium, sodium, iron, and zinc.




Na
Sodium yield (kg/ha) ± SE
0.25
0.20
0.15
0.10
0.05
0.00
a
a
a
a
CT
DG
PS
SE
Treatment


Mg
Magnesium yield (kg/ha) ± SE
1.5
1.0
0.5
0.0
b
b
a
ab
CT
DG
PS
SE
Treatment


Fe
Iron yield (kg/ha) ± SE
0.08
0.06
0.04
0.02
0.00
a
a
a
a
CT
DG
PS
SE
Treatment


Mn
Manganese yield (kg/ha) ± SE
0.3
0.2
0.1
0.0
b
b
a
ab
CT
DG
PS
SE
Treatment

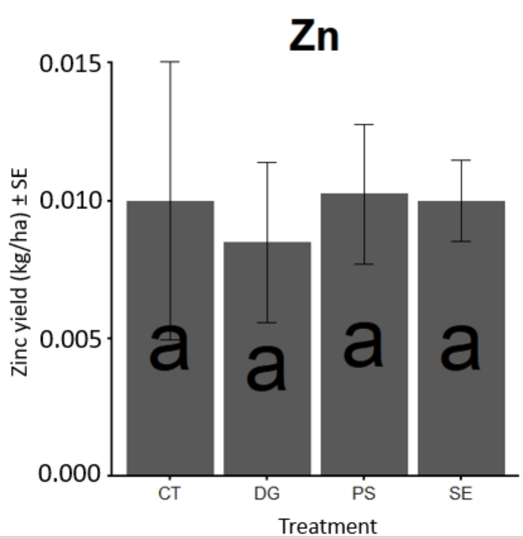
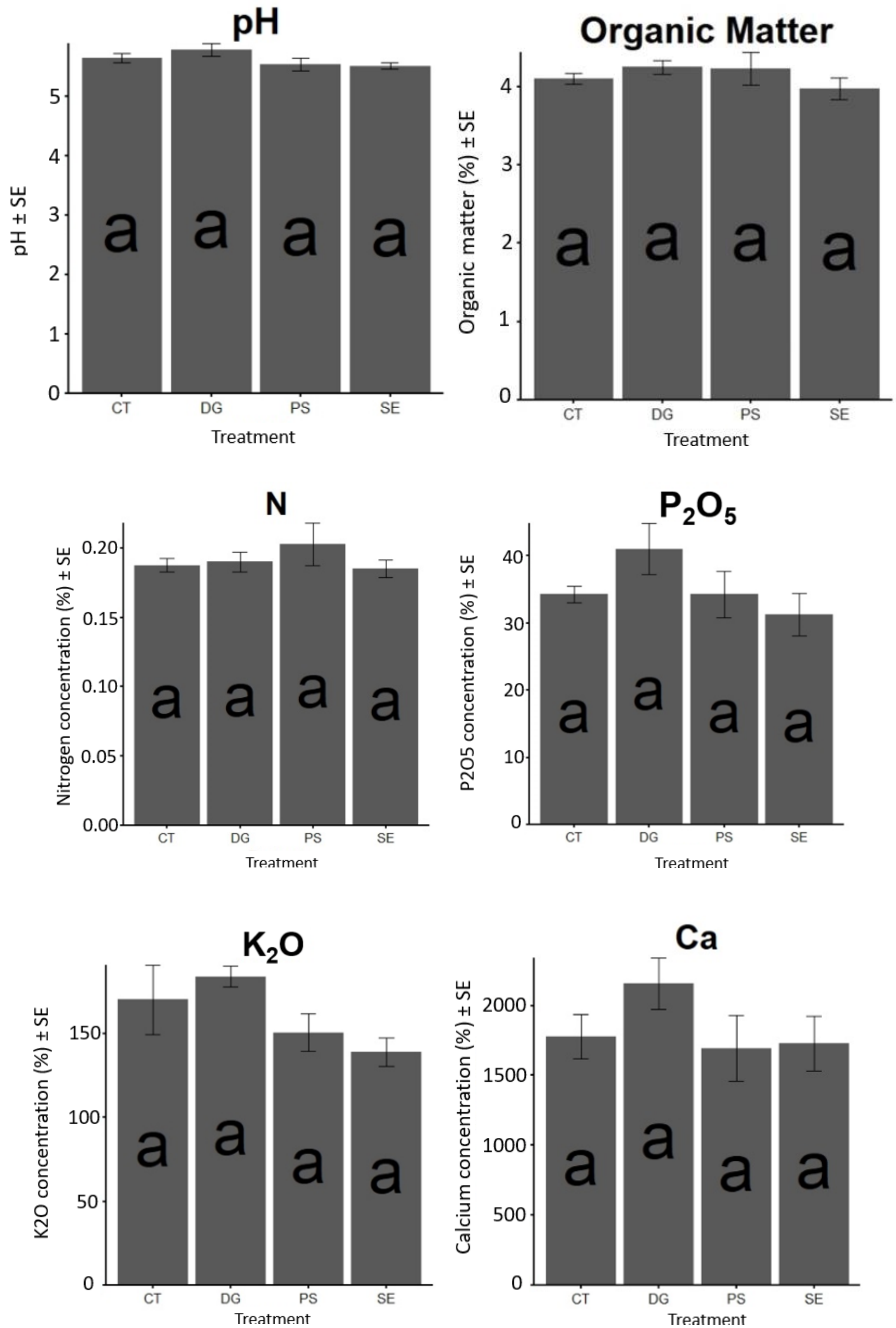

Zn
Zinc yield (kg/ha) ± SE
0.015
0.010
0.005
0.000
a
a
a
a
CT
DG
PS
SE
Treatment

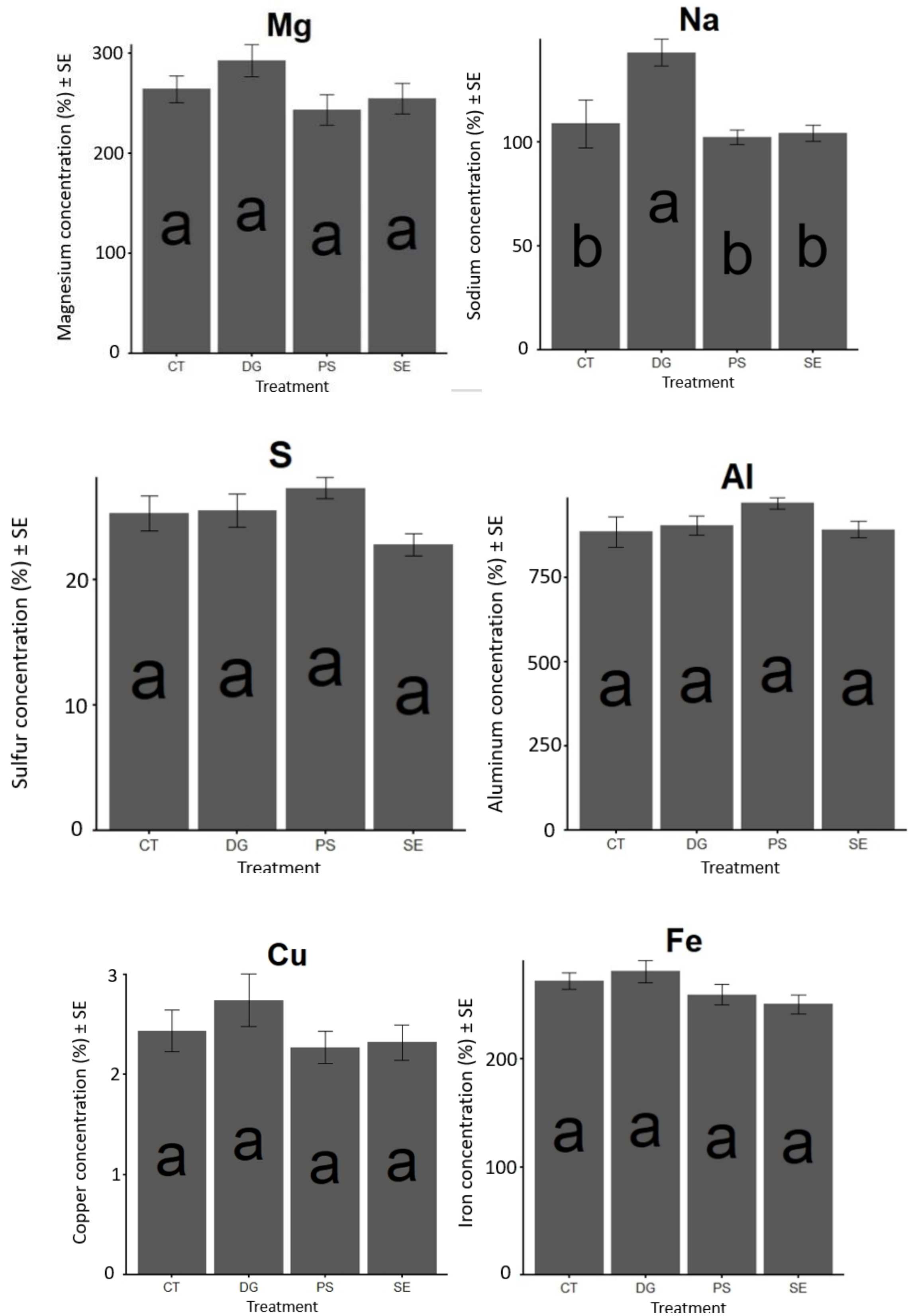
Figure 4.17.1 Shoot nutrient yields for miscanthus grown under different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the Falmouth site in 2021. Within each shoot nutrient yield, Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard errors.

4.18 Soil Nutrients (2021)

A one-way analysis of variance of the soil nutrient data showed no significant differences among soil amendment treatments at the Falmouth site (Fig. 4.18.1). However, at the Chegoggin Point site, the anaerobic digestate treatment resulted in 43 % higher sodium, and the pulp mill sludge 100 % higher manganese than in the control treatment soils (Fig. 4.18.2).

Falmouth


pH
pH ± SE
0
1
2
3
4
5
a
a
a
a
CT
DG
PS
SE
Treatment
Organic Matter
Organic matter (%) ± SE
0
1
2
3
4
a
a
a
a
CT
DG
PS
SE
Treatment
N
Nitrogen concentration (%) ± SE
0.00
0.05
0.10
0.15
0.20
a
a
a
a
CT
DG
PS
SE
Treatment
P_2O_5
P2O5 concentration (%) ± SE
0
10
20
30
40
a
a
a
a
CT
DG
PS
SE
Treatment
K_2O
K2O concentration (%) ± SE
0
50
100
150
a
a
a
a
CT
DG
PS
SE
Treatment
Ca
Calcium concentration (%) ± SE
0
500
1000
1500
2000
a
a
a
a
CT
DG
PS
SE
Treatment


Mg
Magnesium concentration (%) ± SE
300
200
100
0
a a a a
CT DG PS SE
Treatment
Na
Sodium concentration (%) ± SE
100
50
0
b a b b
CT DG PS SE
Treatment
S
Sulfur concentration (%) ± SE
20
10
0
a a a a
CT DG PS SE
Treatment
Al
Aluminum concentration (%) ± SE
750
500
250
0
a a a a
CT DG PS SE
Treatment
Cu
Copper concentration (%) ± SE
3
2
1
0
a a a a
CT DG PS SE
Treatment
Fe
Iron concentration (%) ± SE
200
100
0
a a a a
CT DG PS SE
Treatment

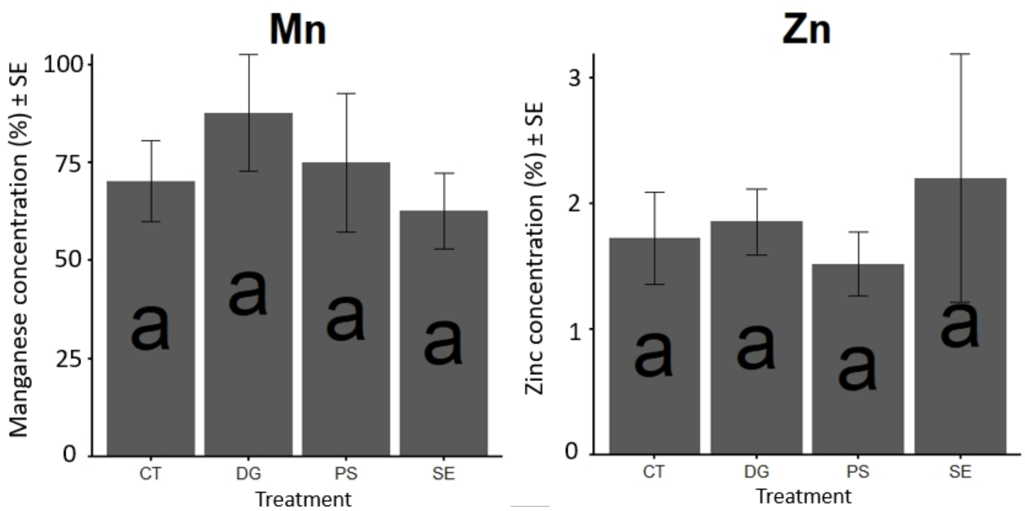
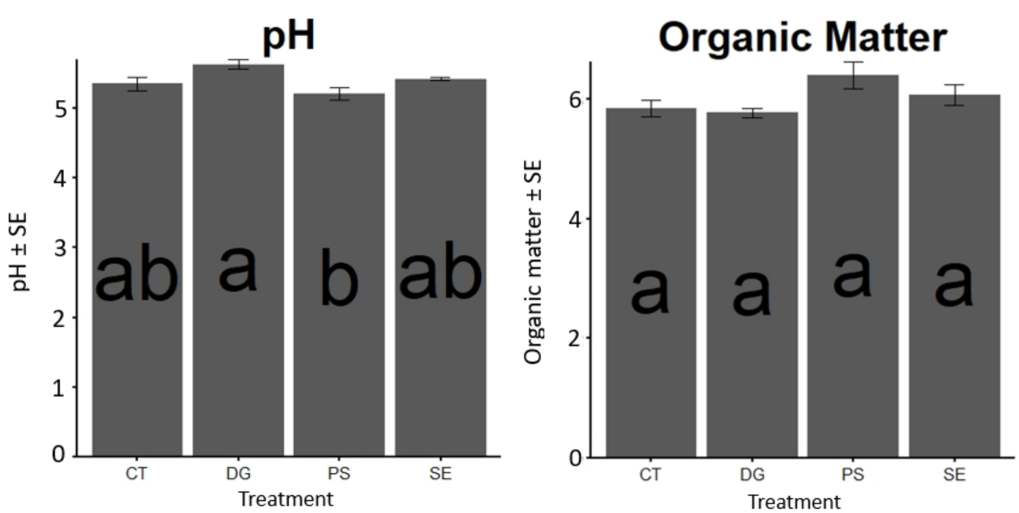
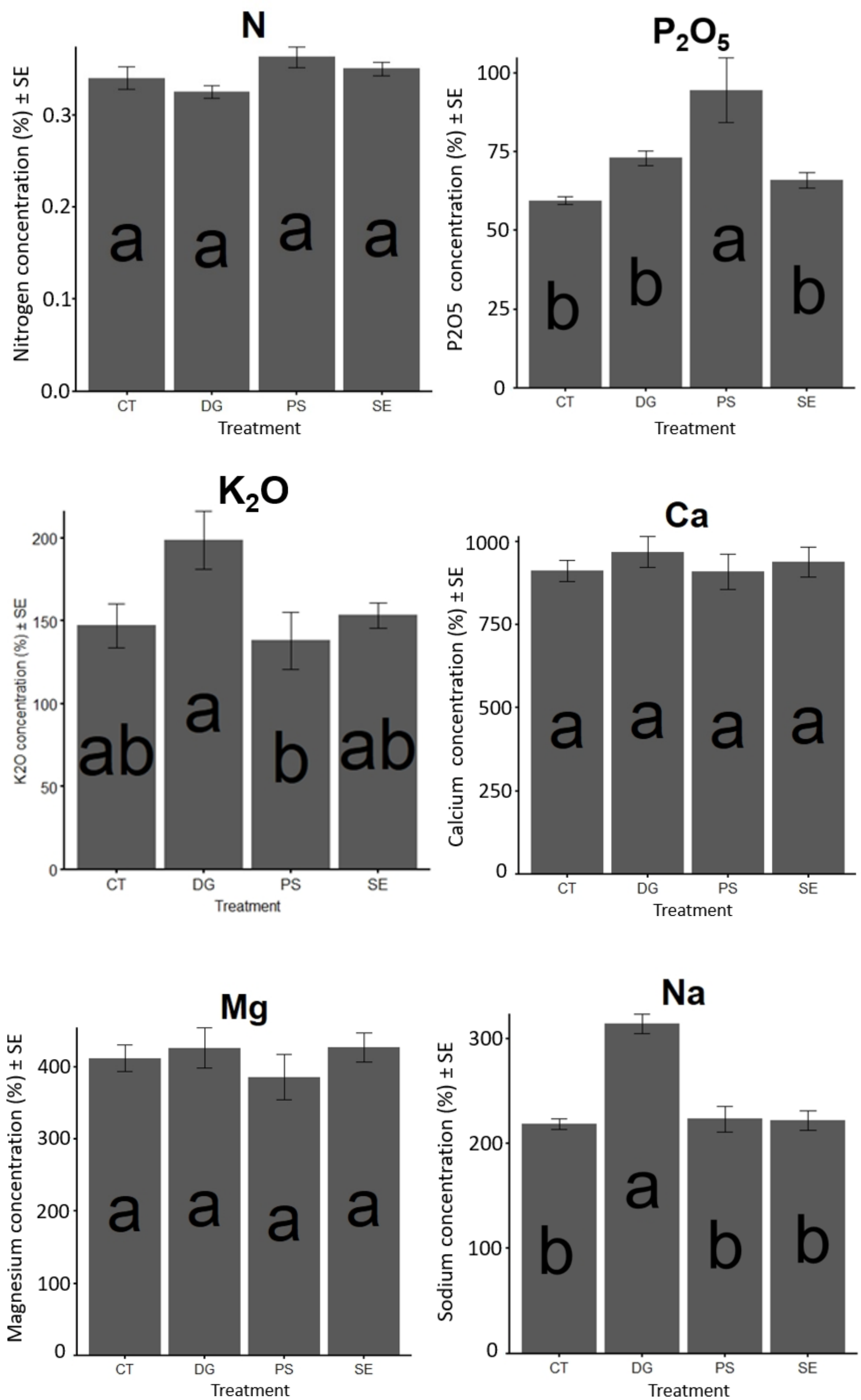
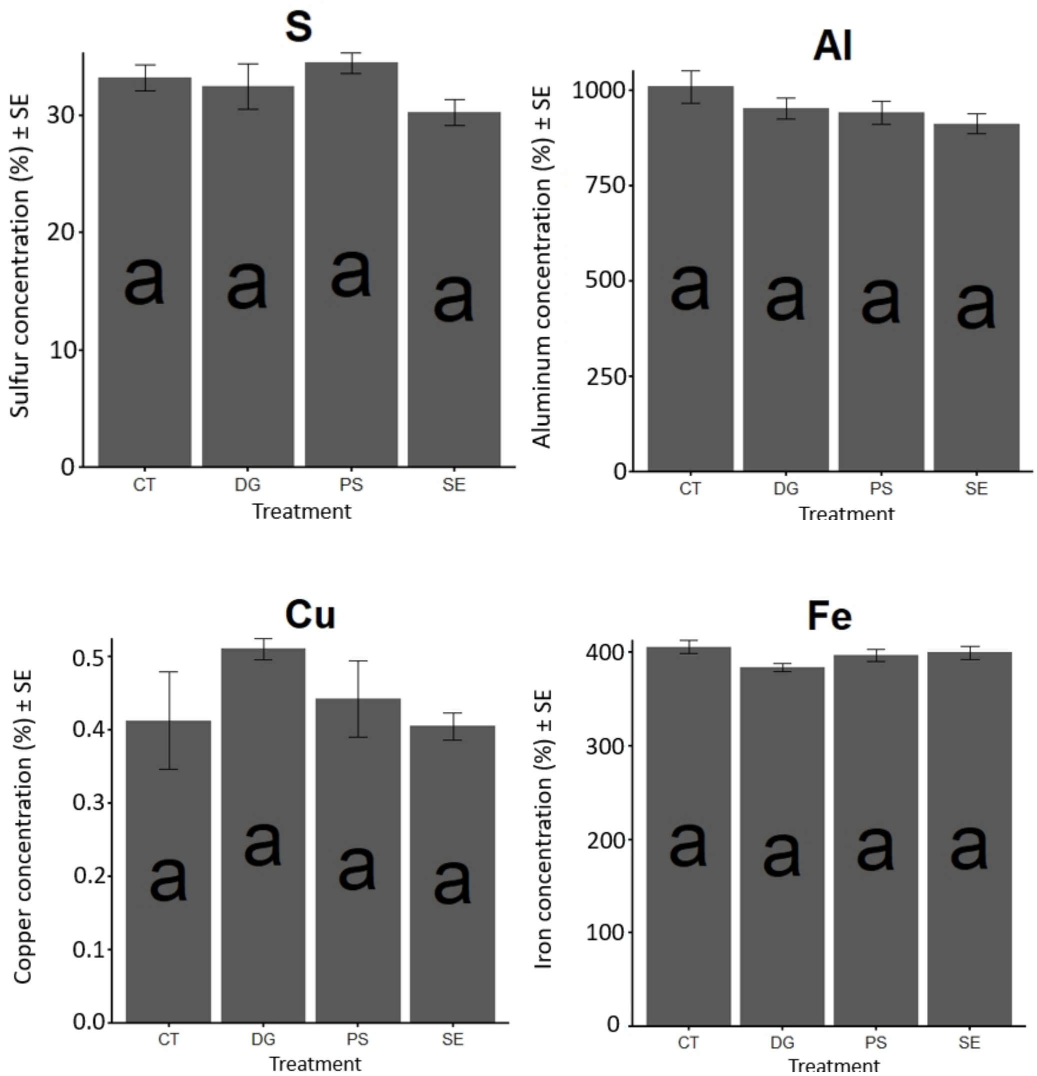


Figure 4.18.1 Soil pH and nutrient concentrations as influenced by different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end of the growing 2021 season at the Falmouth site. Within each soil nutrient, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

Chegoggin Point




N
Nitrogen concentration (%) ± SE
0.0
0.1
0.2
0.3
a
a
a
a
CT
DG
PS
SE
Treatment
P_2O_5
P2O5 concentration (%) ± SE
0
25
50
75
100
b
b
a
b
CT
DG
PS
SE
Treatment
K_2O
K2O concentration (%) ± SE
0
50
100
150
200
ab
a
b
ab
CT
DG
PS
SE
Treatment
Ca
Calcium concentration (%) ± SE
0
250
500
750
1000
a
a
a
a
CT
DG
PS
SE
Treatment
Mg
Magnesium concentration (%) ± SE
0
100
200
300
400
a
a
a
a
CT
DG
PS
SE
Treatment
Na
Sodium concentration (%) ± SE
0
100
200
300
b
a
b
b
CT
DG
PS
SE
Treatment



S
Sulfur concentration (%) ± SE
0
10
20
30
a
a
a
a
CT
DG
PS
SE
Treatment
Al
Aluminum concentration (%) ± SE
0
250
500
750
1000
a
a
a
a
CT
DG
PS
SE
Treatment
Cu
Copper concentration (%) ± SE
0.0
0.1
0.2
0.3
0.4
0.5
a
a
a
a
CT
DG
PS
SE
Treatment
Fe
Iron concentration (%) ± SE
0
100
200
300
400
a
a
a
a
CT
DG
PS
SE
Treatment

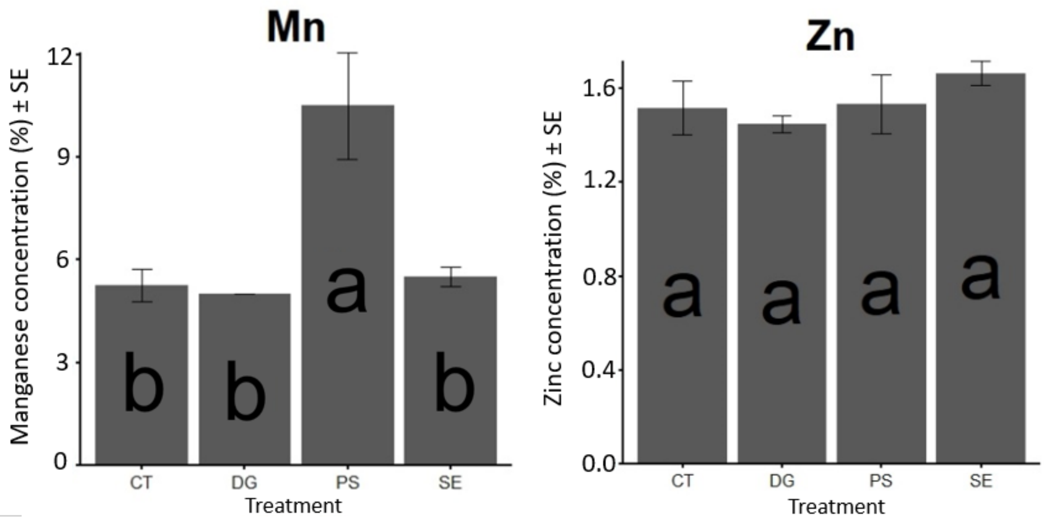
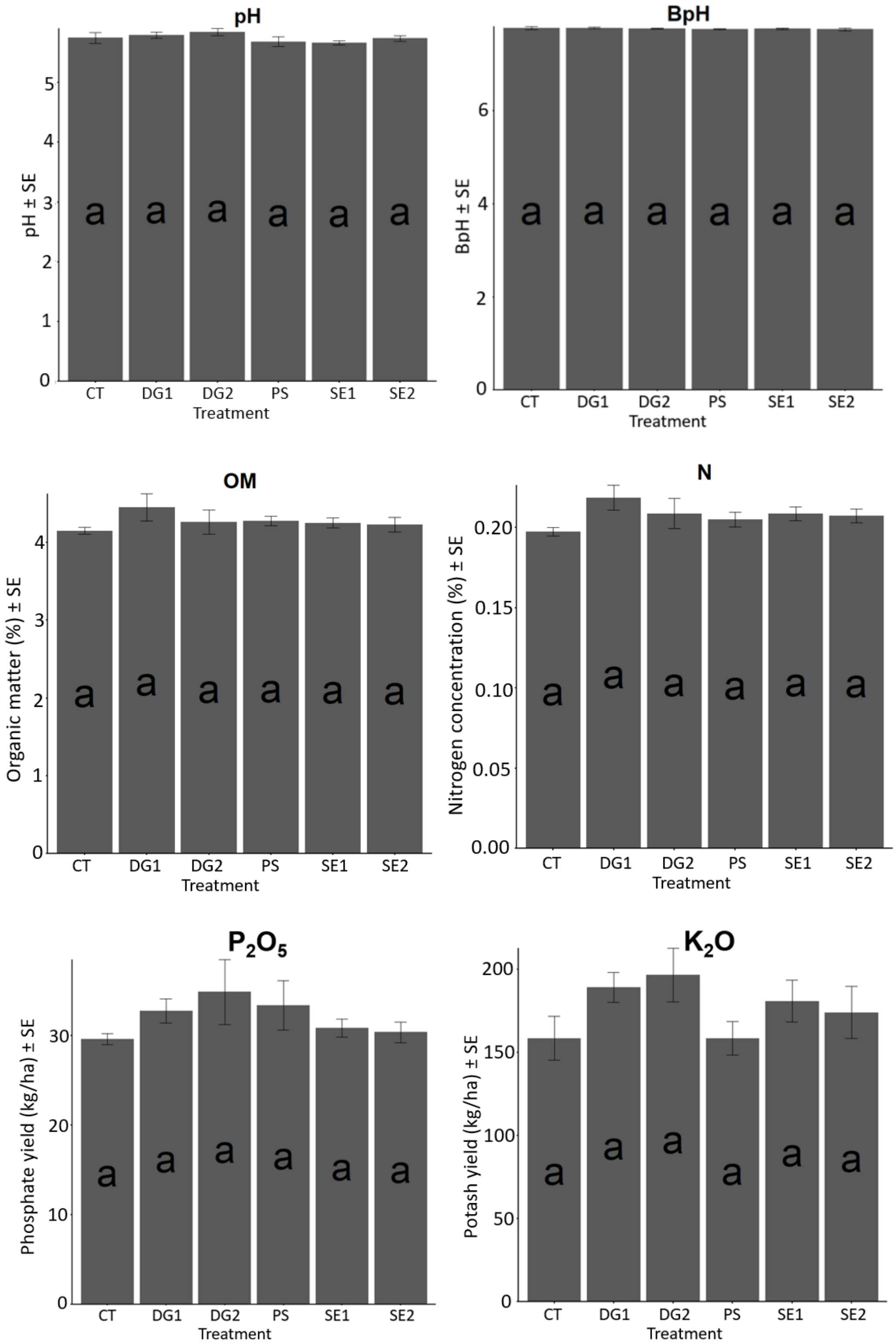


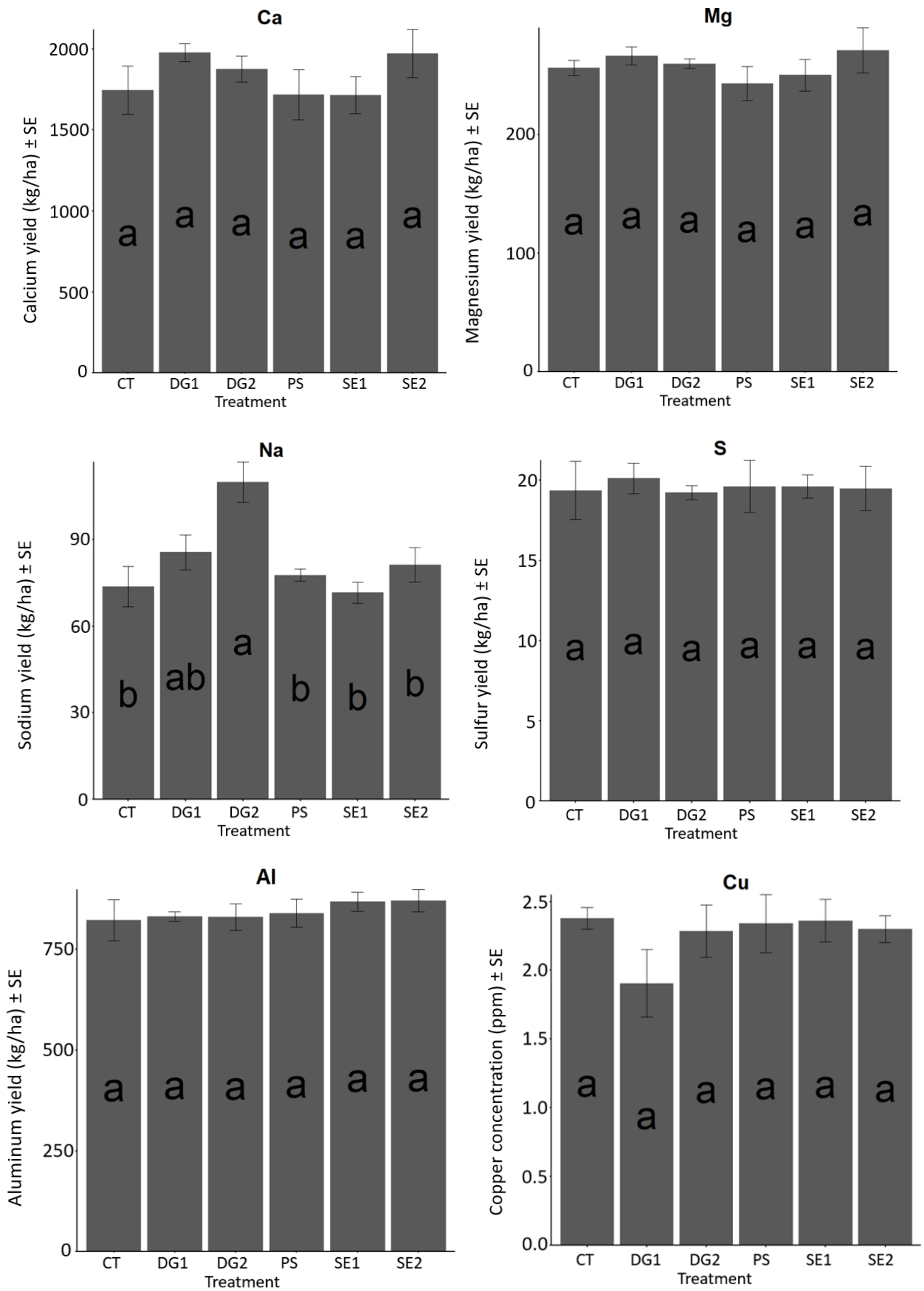
Figure 4.18.2 Soil pH and nutrient concentrations as influenced by soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end of the growing 2021 season at the Chegoggin Point site. Within each soil nutrient, treatments labelled with the same letter are not significantly different from each other (n = 4; $\alpha = 0.05$). Error bars represent standard errors.

4.19 Soil Nutrients (2022)

A one-way analysis of the soil nutrient data variance showed significant differences among soil amendment treatments at the Falmouth site (Fig. 4.19.1). The double application of anaerobic digestate treatment resulted in 49 % higher sodium. However, at the Chegoggin Point site, the double anaerobic digestate treatment resulted in 40 % higher potassium oxide than in the control treatment soils (Fig. 4.19.2).

Falmouth


pH
pH ± SE
0
1
2
3
4
5
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
BpH
BpH ± SE
0
2
4
6
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
OM
Organic matter (%) ± SE
0
1
2
3
4
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
N
Nitrogen concentration (%) ± SE
0.00
0.05
0.10
0.15
0.20
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
P2O5
Phosphate yield (kg/ha) ± SE
0
10
20
30
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
K2O
Potash yield (kg/ha) ± SE
0
50
100
150
200
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Ca
Calcium yield (kg/ha) ± SE
0
500
1000
1500
2000
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Mg
Magnesium yield (kg/ha) ± SE
0
100
200
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Na
Sodium yield (kg/ha) ± SE
0
30
60
90
b ab a b b b
CT DG1 DG2 PS SE1 SE2
Treatment
S
Sulfur yield (kg/ha) ± SE
0
5
10
15
20
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Al
Aluminum yield (kg/ha) ± SE
0
250
500
750
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Cu
Copper concentration (ppm) ± SE
0.0
0.5
1.0
1.5
2.0
2.5
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment

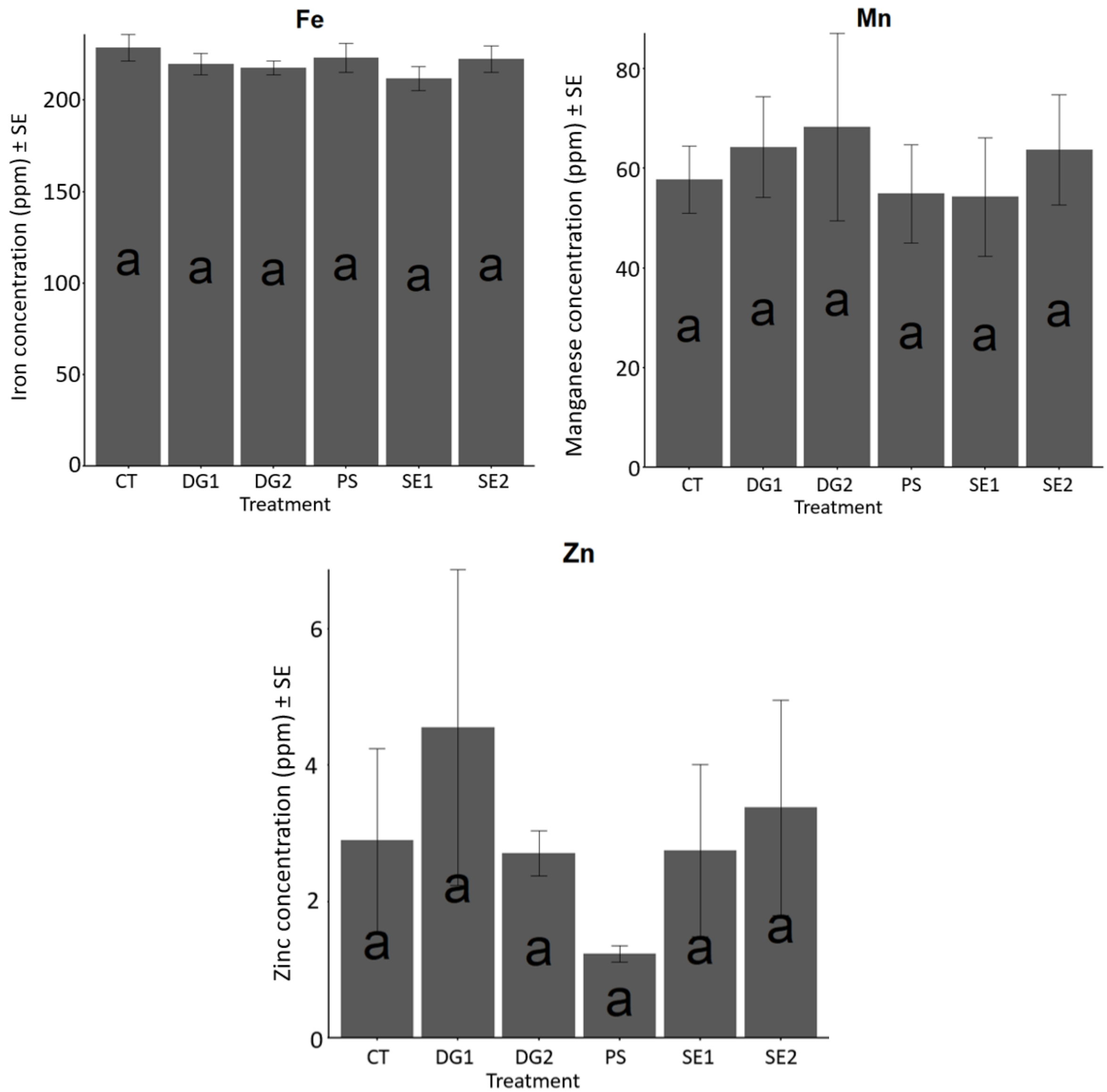
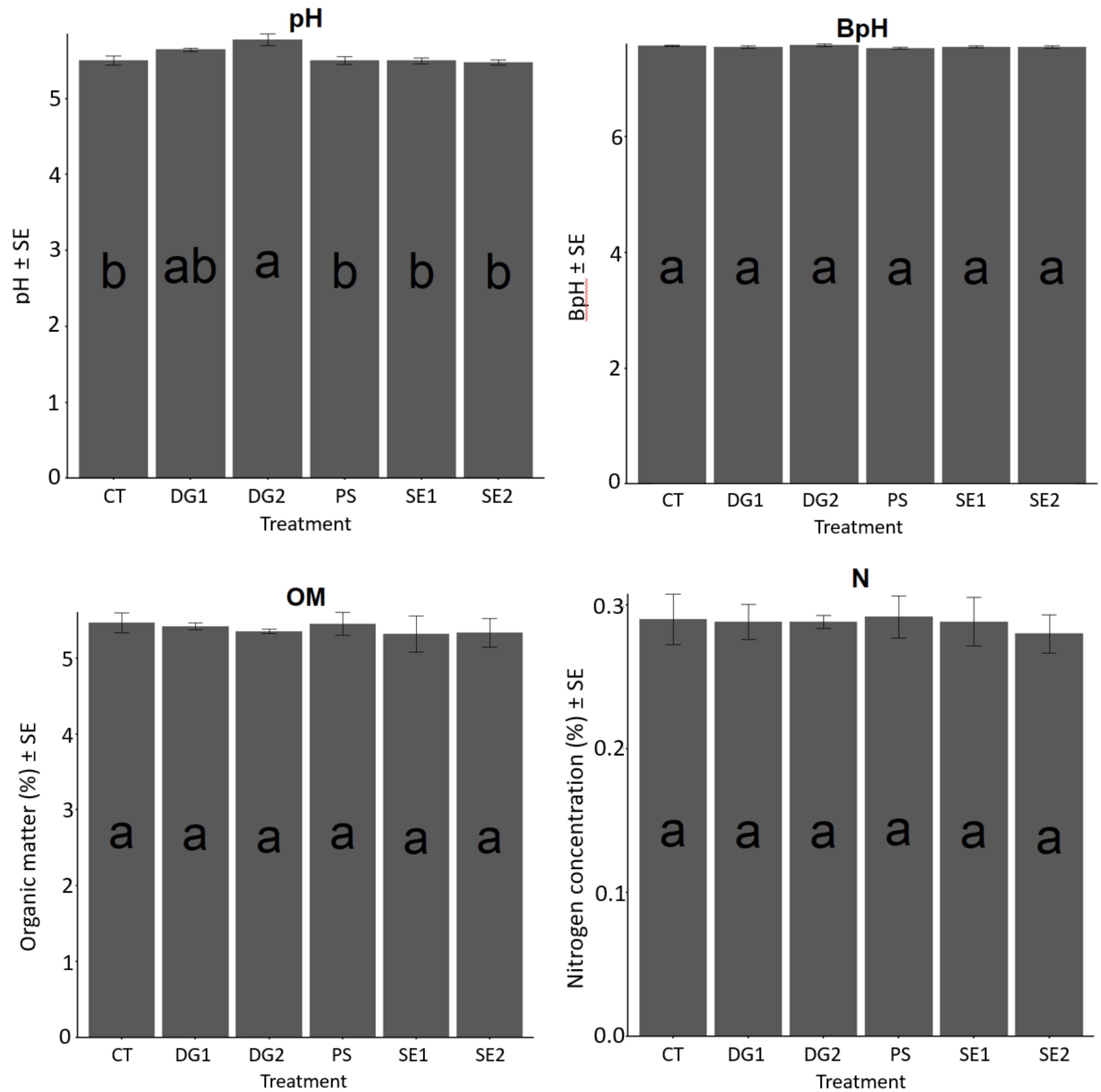
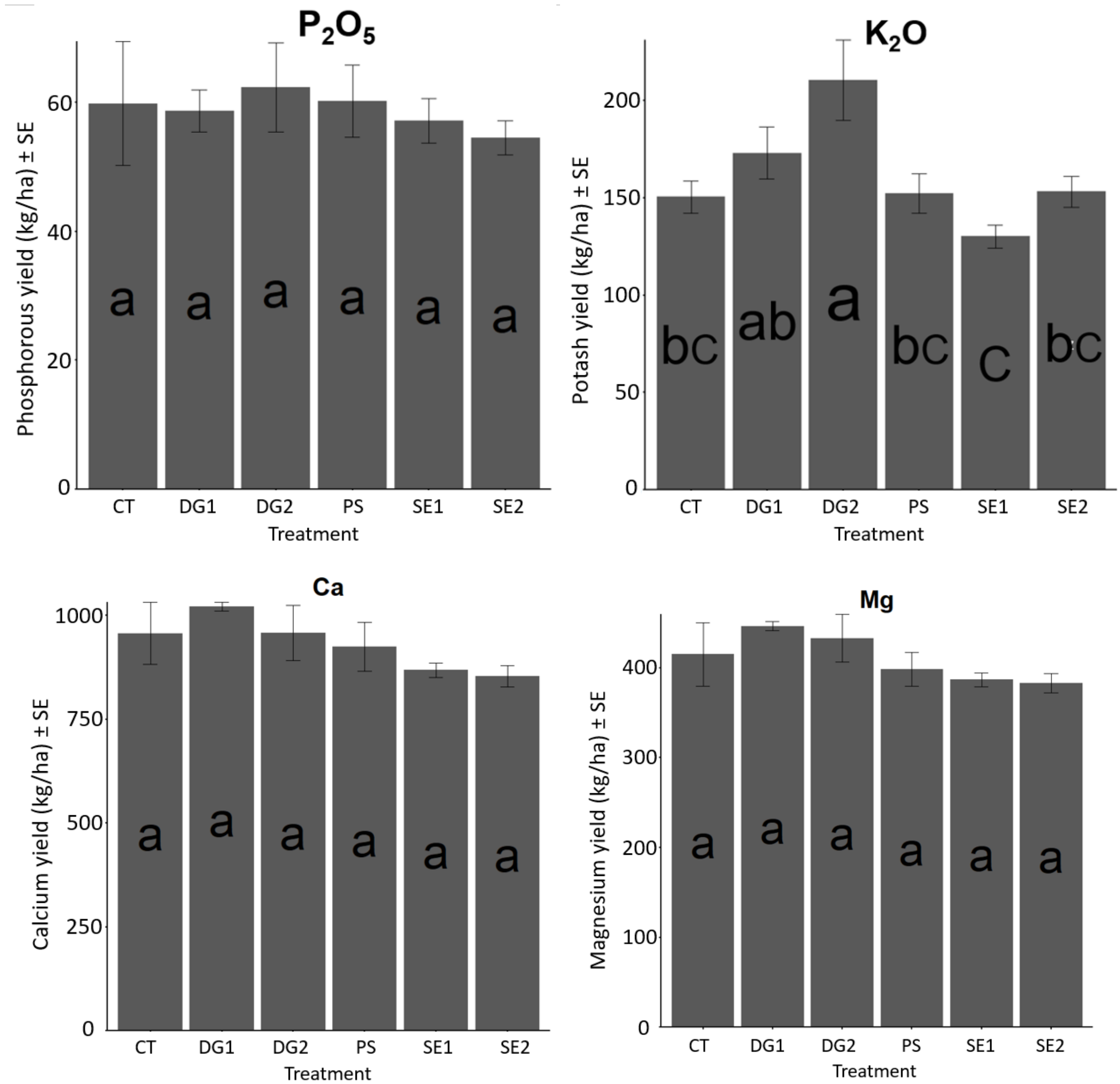


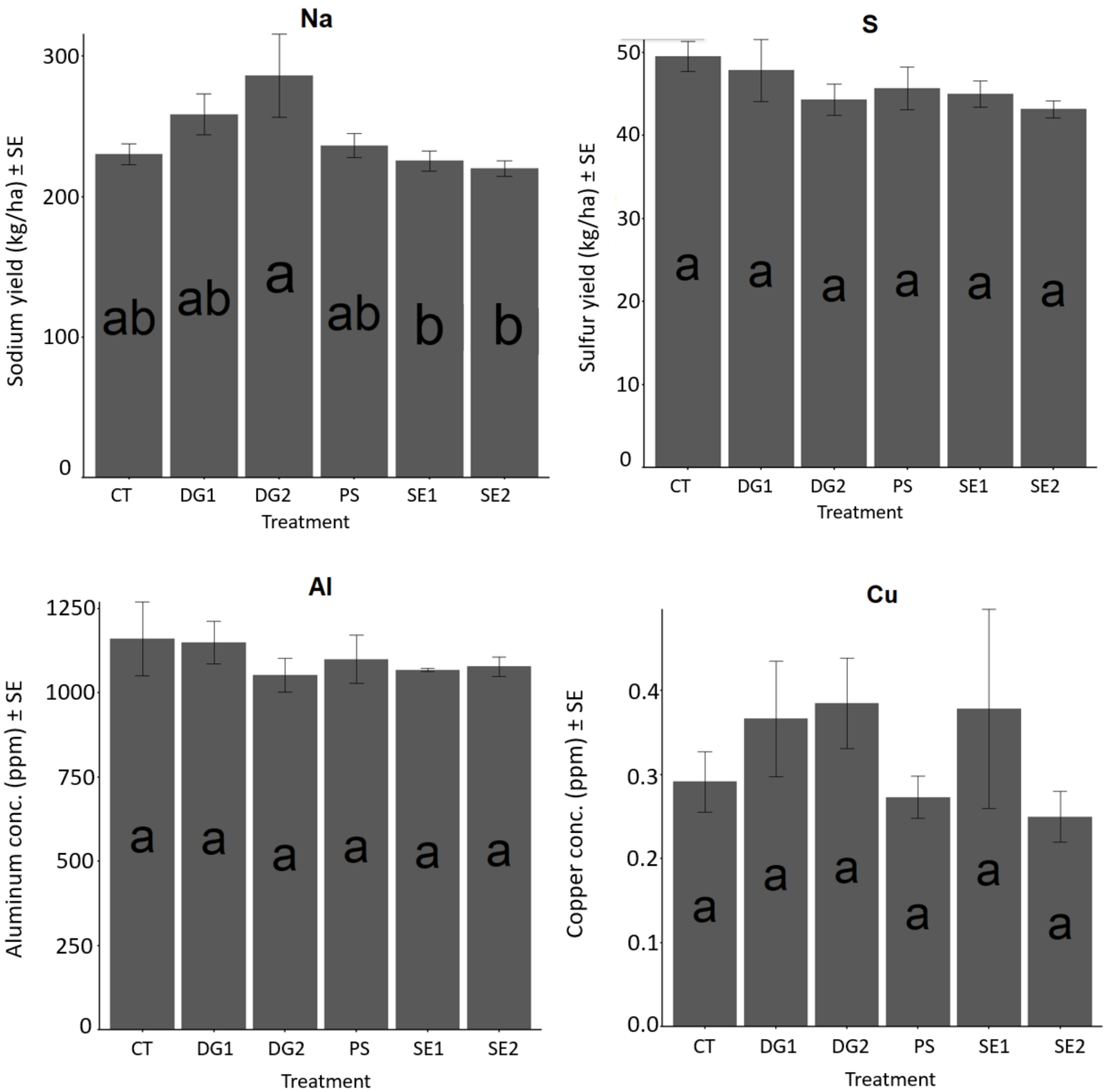
Figure 4.19.1 Soil pH and nutrient concentrations as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1) or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season of the Falmouth site. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Chegoggin Point





P_2O_5
Phosphorous yield (kg/ha) ± SE
0
20
40
60
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
K_2O
Potash yield (kg/ha) ± SE
0
50
100
150
200
bc ab a bc c bc
CT DG1 DG2 PS SE1 SE2
Treatment
Ca
Calcium yield (kg/ha) ± SE
0
250
500
750
1000
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Mg
Magnesium yield (kg/ha) ± SE
0
100
200
300
400
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Na
Sodium yield (kg/ha) ± SE
300
200
100
0
ab
ab
a
ab
b
b
CT
DG1
DG2
PS
SE1
SE2
Treatment
S
Sulfur yield (kg/ha) ± SE
50
40
30
20
10
0
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment
Al
Aluminum conc. (ppm) ± SE
1250
1000
750
500
250
0
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment
Cu
Copper conc. (ppm) ± SE
0.4
0.3
0.2
0.1
0.0
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment

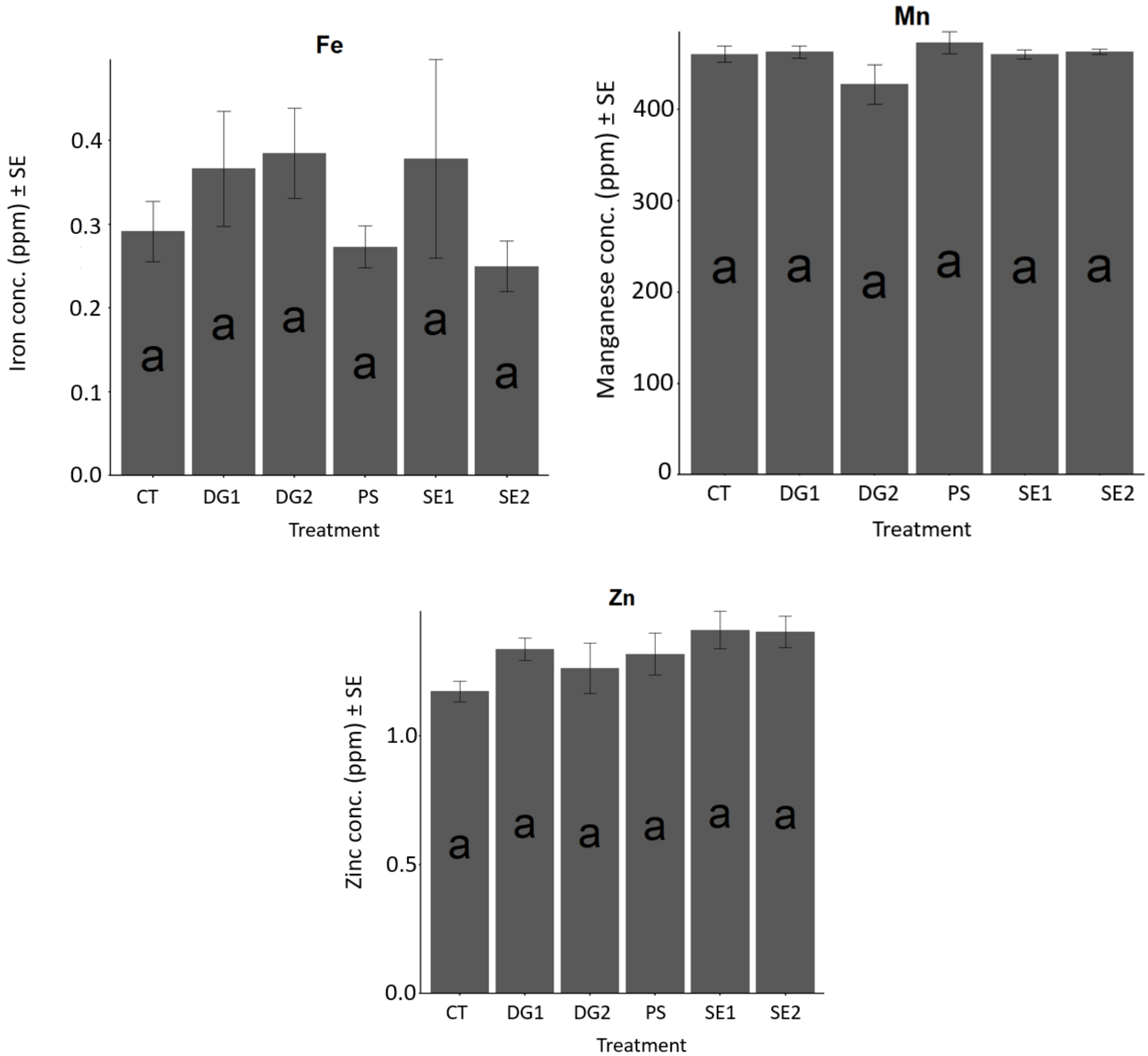


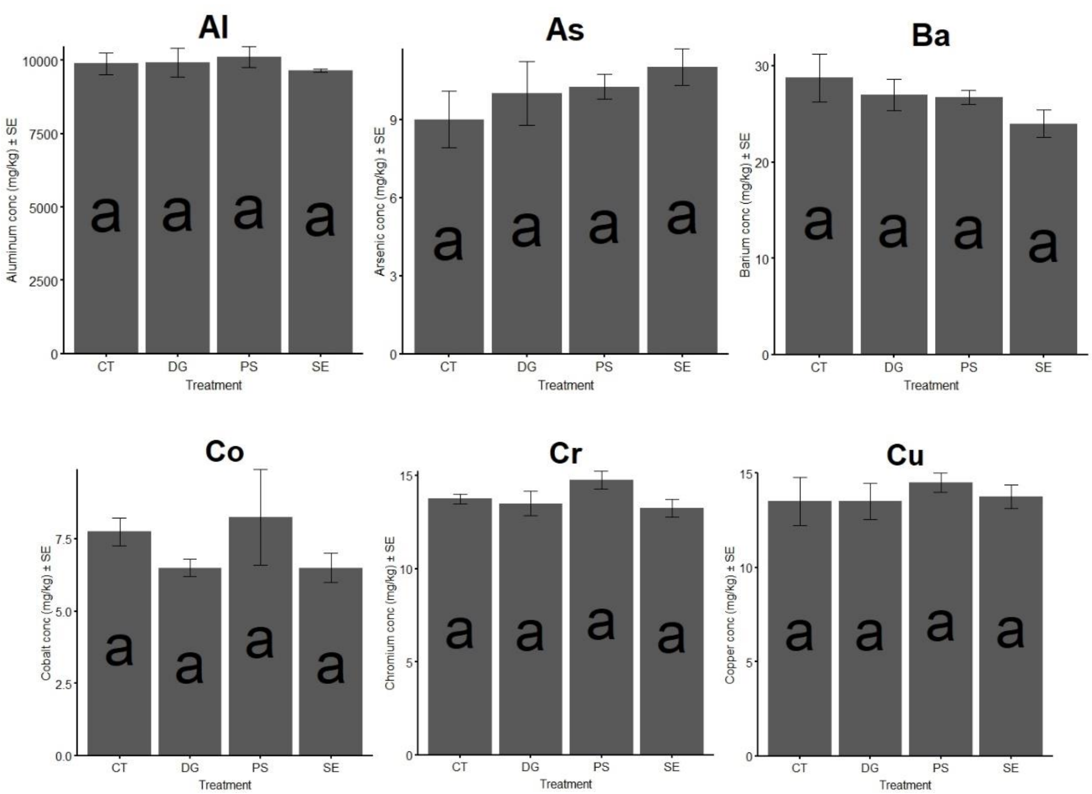
Figure 4.19.2 Soil pH and nutrient concentrations as influenced by different soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end-of-season (2022) at the Chegoggin Point site. Within each soil nutrient, treatments labelled with the same letter are not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

4.20 Soil Heavy Metal Concentrations (2021)

Because anaerobic digestates and pulp mill sludge sometimes contain heavy metals (Abdullah et al., 2015; Hayes, T. D., & Theis, T. L.,1978), soil cores were taken from all subplots at both sites during the end-of-season each site data collection in 2021 and analyzed for heavy metal concentrations by AGAT Laboratories, Dartmouth, NS.

One-way analysis of variance for these data at each site indicated no significant increases in heavy metal concentrations by any of the soil amendments treatments relative to the control treatments, except that the concentration of strontium (Sr) was 10% higher than the control treatment soil in the anaerobic digestate treatment at the Falmouth site (Fig 4.20.1).

Falmouth



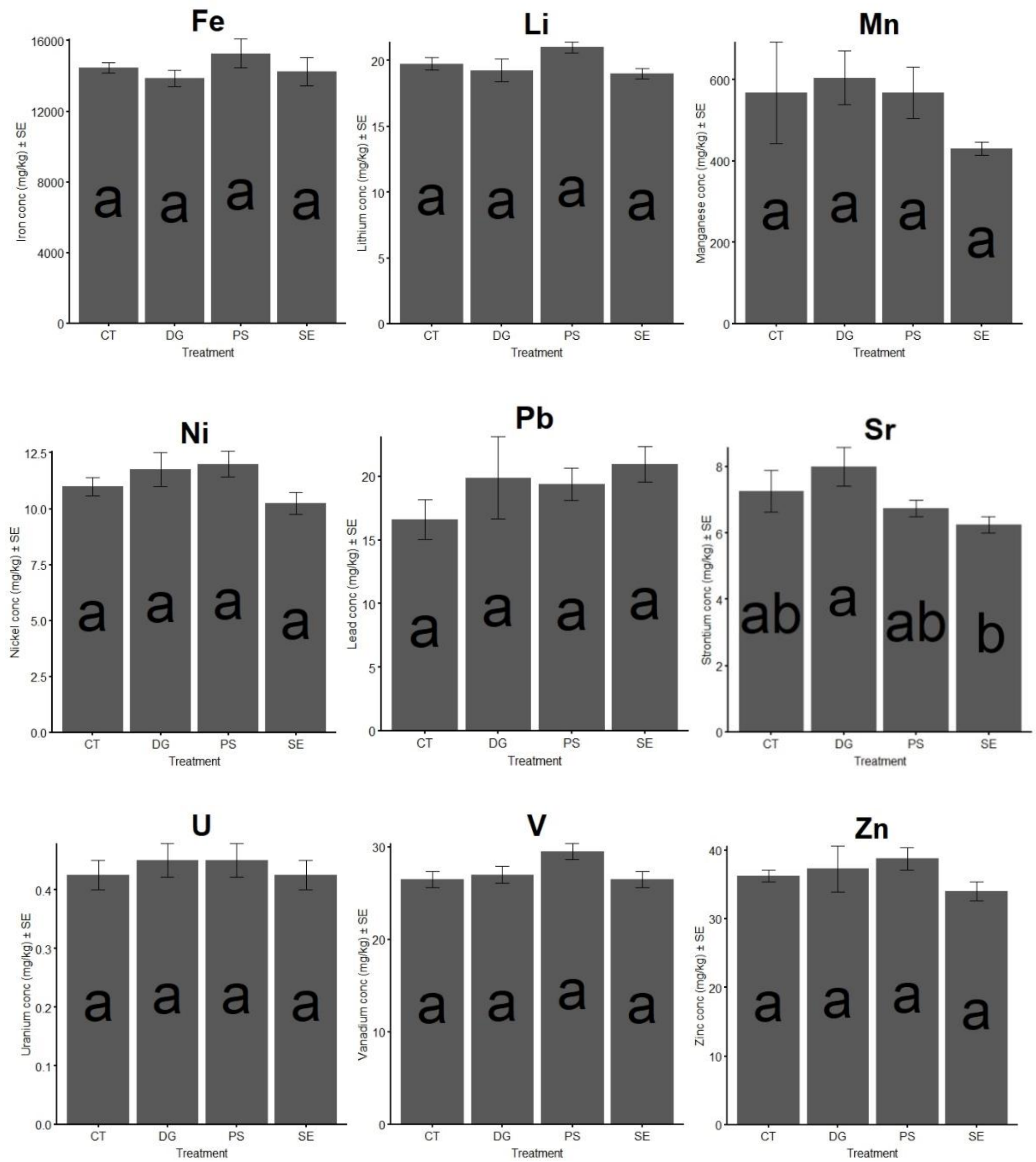
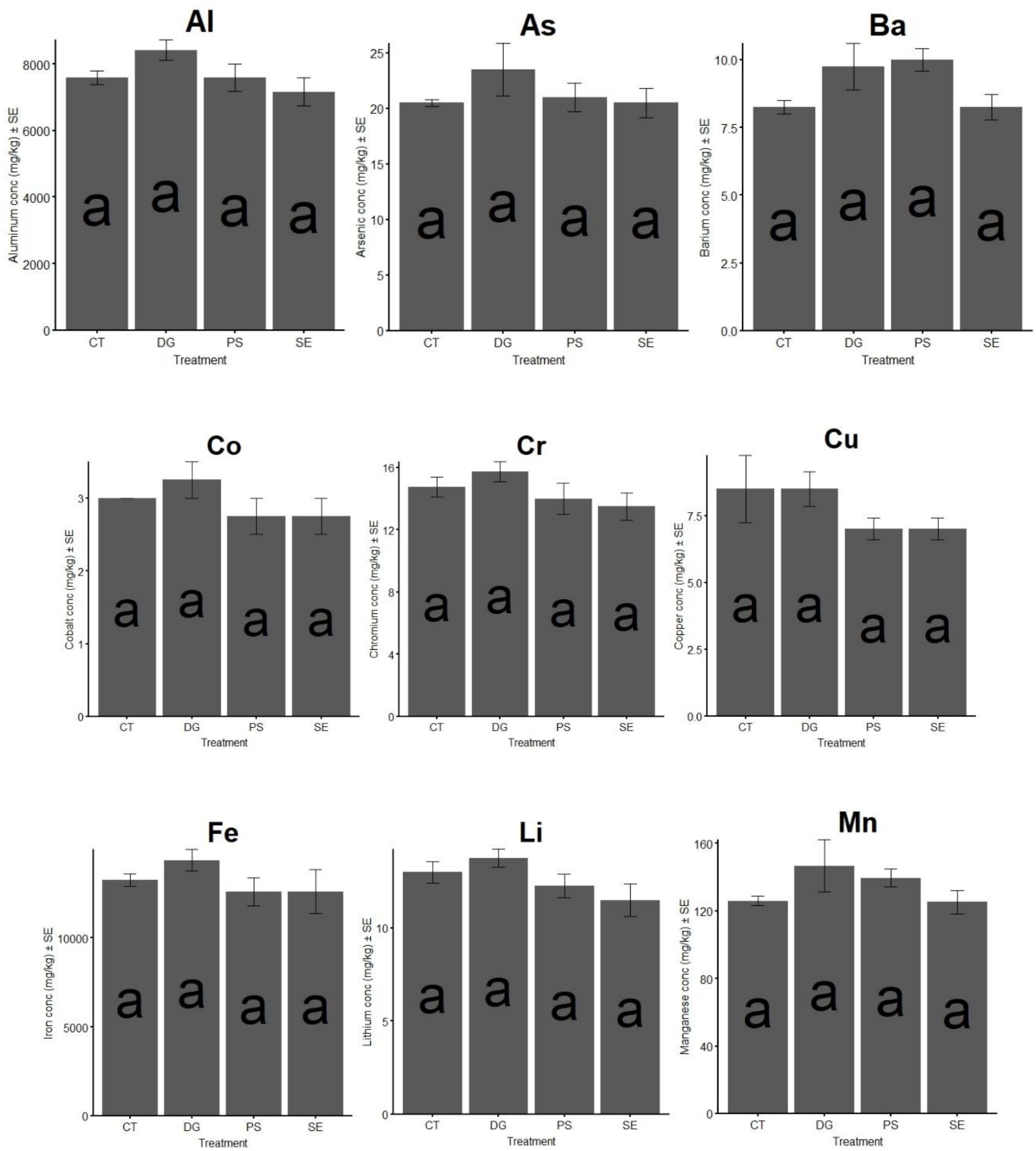


Figure 4.20.1 Soil heavy metal concentrations as influenced by soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end of the growing 2021 season at the Falmouth site. Within each heavy metal, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

Chegoggin Point



Al
Aluminum conc (mg/kg) ± SE
As
Arsenic conc (mg/kg) ± SE
Ba
Barium conc (mg/kg) ± SE
Co
Cobalt conc (mg/kg) ± SE
Cr
Chromium conc (mg/kg) ± SE
Cu
Copper conc (mg/kg) ± SE
Fe
Iron conc (mg/kg) ± SE
Li
Lithium conc (mg/kg) ± SE
Mn
Manganese conc (mg/kg) ± SE
CT
DG
PS
SE
Treatment
a

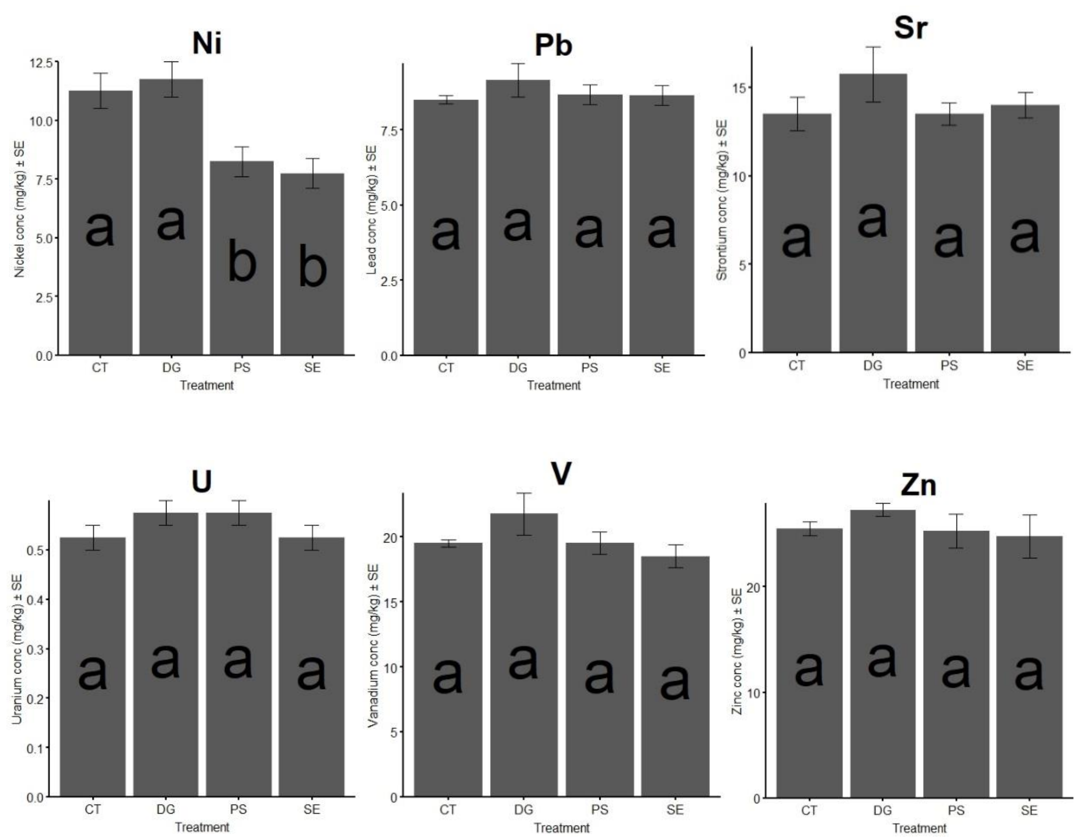


Figure 4.20.2 Effect of amendments on soil heavy metal concentrations from the Chegoggin Point site. Amendments included a no-additives control (CT), paper mill sludge (PS), anaerobic digestate (DG) and liquid A. nodosum extract (SE). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

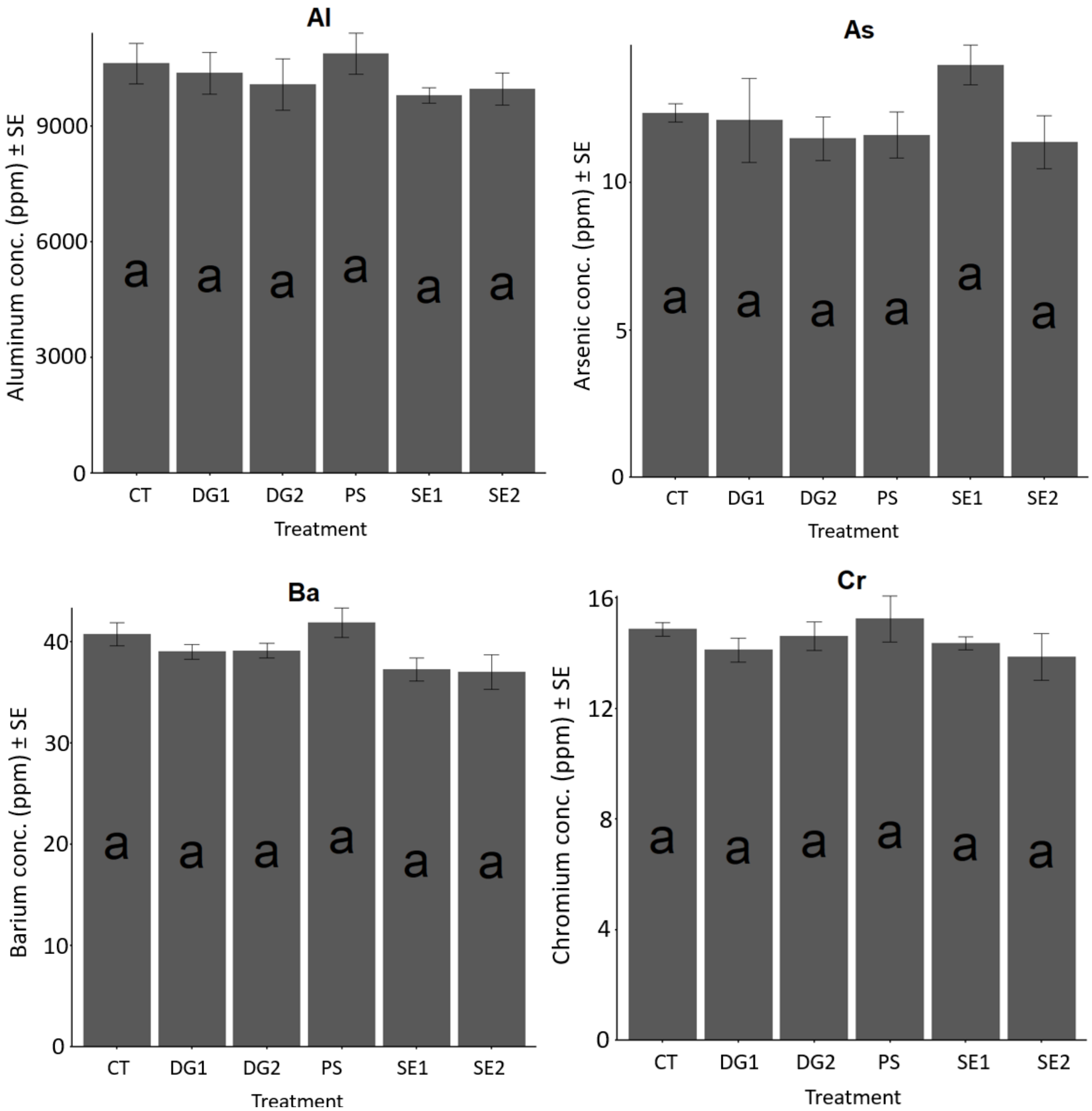
The 2021 one-way analysis showed significant differences in strontium concentration (8 mg/kg) for digestate treatment and no significant differences in Chegoggin Point.

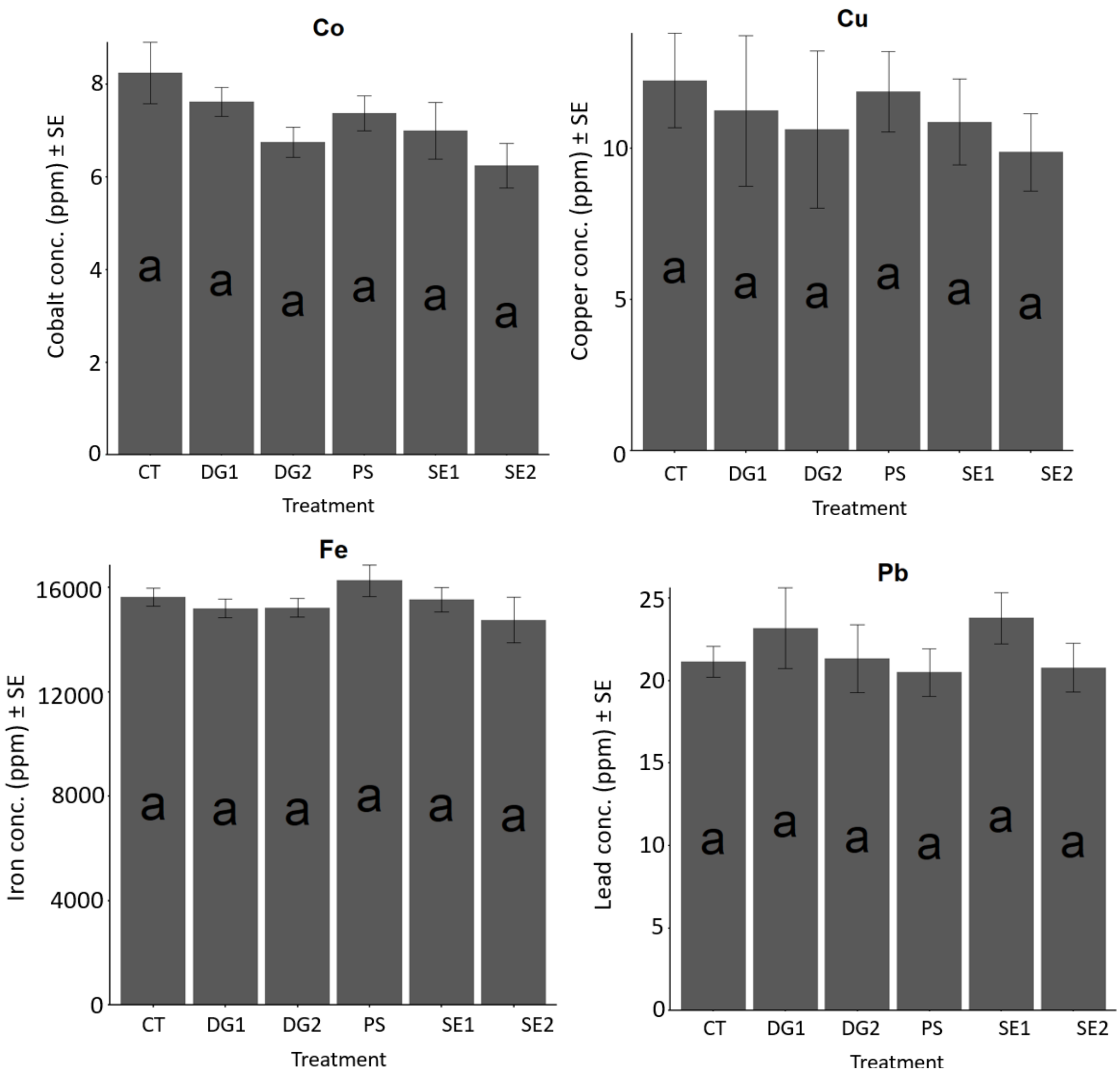
4.21 Soil heavy metal concentrations (2022)

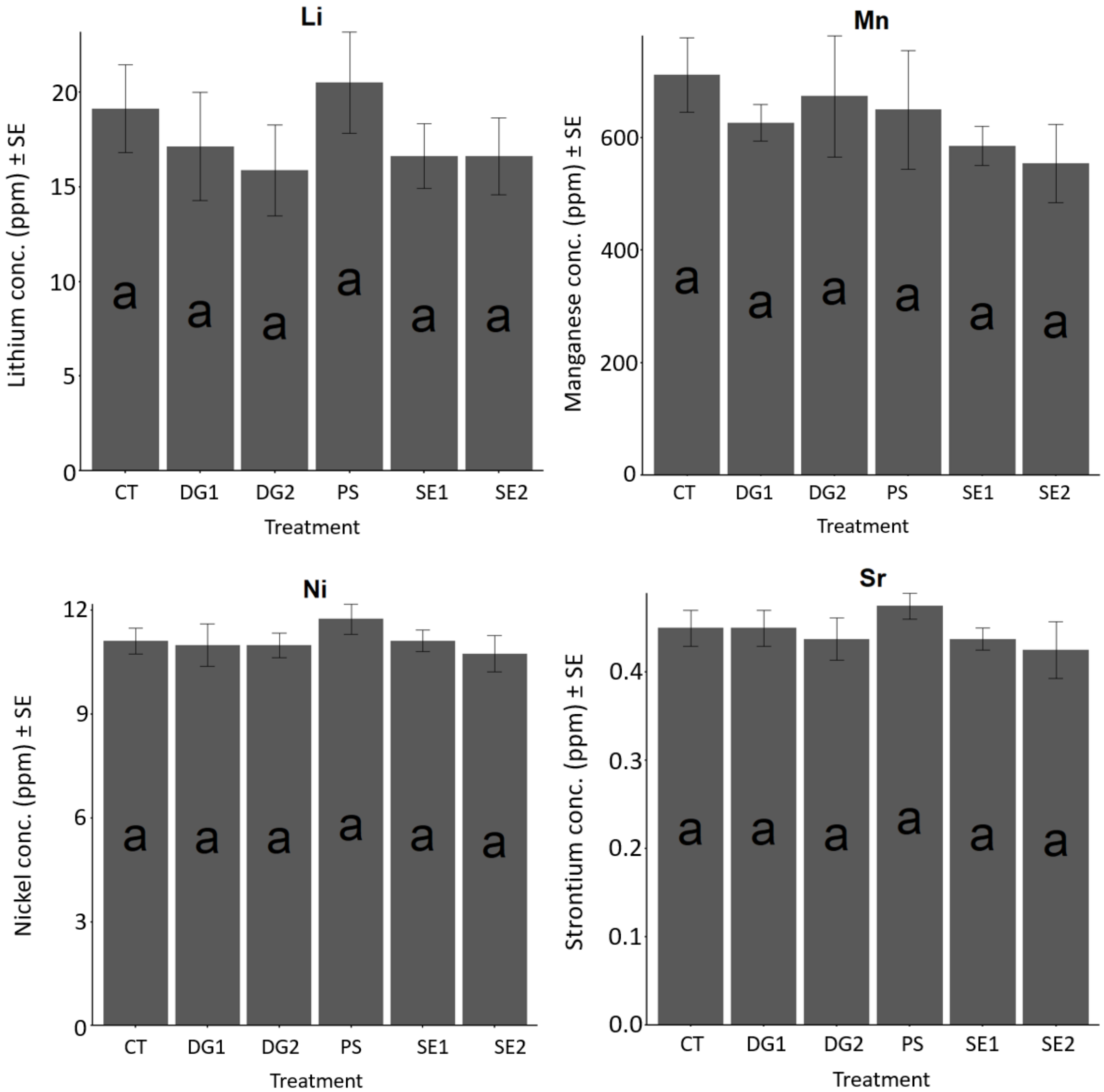
Soil cores were taken from all subplots at both sites during the end-of-season data collection in 2022 and analyzed for heavy metal concentrations by AGAT Laboratories, Dartmouth, NS.

One-way analysis of variance for these data at each site indicated no significant increases in heavy metal concentrations by any of the soil amendments treatments relative to the control treatments (Figs. 4.21.1 and 4.21.2).

Falmouth




Co
Cobalt conc. (ppm) ± SE
0
2
4
6
8
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Cu
Copper conc. (ppm) ± SE
0
5
10
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Fe
Iron conc. (ppm) ± SE
0
4000
8000
12000
16000
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Pb
Lead conc. (ppm) ± SE
0
5
10
15
20
25
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Li
Lithium conc. (ppm) ± SE
0
5
10
15
20
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment
Mn
Manganese conc. (ppm) ± SE
0
200
400
600
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment
Ni
Nickel conc. (ppm) ± SE
0
3
6
9
12
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment
Sr
Strontium conc. (ppm) ± SE
0.0
0.1
0.2
0.3
0.4
a
a
a
a
a
a
CT
DG1
DG2
PS
SE1
SE2
Treatment

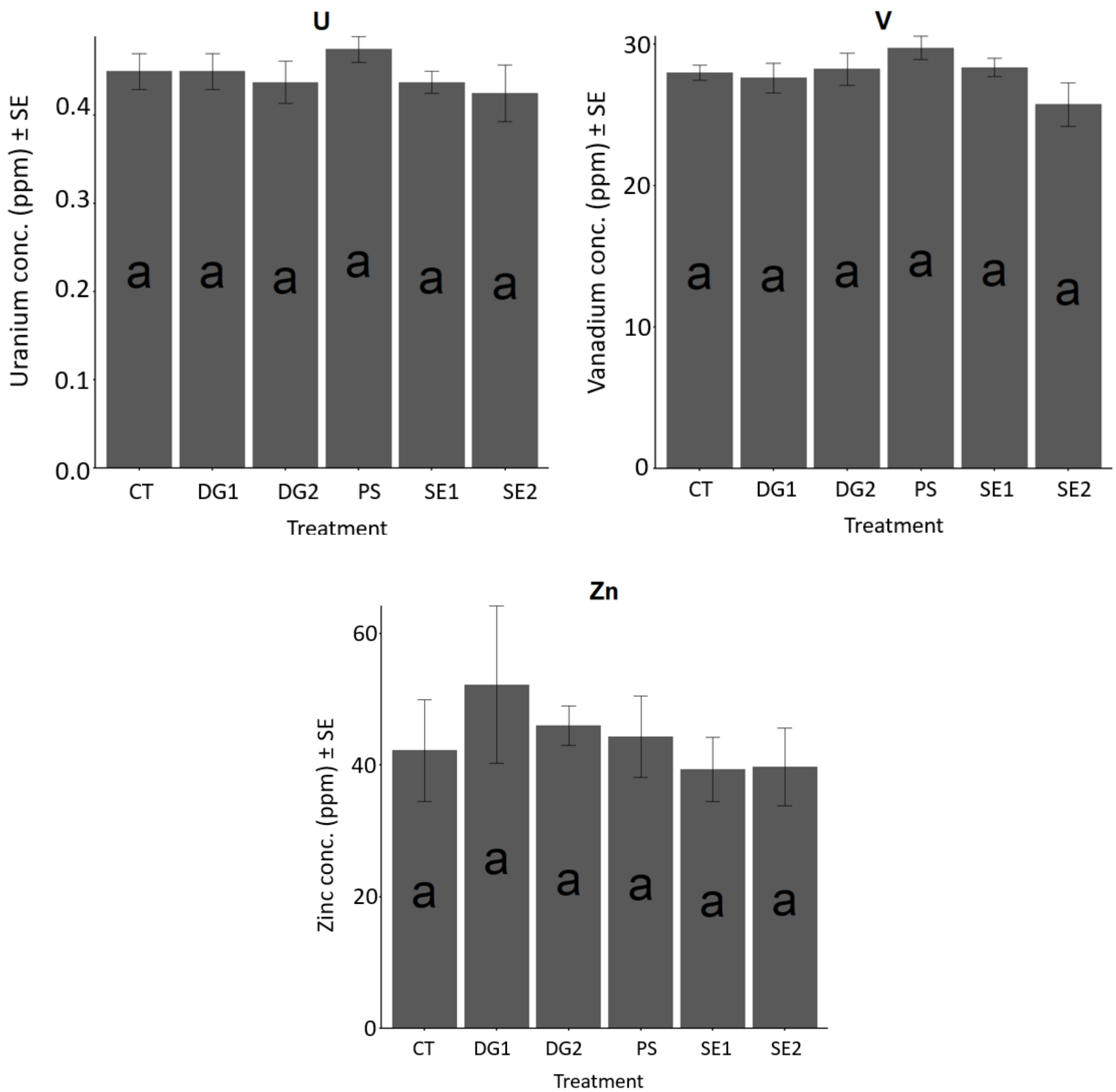
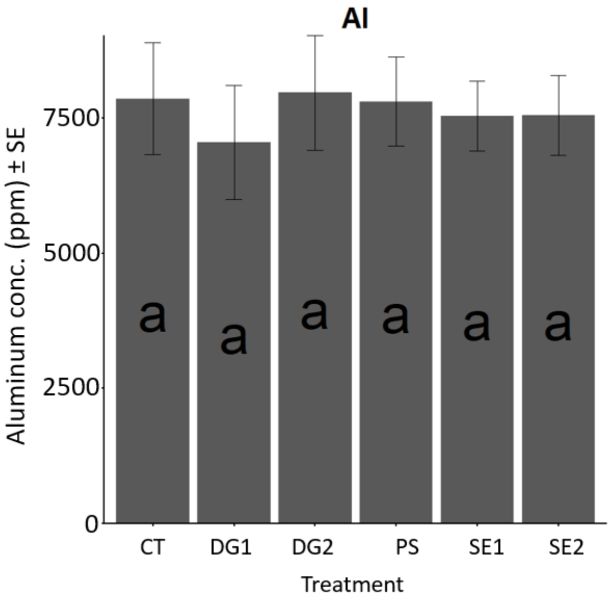
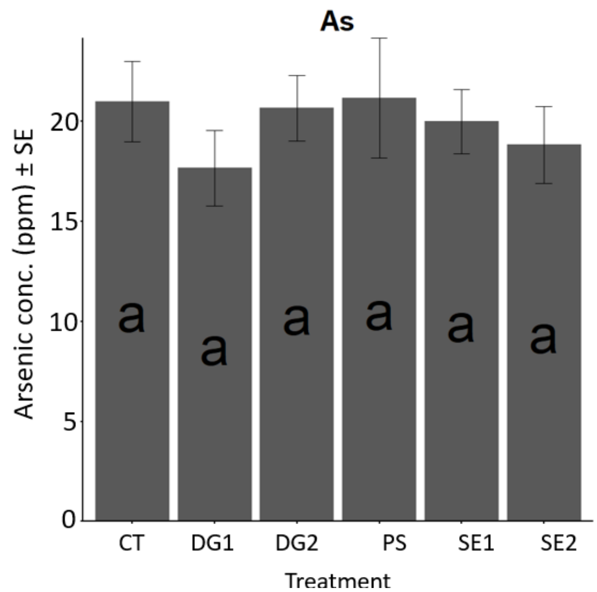
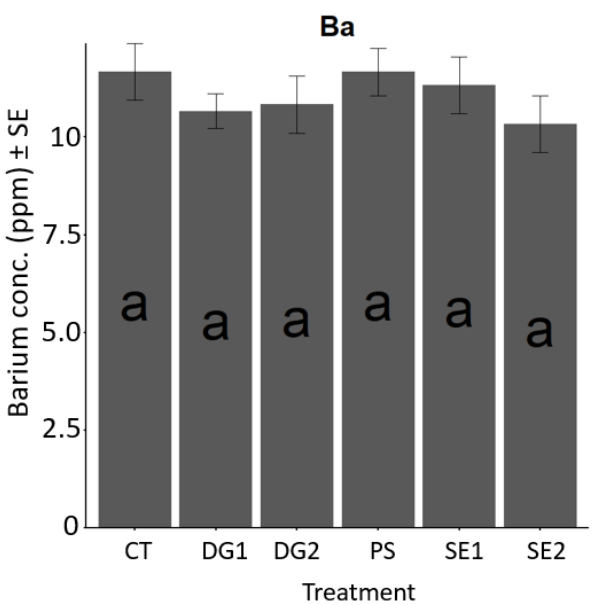


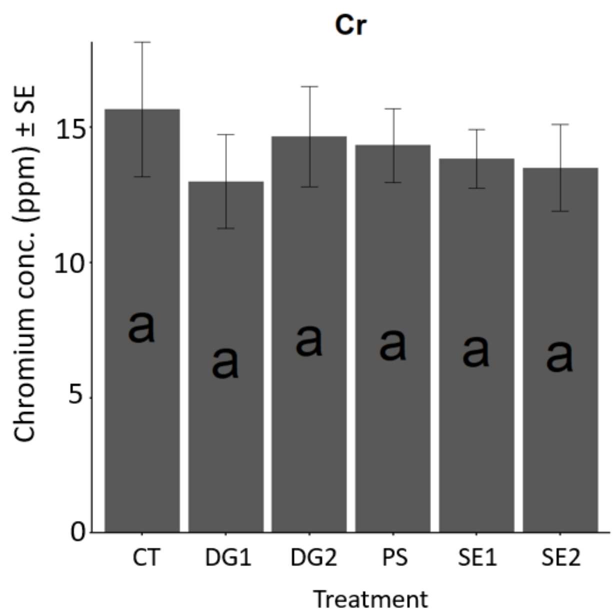
Figure 4.21.1 Soil heavy metal concentrations as influenced by soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end-of-season (2022) at the Falmouth site. Within each heavy metal, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

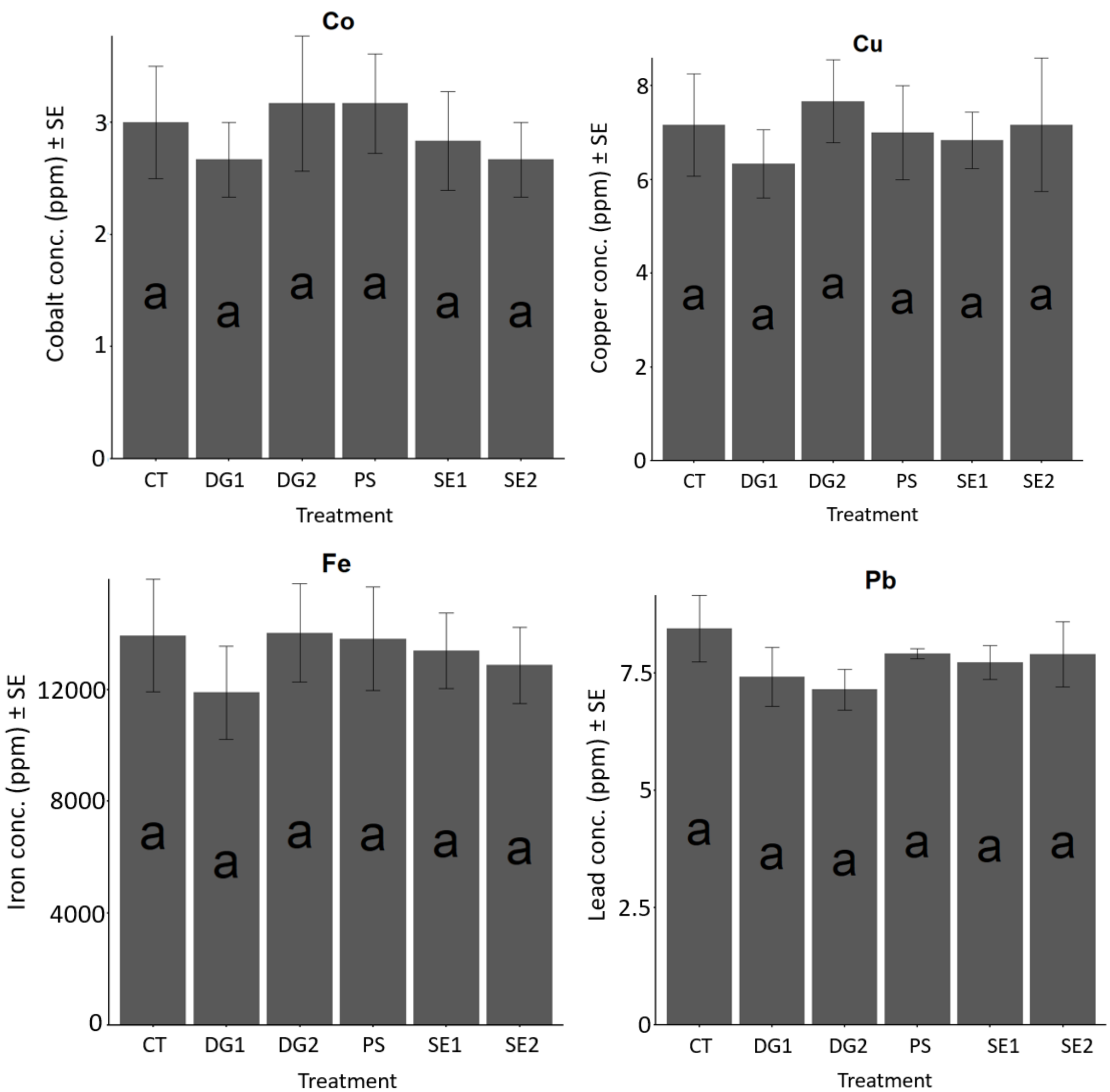
Chegoggin Point

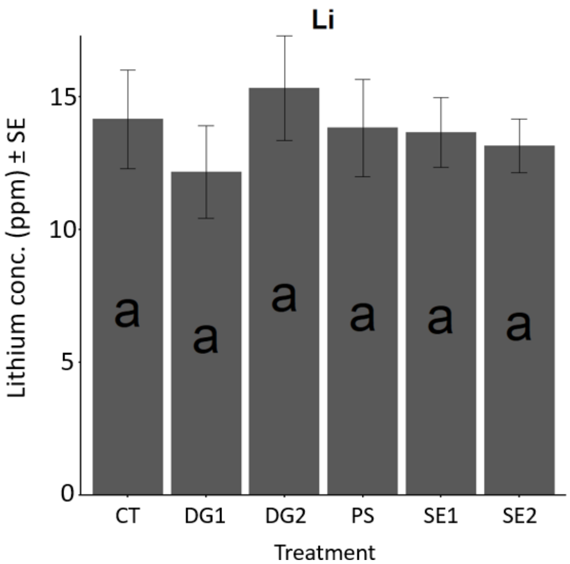

Al
Aluminum conc. (ppm) ± SE
0
2500
5000
7500
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment

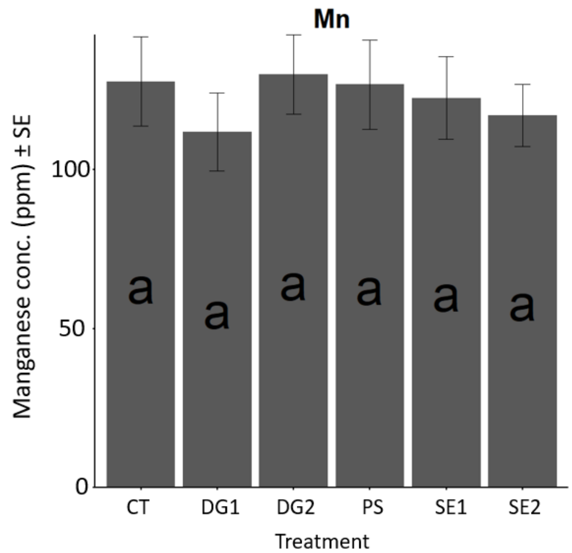

As
Arsenic conc. (ppm) ± SE
0
5
10
15
20
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment

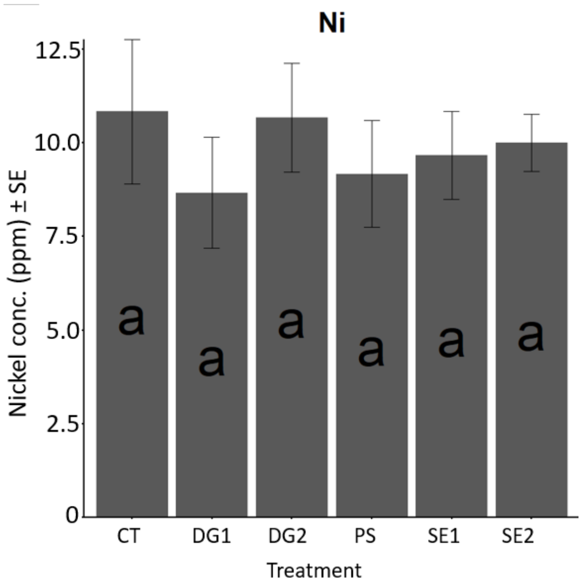

Ba
Barium conc. (ppm) ± SE
0
2.5
5.0
7.5
10
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment

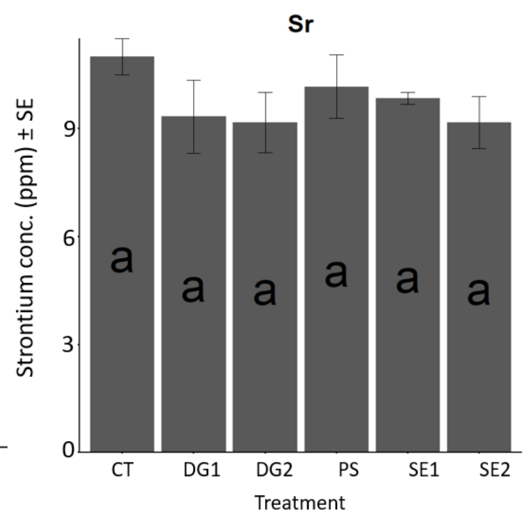

Cr
Chromium conc. (ppm) ± SE
0
5
10
15
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Co
Cobalt conc. (ppm) ± SE
0
1
2
3
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Cu
Copper conc. (ppm) ± SE
0
2
4
6
8
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Fe
Iron conc. (ppm) ± SE
0
4000
8000
12000
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment
Pb
Lead conc. (ppm) ± SE
0
2.5
5
7.5
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Li
Lithium conc. (ppm) ± SE
0
5
10
15
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Mn
Manganese conc. (ppm) ± SE
0
50
100
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Ni
Nickel conc. (ppm) ± SE
0
2.5
5.0
7.5
10.0
12.5
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment


Sr
Strontium conc. (ppm) ± SE
0
3
6
9
a a a a a a
CT DG1 DG2 PS SE1 SE2
Treatment

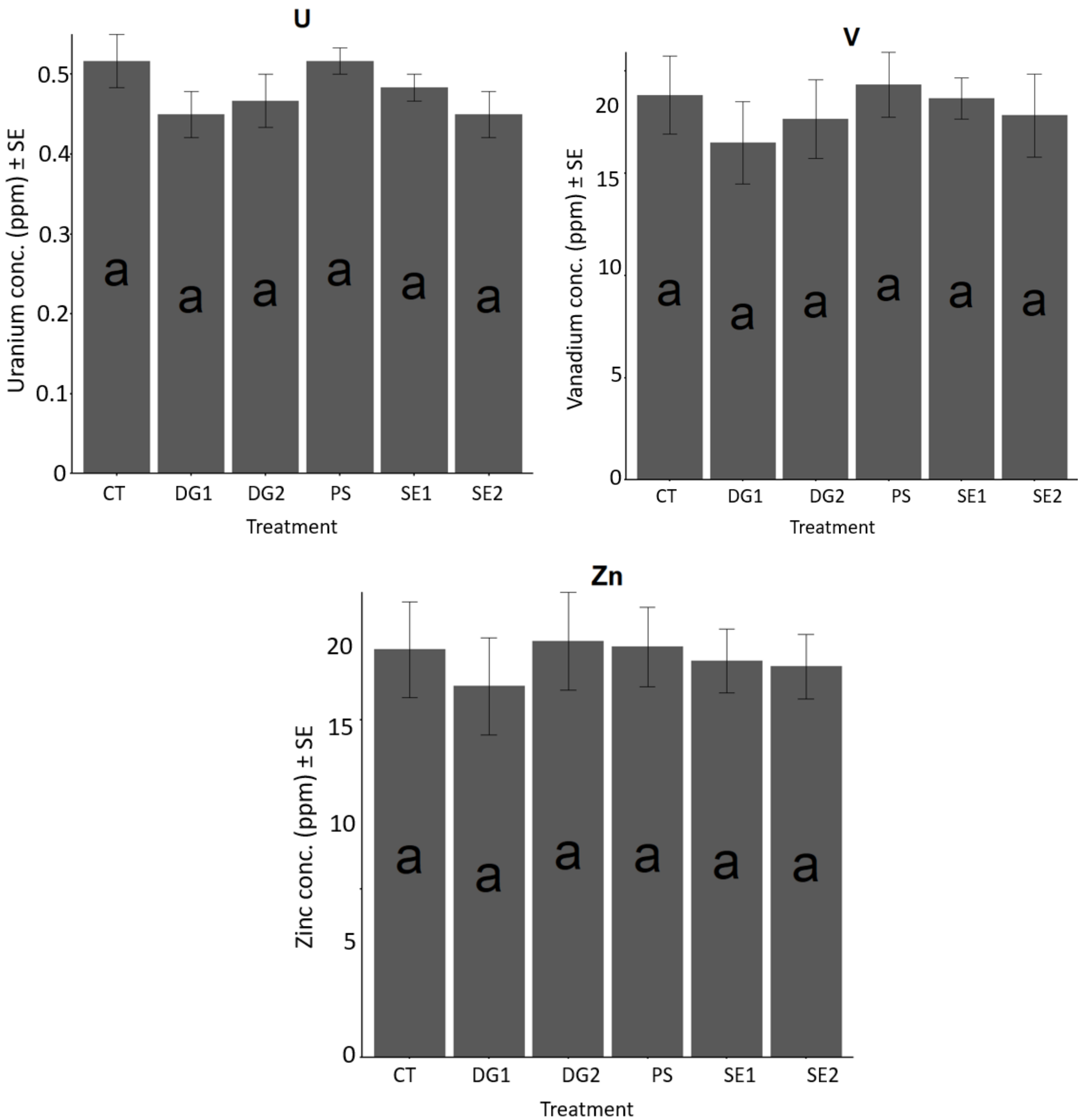


Figure 4.21.2 Soil heavy metal concentrations as influenced by soil amendment treatments (control (CT), seaweed extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) at the end-of-season (2022) at the Chegoggin Point site. Within each heavy metal, treatments labelled with the same letter are not significantly different from each other (n = 4; α = 0.05). Error bars represent standard errors.

4.22 Comparison of Coppiced Hybrid Poplar and Coppiced Willow Growth

Because the planting rates and procedures and soil amendments treatment applications were similar in both the coppiced hybrid-poplar and coppiced willow, it is justified to statistically compare the growth parameters of the two tree species within each research site. A two-way ANOVA was conducted to better understand the effects of the soil amendment treatments on the tree species to compare the treatment effects on growth parameters, such as biomass yield, stem volume, etc., between the coppiced hybrid-poplar and coppiced willow.

4.22.1 Survival Rate, Coppiced Hybrid - Poplar and Coppiced Willow (2022)

The emergence and over-wintering survival rates of the coppiced hybrid-poplar and coppiced willow were recorded in June 2022, approximately 10 months after planting (Fig. 4.22.1.1).

For the Falmouth site, the two-way ANOVA showed a significant difference in the survival rates of poplar and willow ($p < 0.05$) (Table 4.1). A significantly lower survival rate was found in poplars treated with paper sludge, which shows the effect of the soil amendments on the survival rate may differ between poplar and willow. For the Chegoggin Point site, both the trees and treatments significantly affect the survival rate, with poplars treated with paper sludge having significantly lower survival rates compared to willow treated with digestate.

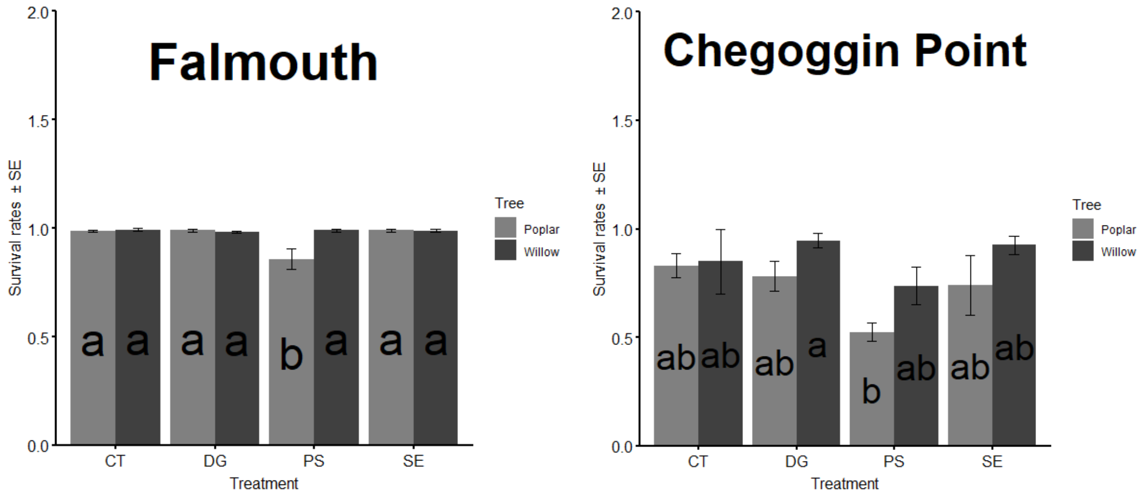


Figure 4.22.1.1 Survival rates of coppiced hybrid-poplar and coppiced willow from at the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by crop type and soil amendment treatments (control (CT), anaerobic digestate (DG), paper mill sludge (PS), and seaweed extract (SE) at the end of the 2022 growing season. Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Table 4.22.1.1 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on Survival in Falmouth.

Falmouth				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Poplar/Paper sludge (1) vs Poplar/Control (2)	-0.1275	0.858	0.958	0.0005
Willow/Paper sludge (1) vs Poplar/Paper sludge (1)	0.1325	0.99	0.858	0.0003

Table 4.22.1.2 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on Survival in Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Poplar/Paper sludge (1) vs Willow/digestate (2)	-0.4200	0.525	0.945	0.0183

4.21.1 Biomass Yield, Coppiced Hybrid - Poplar and Coppiced Willow (2021)

The harvesting of all four energy crops aboveground biomass occurred on November 2021 at both sites around 17 weeks after planting.

The results of the two-way ANOVA indicate that the crop type (poplar vs willow) had a significant effect on the biomass yield, with a p-value of 1.82e-08 in Falmouth and 0.035 in Chegoggin Point. Only the Falmouth site significantly affected the biomass yield, with a p-value of 0.000225. The interaction between crop type and treatment was also found to be significant in the Falmouth site, with a p-value of 0.006296. Willow treated with paper sludge had the overall highest significant yield compared to all tree and treatment combinations. While in the Chegoggin Point site, a significant yield increase of 79.4% was found in willow treated with paper sludge compared to poplars treated with seaweed extract.

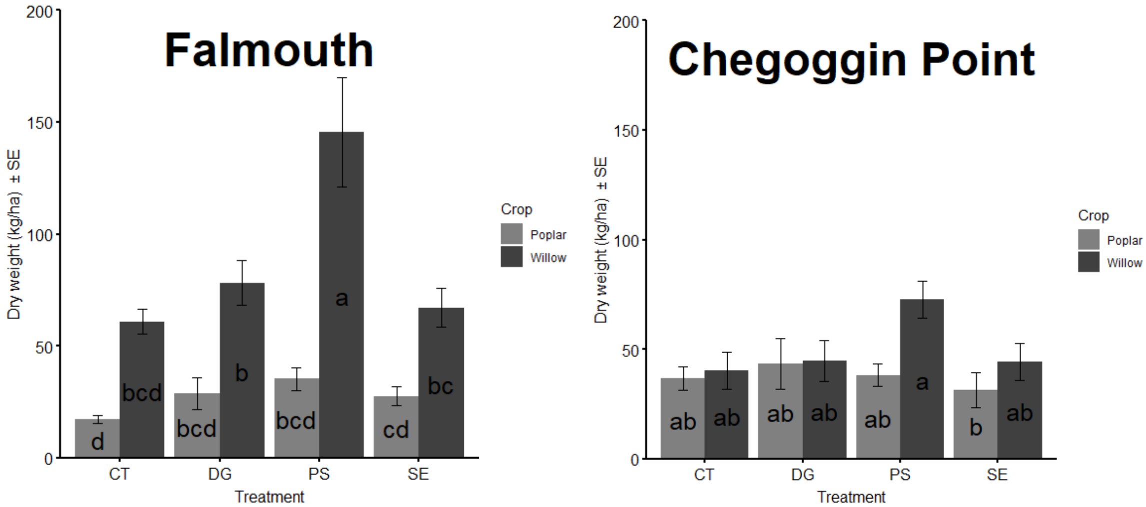


Figure 4.22.1.2 Biomass yields (2021) of coppiced hybrid-poplar and coppiced willow from the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by crop type and soil amendment treatments (control (CT), anaerobic digestate (DG), paper mill sludge (PS), and seaweed extract (SE) at the end of the 2022 growing season. Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Table 4.22.1.3 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on biomass yield in Falmouth

Falmouth				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Willow/Paper sludge (1) vs Poplar/Control (2)	127.97	145	17.4	2 x 10^-^{7}

Table 4.22.1.4 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on biomass yield in Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Poplar/Seaweed (1) vs Willow/Paper sludge (2)	-41.48	31.4	72.8	0.0315

4.22.2 Primary Stem Length, Coppiced Hybrid - Poplar and Coppiced Willow (2022)

The two-way ANOVA showed the Falmouth site having no significant effects between crop type and treatment, indicating that treatment's effects on stem length are consistent between poplar and willow. However, in the Chegoggin Point site, the paper mill sludge treatment with willow had a significantly higher average stem length than all poplar treatments and the control (by 75 %).

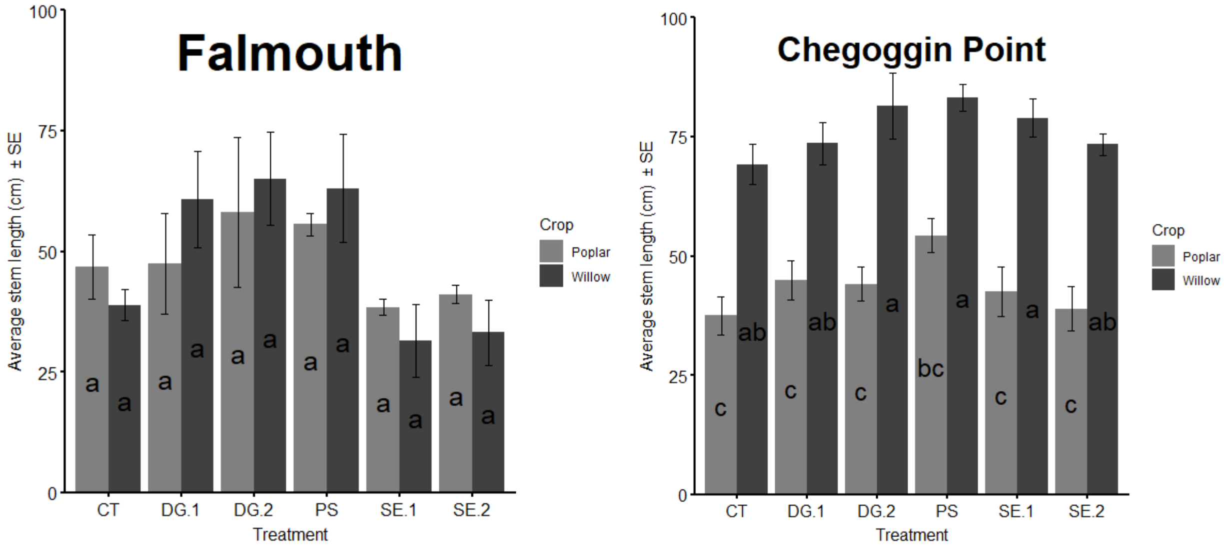


Figure 4.22.2.1 Primary stem length (2022) of coppiced hybrid-poplar and coppiced willow from at the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Table 4.22.2.1 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on average stem length (cm) in Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Willow/Paper sludge (1) vs Poplar/Control (2)	45.575	83.2	37.6	3 x 10 $^{-7}$

4.22.3 Total Stem Length, Coppiced Hybrid - Poplar and Coppiced Willow (2022)

Analzying the two-way ANOVA results of the Falmouth site, the crop type (poplar vs willow) had no significant effect on the total stem length ($p > 0.05$). Also, there was no significant difference between the crop and treatments. The results for the Chegoggin Point site show a significant difference in both the crop type (poplar vs willow) and the treatment (p-value < 0.05). It was found willow treated with paper sludge had a significantly higher total stem length compared to all poplar treatments and than the control (by 75 %)

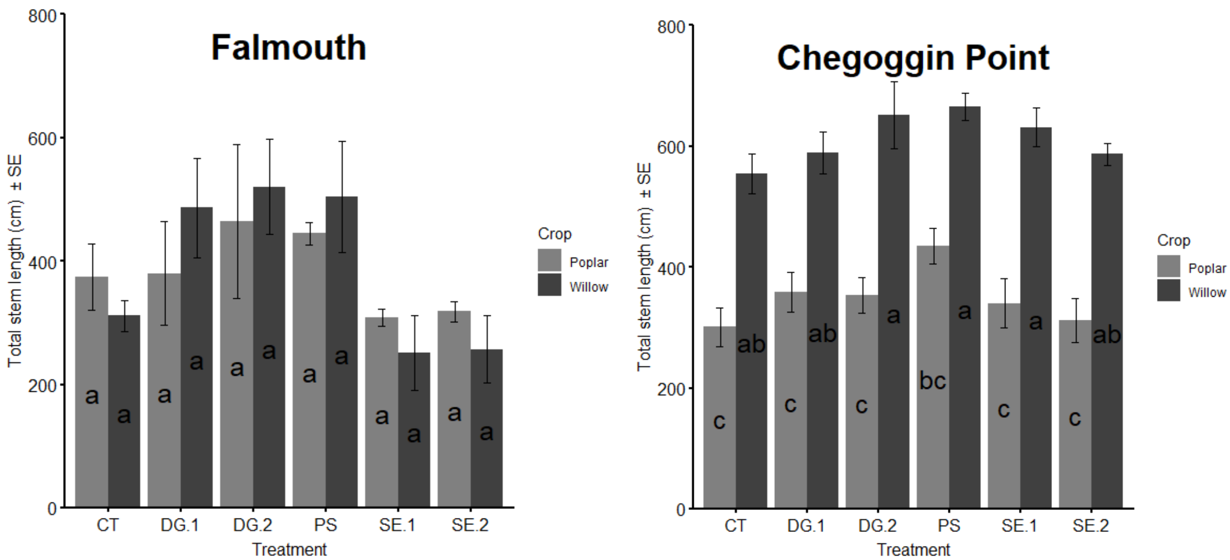


Figure 4.22.2.2 Total stem length (2022) of coppiced hybrid-poplar and coppiced willow from at the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

Table 4.22.2.2 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on total stem length, Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Willow/Paper sludge (1) vs Poplar/Control (2)	364.21	665	301	$3 \times 10\text{-}^{7}$

4.22.4 Primary Stem Diameter, Coppiced Hybrid - Poplar and Coppiced Willow (2022)

Analyzing the two-way ANOVA results for the Falmouth site indicate that the interaction between crop and treatments was insignificant (p = 0.930278), suggesting treatment's effects on average stem diameters are consistent across poplar and willow. The results from the Chegoggin Point site showed a significant effect between crops (poplar vs willow) with a p-value of 1.14e-08. The effects of treatment on stem length were also significant, with a p-value (0.0109).

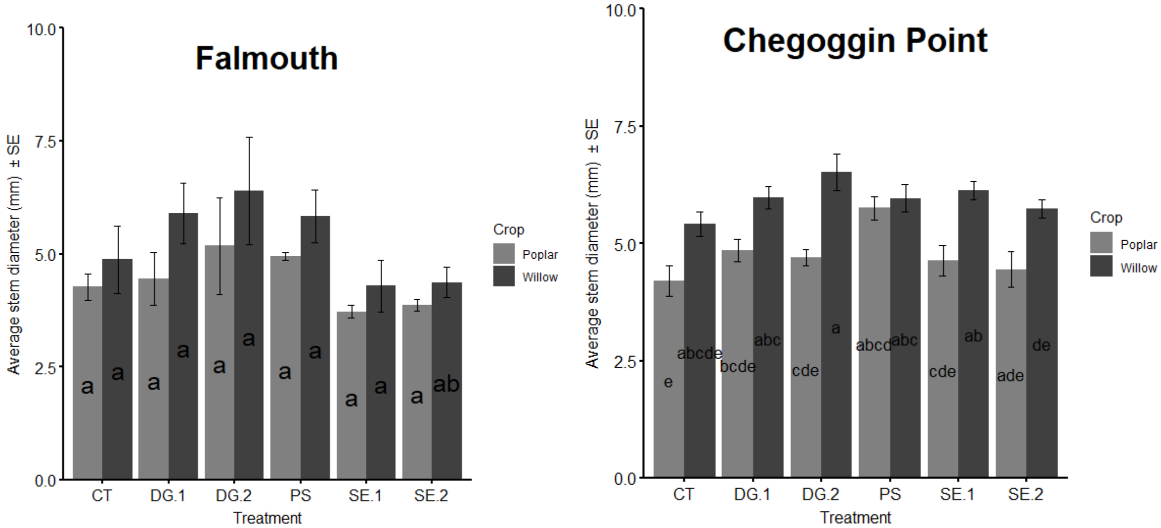


Figure 4.22.4.1 Primary stem diameter (2022) of coppiced hybrid-poplar and coppiced willow from at the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Table 4.22.4.1 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on average stem diameter in Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Willow/Paper sludge (1) vs Poplar/Control (2)	2.3050	6.51	4.20	6.96 x 10^-5

4.22.5 Total Stem Volume, Coppiced Hybrid - Poplar and Coppiced Willow (2022)

Analyzing the two-way ANOVA results of the Falmouth site showed no significant effects on the total stem volumes between crops (p-value 0.2446). Also, no significant effects were found in the interaction between Crop and Treatment (p=0.7872). On the other hand, analyzing the Chegoggin Point site, a significant difference (p-value 2.36e-07) was found in the mean total stem volume between poplar and willow. Also, a significant effect was found in the total stem volume and treatments (p-value = 0.0068). However, no significant difference was found between crop type and treatment.

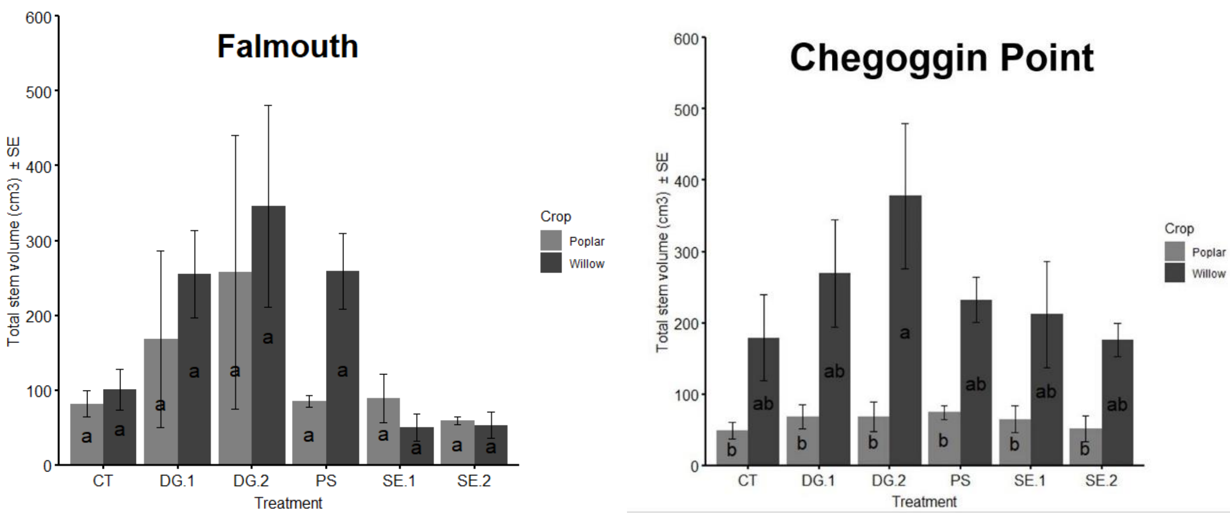


Figure 4.22.5.1 Total stem volume (2022) of coppiced hybrid-poplar and coppiced willow from at the Falmouth (FA) and Chegoggin Point (YA) sites as influenced by soil amendment treatments (control (CT), one application of anaerobic digestate (DG.1), two applications of anaerobic digestate (DG.2), paper mill sludge (PS), one application of seaweed extract (SE.1), or two applications of seaweed extract (SE.2)) at the end of the 2022 growing season. Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Table 4.22.5.1 Significant differences between factors from a two-way ANOVA of trees poplar and willow and treatments control, anaerobic digestate, paper mill sludge, and seaweed extract on total stem volume, Chegoggin Point.

Chegoggin Point				
Tree/Treatment combination	**diff**	**Mean (1)**	**Mean (2)**	**P adj**
Willow/Digestate2nd app.(1) vs Poplar/Control (2)	153	377.94	49.3325	0.0015243

5. DISCUSSION

The objective of this study was to evaluate the yield potential of four biomass crops (switchgrass, miscanthus, coppiced hybrid-poplar, and coppiced willow) treated with three biological inputs/soil amendments (liquid anaerobic digestate, paper mill sludge, and seaweed extract) on two marginal land sites in Nova Scotia. The project's success can pave the way for the economic and agronomic viability of biomass crop production in Nova Scotia by providing a new revenue stream from underutilized marginal lands, attracting investors interested in the biofuel industry, reducing the financial risk to potential biomass farmers and creating new markets for the three biological inputs. Data collection for miscanthus at Chegoggin Point was not possible due to failed emergence. One-way analysis of the data showed that paper sludge had the best treatment effects results in biomass crops. Also, coppiced willow treated with paper sludge showed promising results, which are discussed below. All data obtained were analyzed using a one-way analysis of variance, and the discussion section will interpret the effects of these treatments on the biomass crops and compare them across all treatment groups. Further in the section, the best-performing biomass crop and the highest-yielding soil amendment are also interpreted. Although limited to establishment data from a single study, the project's findings hint at the viability of employing biomass crops for biofuel production. Biofuels could play a role in conserving fossil fuel reserves and curbing greenhouse gas emissions, aligning with the vision of a sustainable future.

5.1 Effects of the Soil Amendments on Crop Yields

When comparing the effects of treatments on biomass yields, it is evident that paper mill sludge had the highest biomass yields, both during the establishment year and at the end of the season. In contrast, the effects of anaerobic digestate and seaweed applications were less pronounced compared to those of paper sludge. The anaerobic digestate treatment exhibited only marginal improvement in biomass yields, which, though noticeable, did not attain significance and was inconsistent, thereby raising questions about its reliable impact on yield enhancement. Interestingly, the application of seaweed extract, while showing no positive effects on crop growth, also did not show any negative effects on crop growth. Thus, paper sludge emerged as the most effective treatment in improving biomass yields, highlighting the significance of its effects amid the varying responses observed with other soil amendments.

5.1.1 Effects of Paper Sludge on Crop Yields

A comparative statistical analysis of the treatments shows the significant treatment effects of paper sludge in biomass yields (Figs. 4.6.1 and 4.7.2). Subplots treated with paper sludge significantly influenced establishment year yields at the Falmouth site. Although there was no statistically significant difference in biomass yields at Chegoggin Point, numerically higher biomass yields were consistently observed across the paper sludge treatments at the Chegoggin Point site. Specifically, paper sludge treatment significantly affected establishment year yields in switchgrass and willow in the Falmouth site, while non-significantly higher biomass yields in miscanthus and poplar, respectively.

5.1.1.1 Effects of Paper Sludge on Switchgrass and Coppiced Willow

Both switchgrass and coppiced-willow crops treated with paper mill sludge (PS) had significantly higher yields compared to all other treatments, with a 114 and 139 % increase in biomass yields, respectively, compared to the control treatments in the establishment year (Fig. 4.6.1). At the Chegoggin Point site, the effects of soil amendments on biomass yield were not significantly different among the crops (Fig. 4.6.2). The dry weight yields of switchgrass and coppiced willow were numerically the highest. Still, they did not differ significantly from the other treatments. In summary, our results suggest that applying paper mill sludge positively influenced the biomass yield of switchgrass and coppiced-willow crops at the Falmouth site. The outcomes of our study are consistent with prior research conducted by Brown et al. (2016), which investigated the impact of sludge containing mixed proportions of municipal sewage waste and paper mill sludge when applied to switchgrass. The study showed paper sludge had positive effects on soil properties and may accelerate the transformation of soils into a suitable medium for switchgrass growth. Furthermore, Dere et al. (2011) observed a decrease in cumulative nitrate (NO_3^-) and phosphate (P) leaching when switchgrass was amended with paper mill sludge. This indicates that paper mill sludge application can effectively mitigate nutrient losses, potentially contributing to improved nutrient retention and availability for plant uptake. Although our study did not specifically investigate nutrient leaching, the positive effects of paper mill sludge on switchgrass imply that nutrient retention in the soil was likely influenced by paper mill sludge. These results support the potential use of paper sludge as a soil amendment to promote sustainable biomass production and minimize the environmental impacts of nutrient loss.

Also, Quaye et al. (2011) have reported the positive effects of paper mill sludge on biomass yield in coppiced willow. The study's findings indicated that applying paper sludge and manure increased plant growth compared to the control group. Moreover, the authors observed that applying paper sludge improved Cation exchange capacity, organic matter content, and nutrient concentrations in both the soil and plant foliage. These outcomes further support that paper sludge can positively influence soil fertility and nutrient availability, ultimately enhancing biomass crops such as willow. By incorporating the findings of Quaye et al. (2011) into the broader context of research on the impacts of paper sludge, it becomes evident that these practices have the potential to promote sustainable biomass production. The increase in plant growth, accompanied by improvements in soil properties and nutrient concentrations, highlights the beneficial effects of these amendments on the overall health and productivity of the ecosystem.

Several factors contribute to this notable performance. The intrinsic composition of paper mill sludge, rich in organic matter, including cellulose and lignin, is a key contributor to improved soil properties (Chantigny et al., 2000a; Murphy et al., 2007; Zhang et al., 1993). Over time, as the paper sludge decomposes, it gradually releases nutrients, sustaining plant growth over an extended period (Fierro et al., 2000; Mahala et al., 2020).

There is also the possibility that paper sludge application might have stimulated microbial activity and enzyme functions in the soil (Gagnon et al., 2001; Medaiyese et al., 2023). This enhanced microbial activity contributes to the breakdown of organic compounds in the sludge, releasing essential nutrients beneficial for plant growth (Chantigny et al., 2000a). Moreover, the improved soil physical properties resulting from paper sludge applications, such as reduced bulk density and enhanced soil aggregation, create a more favorable environment for plant root development (Chow et al., 2003).

The increased soil water holding capacity observed in paper sludge-amended soils is another crucial factor contributing to improved biomass yields. Paper sludge applications have been shown to increase both total soil water content and plant-available water, particularly in soils with inherently low water holding capacity (Abiven et al., 2008; Foley and Cooperband, 2002;

Zhang et al., 1993). This increased water availability allows for better plant growth and development, especially during dry periods (Aitken et al. 1998; Chantigny et al. 2000a).

Additionally, the higher cation exchange capacity (CEC) resulting from paper sludge application improves nutrient retention and availability in the soil, further supporting plant growth and productivity (Einspahr et al., 1984). While these effects have been proposed in previous research, since we didn't directly measure these properties in our study, we can speculate about the potential impact of paper sludge on the soil's physical, chemical, and biological aspects.

The findings from the current study show the yield increase in the crops treated with paper sludge might be because of the added benefits from the application, such as improving the water-holding capacity of the soils and increasing soil moisture and further decomposition of the organic matter. In addition to the direct effects on soil water holding capacity and microbial activity, the paper mill sludge application might have also influenced the soil structure and porosity. These factors, in turn, could have positively influenced the biomass yield of the crops. In conclusion, the application of paper sludge has been shown to benefit biomass yields, especially in switchgrass. The findings from the study are consistent with existing literature, supporting the notion that paper sludge can be an effective soil amendment to enhance crop productivity and contribute to sustainable agricultural practices.

Also, when comparing the yield increase from the establishment to the end-of-season, switchgrass treated with paper sludge had a 60% increase by the end-of-season compared to the yield taken during the establishment year. While significance was not measured, the increase in yield suggests a potential for further investigation on the long-term yield increases of biomass crops.

5.1.1.2 Effects of Paper Sludge on Coppiced Hybrid Poplar

Although not statistically different, the dry-weight yields of hybrid-poplar treated with paper mill sludge had higher yields than the other treatments. A study conducted by Campbell et al. (1995) found that poplar growth was negatively impacted at a higher paper mill sludge application rate of 360 Mg/ha with a resulting decrease in biomass of approximately 20-25%. The poplar in our study did not exhibit higher yields as observed in other crops, such as switchgrass and willow. The decrease in biomass at higher application rates in Campbell's study was potentially attributed to high pH and salt concentrations, specifically sodium and chloride, in the composted sludge. These results suggest that the response of poplar to paper mill sludge application may differ from that of other crops, indicating the importance of considering species-specific responses when evaluating the effects of soil amendments. Despite the potential benefits demonstrated by other crops, the observed lack of significant yield increase in poplar and the lower survival may be related to factors such as the specific nutrient requirements or tolerances of poplar to the pH and salt conditions associated with the paper mill sludge.

Although the specific reasons for the disparity between poplar and other crops in our study are yet to be determined, the findings highlight the need for further research to evaluate the factors influencing poplar growth in the context of paper mill sludge application. These insights show the importance of considering species-specific responses and strategies to optimize biomass production and ensure sustainable growth in poplar. These results highlight the importance of considering specific crop-soil interactions and the potential long-term effects of soil amendments on biomass crop productivity. Further research is needed to explore the mechanisms underlying the observed variations in biomass yield and to optimize soil amendment strategies for different biomass crops.

5.1.2 Effects of Anaerobic Digestate and Seaweed Extract Treatments

The application of anaerobic digestate significantly affected a few growth aspects of coppiced hybrid-poplar and coppiced willow. In particular, the second digestate application showed better results (Figs.4.9.1, 4.11.1, 4.13.1, 4.15.1). Also, when comparing the effects of digestate treatments on grasses and trees, it was observed that trees responded better to the digestate application. Furthermore, the study shows that digestate application had better results during the end-of-season, which shows that digestate application affects plant growth in the later stages of development. This is also supported by Odlare et al. (2008), who found that the soil's chemical properties hardly change in the short term when treated with anaerobic digestates. Also to note is the nutritional analysis of digestates shown in Tables 3.4 and 3.5, which indicates relatively very low nitrogen concentrations in anaerobic digestates. The low nitrogen content and the results obtained from this study show that anaerobic digestates cannot be used as a standalone fertilizer and cannot fulfil the fertilization needs of the plant, which is evident in the biomass yield obtained from the grasses. Also, the significant results obtained in willow did not show any better results until a year after its establishment. These findings highlight the complex relationship between digestate application, plant growth, and nutrient availability. While digestate application significantly affected certain growth parameters, it's important to acknowledge that the effects extend beyond nutrients. Anaerobic digestates contain a range of supplementary nutrients known as bioactive substances that include phytohormones like auxins, gibberellic acid, indoleacetic acid, and abscisic acid, as well as nucleic acids, monosaccharides, free amino acids, vitamins, unsaturated fatty acids, proline, linoleic acid, and fulvic acid. These substances are easily absorbed by plants and can stimulate root system expansion, overall plant growth, resilience against biotic and abiotic stressors, and even the delay of senescence (Feng et al., 2011; Liu et al., 2009; Scaglia et al., 2015). However, the relatively low nitrogen content in digestates, coupled with the observed delayed response, emphasizes the necessity of exploring supplementary fertilization strategies and conducting comprehensive long-term assessments for optimal biomass yield.

In conclusion, applying anaerobic digestate positively affected the growth of trees such as willow and poplar. However, further research is necessary to understand using anaerobic digestate in combination with mixed fertilization approaches. Furthermore, it is important to note that digestate application appears to induce growth changes in the later stages of development. Hence, comprehensive investigations are necessary to better understand the specific interactions between digestate and other fertilizers and the long-term implications for biomass crop production.

Applying seaweed extract did not result in significant treatment effects on the biomass crops in both sites. The performance of the seaweed extract treatment was marginally better or similar to that of the control (Figs.4.6.1, 4.7.2). While not yielding significant crop yield improvements, it's important to note the absence of negative effects on crop growth when treated with seaweed extract. Specifically, in the cases of poplar and miscanthus, the seaweed extract treatment displayed slight advantages over the control (Figs. 4.6.1, 4.7.1). Fei et al. (2017) demonstrated its effectiveness in enhancing hybrid poplar and switchgrass growth, with similar positive effects reported for miscanthus by Fei et al. (2019). These findings highlight the potential of these additives for enhancing biomass production. Our study suggests that treating seaweed extract alone may not significantly improve biomass yields. However, further research is needed to determine the optimal concentration and method of application for seaweed extract. Also, the possibility of combining seaweed extract with other soil amendments and their effectiveness is still undiscovered. Therefore, further research is needed to fully understand seaweed's effects on biomass crops and identify potential synergies with other soil amendments in plant growth. Additionally, exploring the potential synergies between seaweed extract and other soil amendments remains unexplored.

5.2 Effects of the Treatments on Tree's Length and Diameter

Organic fertilizers, such as paper sludge and digestate, have been shown to improve soil fertility and enhance plant growth (Siebielec et al.,2018). Given the potential benefits of using organic fertilizers, there is a growing interest in exploring their effectiveness in promoting tree growth and biomass accumulation. The study was done to investigate the effects of paper sludge, anaerobic digestate and seaweed extract application on tree growth and biomass accumulation in Chegoggin Point and Falmouth, respectively. While the current study assessed the effects of these treatments on tree growth, it should be noted that the sampling was not destructive. While this allowed for a non-invasive way to measure tree growth, actual destructive sampling may be necessary to estimate the real-world biomass yields of the trees. By assessing the average stem diameters, total stem lengths, and stem volumes of the trees, this study aimed to determine whether biological inputs positively affect tree yields. Both paper mill sludge and the double digestate application positively affected the total stem volumes. However, the effects of the double digestate application on stem measurements in willow were particularly notable (Figs.4.9.1, 4.11.1, 4.13.1, 4.15.1). The positive effects of paper sludge and second digestate applications on tree diameter are supported by Stettler et al. (1996), who found that fertilization with organic materials increased the diameter of hybrid-poplar trees. The increased stem estimates observed with the double digestate treatment can be attributed to several factors. Firstly, the digestate, a byproduct of anaerobic digestion, contains a rich blend of nutrients, including nitrogen, phosphorus, and potassium, which are essential for plant growth and has been supported in the soil and nutrient analysis conducted in this study. Secondly, the digestate application may have influenced the soil microbial community, and a double digestate application might have increased the proliferation of beneficial soil microorganisms immensely (Gielnik, Anna & Pechaud et al., 2019). In further research, it would be helpful to incorporate destructive sampling techniques to assess the actual biomass yields of the trees. This will enable a more comprehensive understanding of the effects of organic fertilizers on tree yields and will be crucial in developing sustainable and effective strategies for improving tree growth and biomass accumulation. Moreover, assessing the long-term effects of the double digestate treatment on stem measurements and biomass yield would provide valuable insights into the sustained benefits of this application over multiple growing seasons.

5.3 Identifying the best crop and treatment combination:

In comparing the yield potential of short-rotation coppice (SRC) poplar and willow, the study by Aylott et al. (2008) observed that yields were generally higher in willow compared to poplar, due to factors such as the susceptibility of older poplar genotypes to rust and their tendency for single stem dominance. Supporting this finding, the study conducted by Bergante et al. (2016) also reported higher yields in willow compared to poplar. These studies highlight the consistent trend of willow outperforming poplar in biomass yield. In line with these findings, our study revealed that willow demonstrated superior performance and yielded higher biomass than poplar. The higher biomass yields of willow observed in our results align with the results of previous studies, providing further support that willow has a greater potential for biomass production compared to poplar. The reasons behind the superior performance of willow in terms of biomass yield can be due to various factors. Coppiced production in poplar concentrates the biomass into a single dominant stem, which may result in a lower bark-to-wood ratio than willow, also producing a large number of smaller diameter stems after each harvest (Volk et al.,(2018).

Looking at the treatment effects, poplars had equally higher yields when treated with paper sludge and digestate during the establishment year, and the same was also observed during the end-of-season stem measurements. Overall, the results suggest that poplars treated with paper mill sludge and liquid anaerobic digestate treatment may be the optimal choice, while Willow treated with paper sludge had the highest biomass yield during the establishment year. However, during the end-season stem measurements, both anaerobic digestate and paper sludge had the best results in stem measurements. This suggests that the initial effectiveness of treatments may differ from the long-term effects on biomass yield. Overall, the results suggest that the optimal treatment for willow may be the application of either liquid anaerobic digestate or paper mill sludge, depending on the crop's growth stage.

Taking into account the consistent findings from previous research and our own results, it can be concluded that willow offers greater yield potential and superior biomass yields compared to poplar. These insights highlight the importance of selecting suitable biomass crops based on their performance and productivity and further emphasize the potential of willow as a valuable feedstock for bioenergy production.

When comparing the potential biomass yield of switchgrass and miscanthus, it's important to note that no statistical analysis was conducted in our study. According to Oliveira et al. (2017), switchgrass exhibited higher annual yields in the first two years after establishment, but beyond that, the productivity of miscanthus significantly surpassed switchgrass, with miscanthus yielding 14.96 Mg ha^{-1} compared to 11.93 Mg ha^{-1} for switchgrass in the 3 to 6-year period. The finding concluded that switchgrass tends to exhibit higher yields in the initial years after establishment, but over time, miscanthus demonstrates greater productivity, surpassing switchgrass in terms of biomass yield.

Moreover, it is important to note that the biomass yield of switchgrass and miscanthus obtained in this study revealed that switchgrass had the highest biomass yield. However, it is important to consider that the observed difference in yield could be attributed to the establishment method of miscanthus used in this study. Specifically, our study's poor establishment of miscanthus rhizomes may have contributed to lower biomass yields (Fig.4.2.1). It is worth noting that previous research has indicated that miscanthus established from rhizomes generally exhibits lower biomass yields compared to plantlets.

However, it is essential to acknowledge that various factors, including establishment methods and environmental conditions, can influence the performance of miscanthus. Therefore, the discrepancy in yield between switchgrass and miscanthus in this study could be a result of these interacting factors.

It is important to further investigate and evaluate the establishment methods of miscanthus, particularly considering the potential differences in biomass yield when established from rhizomes versus plantlets. Future research could explore alternative establishment techniques that may demonstrate improved establishment and subsequent biomass production for miscanthus.

Comparing the treatment effects of switchgrass and miscanthus, for switchgrass, the paper sludge treatment had the overall best biomass yields (Figs. 4.6.1, 4.7.1). It was significantly higher in Falmouth and had high non-significant results in Chegoggin Point than all the other treatments in the establishment and end-of-season. For Miscanthus, biomass yield data was only available for the Falmouth site, as all the rhizomes in the Chegoggin Point site had failed emergence. Replanting was done with miscanthus plantlets for the control plots, and the plantlets had 100% emergence success. Also, to note is the higher salt percentage in the Chegoggin Point; from the study, it can be assumed that salt concentrations can affect miscanthus rhizomes emergence. The findings of the biomass yield estimate from the Falmouth site showed no significant results among treatments; however, miscanthus treated with paper sludge had the overall best results.

However, the effectiveness of different treatments varied among the crops tested, and the choice of crop and treatment may depend on factors such as regional climate, soil conditions, and management practices. In determining the best-performing crop for both sites, it is evident that miscanthus rhizomes are not the ideal choice due to the failed emergence; however, the success rate when planted with tissue cultured needs to be explored further. Thus, switchgrass treated with paper sludge is the ideal choice for a grass-based biomass crop. Looking at the trees, hybrid poplars treated with paper mill sludge had low survival rates, suggesting the treatment may not be an ideal choice for this crop despite being one of the best treatments for poplar. Willow treated with paper sludge had the best biomass yields during the establishment year; however, both anaerobic digestate and paper sludge treatments had the highest stem measurements at the end of the growing season. The overall results indicate willow treated with paper sludge is the most effective plant and treatment combination for tree biomass production.

5.4 Site Influence on the Survival Rates of the Biomass Crops

Biomass crops like willow, poplar and miscanthus have been identified as promising biofuel feedstocks due to their high yield potential and adaptability to marginal soil conditions. However, the success of a crop depends largely on its survival. A crop's survival can be affected by various factors such as soil properties, planting material, weather conditions etc. (Gurjar et al.,2017).

This study assessed the survival rates of willow, poplar, and miscanthus at two sites with varying soil characteristics and treatments. Although not analyzed statistically, our observations revealed a noticeable difference between the two sites. While Chegoggin Point showed impressive crop growth and higher biomass yields for plants like switchgrass and poplar (Fig. 4.6.2 and Fig. 4.7.2), the actual number of surviving crops was lower. In contrast, at the Falmouth site, more crops survived overall. Interestingly, even though Chegoggin Point had more biomass yields, Falmouth's survival was higher. Notably, coppiced willow emerged as the crop with the best overall survival at both sites, highlighting the significance of crop endurance alongside biomass production. One possible explanation for lower survival rates in Chegoggin Point could be the differences in soil characteristics and environmental conditions.

The lower survival, particularly the establishment of miscanthus rhizomes, at the Chegoggin Point site, needs a thorough discussion. The higher salt concentrations in the Chegoggin Point combined with the paper sludge treatment might have caused a negative effect by increasing salinity, potentially contributing to the observed decrease in survival rates. While this hypothesis is plausible, it's important to note that there is currently no scientific literature directly supporting this specific interaction between salt content, paper sludge, and crop survival. A relevant study by Stavridou et al. (2017) demonstrated that increasing salt levels significantly reduced biomass yield in Miscanthus while also affecting root and rhizome dry weight, stem height, photosynthesis, and water use efficiency due to elevated salinity. Comparing these findings with the higher salt concentration at Chegoggin Point provides valuable insights into how salt might have influenced the survival of the crops. Moreover, it's worth mentioning that the lower survival rate of poplar treated with paper sludge in Chegoggin Point was not statistically significant compared to the control treatment, suggesting the need for further investigation. Although there is no direct evidence of paper mill sludge affecting salinity, exploring its potential role in combination with salt concentrations is vital for a comprehensive understanding of the observed outcomes.

The study also highlights the lower pH and the high sodium contents in the soil at Chegoggin Point, which may have also contributed to the poor emergence of miscanthus at this site. The failed emergence of miscanthus at the Chegoggin Point site may be attributed to two potential factors that differ from other sites. Firstly, it could be due to using rhizomes instead of tissue-cultured plantlets as planting material. Studies by Boersma and Heaton (2014a) and Christian et al. (2009) have shown higher losses (23%) when establishing *Miscanthus* × *giganteus* from rhizomes compared to the plantlets. Losses during establishment from rhizomes can be due to intrinsic properties of the rhizomes like lack of active buds, small size, loss of germination capacity due to bacterial or fungal attacks during storage, and soil and climatic conditions (Covarelli, Beccari, & Tosi, 2012; Xue et al., 2015; Boersma & Heaton, 2014b). In this study, a notable effort was undertaken to ascertain the dominant factor contributing to the failure of miscanthus emergence at Chegoggin Point. Given the challenges faced with rhizome establishment, replanting was made using tissue-cultured plantlets. Replanting was done to ascertain whether the failure of the miscanthus to establish itself in 2021 resulted from poor-quality rhizomes or other potential edaphic and environmental factors. The use of tissue-cultured plantlets can overcome these difficulties, providing a more successful establishment and avoiding the need for re-establishment or significant delays (Pyter, Dohleman, & Voigt, 2010).

Secondly, the soil at Chegoggin Point having higher salt concentrations compared to other sites might have also contributed to the failure of miscanthus emergence. High salt concentrations in the soil can negatively affect plant growth and establishment. While the specific impact of salt on miscanthus emergence has not been made in this study, studies (Chen et al.,2017; Stavridou et al.,2017; Stavridou et al., 2020) have highlighted the detrimental effects of salt on miscanthus growth and establishment. Thus, tissue-cultured plantlets were planted at the control plots after winter to determine the dominant factor behind the failure of miscanthus emergence at Chegoggin Point. They were replanted only in the control plots, allowing to isolate and analyze the potential impact of planting material and soil conditions on miscanthus establishment without the confounding effects of additional treatments. Remarkably, when replanting Miscanthus tissue cultured plantlets, a 100% survival rate was observed at Chegoggin Point, indicating the successful establishment and viability of the plantlets in this particular site. This further supports the potential benefits of using plantlets over rhizomes, including higher survival rates and improved regrowth rates (Pyter, Dohleman, & Voigt, 2010; Boersma & Heaton, 2014a). In both sites, the plantlets demonstrated 100 % emergence within four months, indicating that the use of rhizomes as planting material, coupled with the elevated salt concentrations in the Chegoggin Point soil, may have contributed to the initial failure of miscanthus establishment. It's worth noting that during the recent site visit, the control plots did not appear to exhibit a 100% survival rate. This suggests that the long-term effects of these factors on plant survival and growth are still to be fully understood. Additionally, at the Falmouth site, where a 35% emergence of rhizomes was observed, there could be a variety of factors influencing this lower establishment rate, warranting further investigation and consideration. Ouattara et al. (2020) also supported the failure of the rhizomes and that miscanthus establishment from plantlets resulted in higher establishment (between 87% and 92%) rates compared to the establishment from rhizomes. Overall, the study provides valuable insights into the survival rates of biomass crops in different soil conditions and treatments. By considering the factors that affect plant survival, such as soil nutrients and planting material, we can optimize the success rate of these crops and promote sustainable energy production.

5.5 Site Influence on the Biomass Yield of the Biomass Crops

Biomass yield refers to the amount of plant material that can be harvested from a crop in a given area. Maximizing the biomass yield from the crops is essential to establish biofuels as a viable alternative to fossil fuels. Several factors can impact biomass yield, including soil properties, climate conditions, and agronomic practices. Soil properties, such as pH, texture, and nutrient levels, are critical in providing the conditions for optimal plant growth and development. Also, nutrient deficiencies or imbalances can significantly restrict biomass accumulation (Morgan, J. B. & Connolly. 2013). Furthermore, climate conditions, including temperature, rainfall, and sunlight availability, directly influence the physiological processes of crops, ultimately impacting their growth and yield (Hatfield, J. L., & Prueger, J. H. 2015). In our study, weather and soil data were collected to explore the potential influence of these factors on the observed yield variations between the Falmouth and Chegoggin Point sites. However, it's important to clarify that these sites were not statistically compared in the context of this analysis.

Analyzing the soil moisture data revealed variations between the two sites. Daily soil moisture levels from the Falmouth site were consistently lower compared to those from Chegoggin Point. Upon calculating the total amount of precipitation, it became evident that Chegoggin Point (Fig.3.15.4) had received 15% more rainfall than Falmouth (Fig.3.15.3). This increased precipitation likely contributed to the higher soil moisture content observed at the Chegoggin

Point site, aligning with our findings. The difference in soil moisture content between the two sites indicates a potential link to yield variations, particularly evident in Chegoggin Point, which showed the highest yield for switchgrass. However, it's essential to note that despite the significant increase in switchgrass yield, the stem volumes of trees remained relatively similar across both sites. Adequate soil moisture plays a crucial role in supporting plant growth and development, facilitating various physiological processes necessary for optimal biomass accumulation. Higher soil moisture levels provide favorable conditions for nutrient uptake, photosynthesis, and transpiration, all contributing to improved yields. The Chegoggin Point site had a 10% higher average water content (November 2021 – October 2022) compared to that of Falmouth. This discrepancy in water availability likely granted Chegoggin Point an advantage in terms of soil moisture. This environmental distinction likely contributed to improved initial crop establishment, early growth, and subsequent biomass production at Chegoggin Point. Also, the increased soil moisture during crucial growth stages might have acted as a catalyst for optimal nutrient absorption and metabolic activity within the plants, ultimately translating to higher yields. In contrast, the Falmouth site exhibited comparatively lower soil moisture content, particularly between the months of July and September, which was 18% less than what was found at Chegoggin Point. This condition could have hindered water availability to the crops, potentially causing water stress, impeding nutrient absorption, and subsequently impacting the overall productivity of the crops. These circumstances at Falmouth could be among the reasons for the observed lower yields in comparison to Chegoggin Point. In contrast, Chegoggin Point managed to maintain higher soil moisture content, providing a more favorable environment for plant growth and development. This difference in soil moisture levels between the two sites likely played a significant role in driving the higher yields noted at Chegoggin Point. While soil moisture content is a crucial factor influencing crop growth, it is essential to consider other variables, such as soil composition and nutrient concentrations, contributing to yield variations. Therefore, a comprehensive assessment of all relevant factors is necessary to fully understand the relationship between the yield differences between the two sites.

Also noted are the high soil baseline nutrients in the Chegoggin Point site. Analyzing Tables (3.10.1 and 3.11.1) shows that the Chegoggin Point site had higher soil baseline nutrients, such as nitrogen, phosphate, potassium dioxide, and organic matter, compared to the Falmouth site. The observed disparity in biomass yield between the Chegoggin Point and Falmouth sites can be attributed to various factors, the higher soil organic matter content being a notable factor in the enhanced productivity at Chegoggin Point. Analyzing the soil characteristics between the two sites, it becomes evident that the Chegoggin Point site had a 38% higher organic matter content compared to the Falmouth site. This higher organic matter content positively affects crop production and soil characteristics, influencing overall yields (Johnston, A. E. 1986). Organic matter positively impacts soil structure by promoting stable soil aggregates and improving water infiltration and retention (Salter & Williams, 1969). This structural improvement minimizes surface crusting and erosion risks, creating a more favorable growth environment (Kemper and Koch 1966).

Moreover, the increased water-holding capacity of soil with higher organic matter content is also an advantage evident from the soil moisture data (section 3.16). This advantageous property allows soils to absorb and retain substantial amounts of water, providing plants with a consistent water supply even during dry periods. The higher biomass yield observed at the Chegoggin Point site likely had positive effects, including improved soil structure, enhanced water retention, and microbial activity. These combined benefits a more productive environment for crop growth, ultimately translating into higher yields compared to the Falmouth site.

It is worth mentioning that the presence of these high macronutrients holds the potential to significantly increase plant growth and a greater biomass accumulation in the longer run at the Chegoggin site. For example, research by Haines et al. (2015) showed that macro-nutrients like nitrogen and phosphorus significantly influence the establishment and early growth of Giant Miscanthus, leading to increased biomass production. In the longer run, this enhanced macronutrient content can contribute to progressively higher biomass yields at the Chegoggin Point site.

5.6 Impact of Confounding Effects on Study Results

Our study investigated the feasibility of using biological input and locally sourced industrial byproducts for biomass production on marginal lands. While our findings provide valuable insights into this area, it is important to acknowledge the presence of certain confounding factors that could have influenced the observed results. These confounding effects highlight the complexity of field studies and the need for careful consideration when interpreting the outcomes.

5.6.1.1 Site Preparation and Disturbance

The differences in site preparation and historical land use might have introduced a confounding effect in our study. This is particularly evident when considering the difference in organic matter content between the two sites, where the Falmouth site exhibited lower organic matter levels. This difference in organic matter can be attributed to the Falmouth site's history, which involved heavy disturbances to the soil during the removal of poplar trees prior to our study. The intensive tillage operations and disruption of the soil profile during poplar removal would have influenced the organic matter content, as demonstrated by research (Paustian et al., 1997) highlighting how tillage and soil disturbance can impact soil organic matter. It's crucial to acknowledge that site history and preparatory activities can significantly affect soil characteristics, which in turn may have contributed to variations in nutrient microbial activity and overall crop yields. Further exploration into the long-term consequences of such disturbances on soil health and their implications for biomass crop productivity would provide a more comprehensive understanding of these effects.

5.6.1.2 Paper Sludge Application

The application process of paper sludge introduces a chance for a confounding effect on the study's outcomes. Notably, the paper sludge treatment was incorporated into the soil before planting, differing from the topsoil application of anaerobic digestate and seaweed extract. The difference in application methods could have influenced the soil characteristics and overall growth dynamics of the biomass crops. Thus, it is necessary to acknowledge the possibility that the slight improvement in growth attributed was due to the unique treatment application method or the inherent treatment effects. While we recognize this potential factor, it is challenging to isolate the precise influence of the application method. To gain a clearer understanding, future investigations could explore a range of application techniques, allowing us to assess the extent to which treatment effects and application methods contribute to the observed results.

5.6.1.3 Weed Control Methods

The weeding procedures might have presented yet another confounding element in our study. While consistent weeding measures were applied across most biomass crops, the approach for switchgrass differed due to its grassy nature and dense growth. The selective weeding process for switchgrass involved manually trimming the entire plot to the height of the switchgrass itself. This method ensured that only the taller weeds, those higher than the switchgrass, were trimmed. In contrast, other crops were subjected to comprehensive weeding to eliminate surrounding weeds. This divergence in weeding methods could have affected the competition for nutrients, water availability, and overall plant growth dynamics. It underscores the need to account for variations in weeding practices when interpreting yield outcomes.

5.6.1.4 Differences in Harvest dates

The differences in harvest dates between the Falmouth and Chegoggin Point sites introduced a significant confounding element. The substantial 5-week gap in planting dates would have resulted in distinct maturity stages of the biomass crops during the sampling period. This variation in maturity levels could have led to incongruent results when comparing biomass yields between the sites. The earlier planting schedule at Chegoggin Point might have allowed for an extended growth period, potentially contributing to enhanced biomass accumulation. Acknowledging this challenge during planting, resource limitations prevented simultaneous plantings in both sites. Despite this, recognizing the impact of harvest timing on results underscores the complexity of managing multiple factors in biomass crop research and emphasizes the importance of meticulous experimental design.

5.7 Future Research

Even though the study provided some key findings into the effects of three biological inputs and soil amendments, there are still many areas for future research. One key area to explore is the long-term effects of these treatments. For instance, applying paper sludge can potentially increase water-holding capacity in soils and the decomposition of organic matter, influencing soil microbial populations. Therefore, future research should investigate the long-term impacts of these treatments on nutrient availability, microbial growth, and carbon sequestration over multiple years. This will provide an understanding of the sustained benefits of these soil amendments and their potential as innovative alternatives to traditional fertilizers, contributing to climate change mitigation efforts. Also, future work has to be done to evaluate the economic feasibility of these industrial byproducts and their use as soil amendments, as it can create a potential for creating new markets for these waste materials.

Considering the study's design, conducting a statistical analysis to compare yields between the two sites may not add substantial value due to the presence of numerous uncontrolled variables across sites that could potentially influence crop biomass outcomes. However, for future investigations, the possibility of conducting a more comprehensive analysis can be explored. This analysis could encompass a qualitative examination, considering factors that may contribute to yield variations between sites without solely relying on statistical methods.

6. CONCLUSION

In conclusion, the findings of this study show the use of industrial byproducts such as paper sludge and anaerobic digestate can significantly impact the growth characteristics and yields of the four biomass crops tested in this study. Specifically, paper sludge had the overall best establishment year biomass yields. In contrast, both treatments, anaerobic digestate and paper sludge, performed equally better in promoting stem sizes during the end of the growing season. These results are also consistent in previous studies and were supported by other sites of the Biomass Project 6, which shows the benefits of using organic soil amendments in biomass crop production. The use of these biological inputs not only serves as a sustainable alternative to inorganic fertilizers but also serves as a potential solution to the growing problem of industrial waste disposal. Using these industrial by-products as soil amendments can also mitigate the negative impacts caused by conventional agricultural practices like excessive use of synthetic fertilizers and pesticides, which would affect soil health and biodiversity. This study's results also signify the use of marginal lands unsuitable for traditional crop production due to poor soil quality making them ideal for biomass production. The utilization of marginal lands combined with the help of locally sourced industrial byproducts provides an economically and environmentally sustainable method of biomass production. The present study would offer valuable insights to the agricultural industry and policymakers about the feasibility of utilizing biological inputs and locally sourced industrial byproducts for biomass production on marginal lands. However, there is a need for further research to examine the long-term impact of these treatments on soil quality and their scalability to larger production systems.

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8. APPENDIXES

8.1 Biomass yield (2021)

Table 8.1.1 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	975536	12	574953	6.788	0.00629 **

Table 8.1.2 Tukey's test: Treatment effects on yield (kg/ha) for Switchgrass grown in the Falmouth site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	-21.6	0.9989
PS-CT	560	0.0160 *
SE-CT	-8.3	0.9999

Table 8.1.3 Effect of soil amendments on Switchgrass yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	1048.3	a
Control	488.3	b
Seaweed	480	b
Digestate	466.7	b

Table 8.1.4 ANOVA: Treatment effects on yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	7014	12	17871	1.572	0.247

Table 8.1.5 Tukey's test: Treatment effects on yield (kg/ha) for Miscanthus grown in the Falmouth site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic

digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	25.312	0.7907
PS-CT	55.293	0.2315
SE-CT	44.043	0.4068

Table 8.1.6 Effect of soil amendments on Miscanthus yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	141.525	a
Control	86.231	a
Seaweed	130.275	a
Digestate	111.543	a

Table 8.1.7 ANOVA: Treatment effects on yield (kg/ha) for Poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	663	12	1155	2.295	0.13

Table 8.1.8 Tukey's test: Treatment effects on yield (kg/ha) for Poplar grown in the Falmouth site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	11.295	0.4
PS-CT	18.0	0.0945
SE-CT	10.32	0.4739

Table 8.1.9 Effect of soil amendments on Poplar yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	35.38	a
Control	17.38	a
Seaweed	27.70	a
Digestate	28.68	a

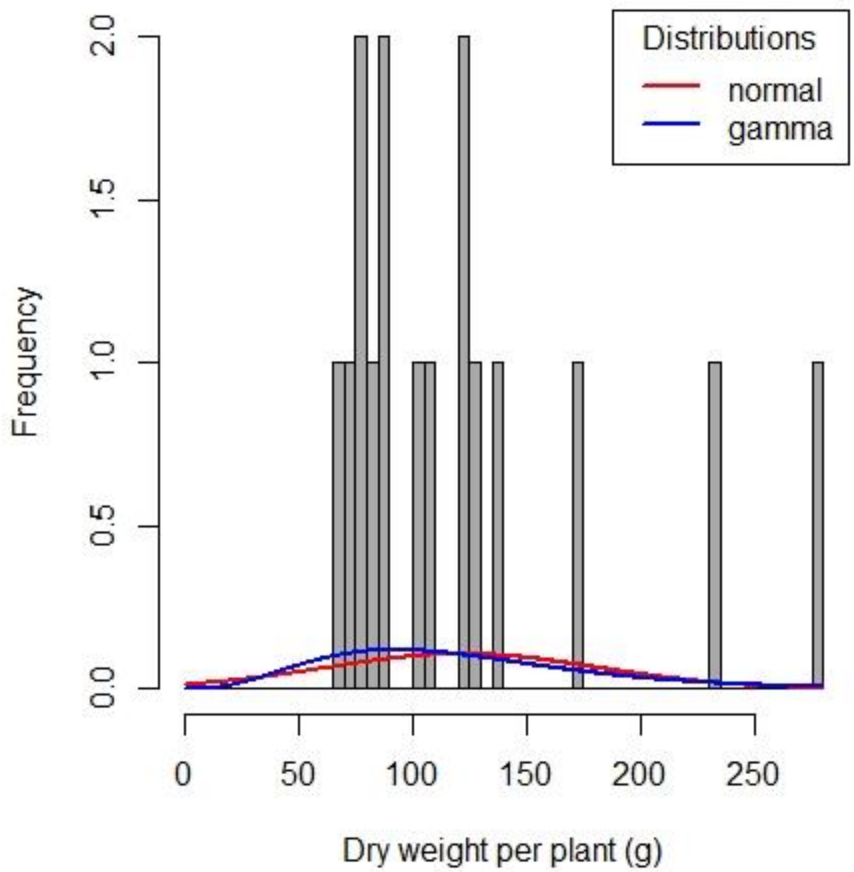

Figure 8.1.10 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow yield (kg/ha) from the Falmouth.

Table 8.1.11 ANOVA: Treatment effects on yield (kg/ha) for Willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	2.008	12	0.85578	9.675	0.00158**

Table 8.1.11 Tukey's test: Treatment effects on yield (kg/ha) for Willow grown in the Falmouth site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	17.34	0.8210
PS-CT	84.58	0.0055
SE-CT	6.37	0.9881

Table 8.1.12 Effect of soil amendments on Willow yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	145.35	b
Control	60.77	a
Seaweed	67.155	a
Digestate	78.122	a

Table 8.1.13 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	372659	12	984328	1.513	0.261

Table 8.1.14 Tukey's test: Treatment effects on yield (kg/ha) for switchgrass grown in the Chegoggin Point site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	188.4	0.7897
PS-CT	396.8	0.2561
SE-CT	333.5	0.3914

Table 8.1.15 Effect of soil amendments on switchgrass yield (kg/ha) from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	1498.4	a
Control	1101.6	a
Seaweed	1435.1	a
Digestate	1290.0	a

Table 8.1.16 ANOVA: Treatment effects on yield (kg/ha) for poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	301.7	12	3007.9	0.401	0.755

Table 8.1.17 Tukey's test: Treatment effects on yield (kg/ha) for poplar grown in the Chegoggin Point site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	6.82125	0.9270
PS-CT	1.54375	0.9990
SE-CT	-5.36375	0.9623

Table 8.1.18 Effect of soil amendments on poplar yield (kg/ha) from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	38.27	a
Control	36.72	a
Seaweed	31.36	a
Digestate	43.54	a

Table 8.1.19 ANOVA: Treatment effects on yield (kg/ha) for willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	2678	12	3654	2.932	0.0768

Table 8.1.20 Tukey's test: Treatment effects on yield (kg/ha) for willow grown in the Chegoggin Point site. Treatments included a no-additives control (CT), liquid A. nodosum extract (SE), anaerobic digestate (DG), and paper sludge (PS). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	P-value
DG-CT	4.4275	0.9834
PS-CT	32.46	0.0889
SE-CT	4.1450	0.9862

Table 8.1.21 Effect of soil amendments on willow yield (kg/ha) from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	72.8425	a
Control	40.3825	a
Seaweed	44.5275	a
Digestate	44.81	a

8.2 Miscanthus tissue nutrient concentrations (2021)

Table 8.2.1. Chemical analysis of Miscanthus biomass grown in the Falmouth site (2021).

	Mean nutrient concentrations ± standard error							
Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P (%)	Na (%)	Fe (ppm)	Mn (
Control	1.81 ± 0.091	0.38 ± 0.009	1.14 ± 0.060	0.16 ± 0.002	0.15 ± 0.010	0.04 ± 0.002	81.87± 5.840	221. 19.55
Digestate	1.99± 0.116	0.37± 0.016	1.29± 0.062	0.17± 0.008	0.16± 0.006	0.05± 0.004	105.57± 22.426	127. 10.67
Paper mill sludge	2.32± 0.103	0.45± 0.022	0.85± 0.079	0.28± 0.020	0.19± 0.004	0.05± 0.016	94.99± 5.052	445. 77.28
Seaweed	1.92± 0.024	0.39± 0.033	1.18± 0.071	0.16± 0.008	0.15± 0.007	0.04± 0.003	98.63± 17.198	197. 22.77

Table 8.2.2 ANOVA: Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.5741	12	0.5297	4.335	0.0274 *

Table 8.2.3 Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen concentration (%)	Groups
Paper sludge	2.3175	a
Control	1.8075	b
Seaweed	1.9225	ab
Digestate	1.9925	ab

Table 8.2.4 ANOVA: Treatment effects on average phosphorous concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.00539	12	0.0033	6.53	0.00723**

Table 8.2.5 Treatment effects on average phosphorous concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorous concentration (%)	Groups
Paper sludge	0.1920	a
Control	0.1487	b
Seaweed	0.1455	b
Digestate	0.1630	ab

Table 8.2.6 ANOVA: Treatment effects on average potassium concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.4324	12	0.2997	5.772	0.0111*

Table 8.2.7 Treatment effects on average potassium concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potassium concentration (%)	Groups
Paper sludge	0.8485	b
Control	1.1407	ab
Seaweed	1.1845	a
Digestate	1.2927	a

Table 8.2.8 ANOVA: Treatment effects on average Calcium concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.09738	12	0.18496	1.987	0.1698

Table 8.2.9 Treatment effects on average Calcium concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium concentration (%)	Groups
Paper sludge	0.4522	a
Control	0.3815	a
Seaweed	0.3875	a
Digestate	0.3710	a

Table 8.2.10 ANOVA: Treatment effects on average Sodium concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.2681	12	1.6886	0.5402	0.6638

Table 8.2.11 Treatment effects on average Sodium concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium concentration (%)	Groups
Paper sludge	0.0487	a
Control	0.0425	a
Seaweed	0.0350	a
Digestate	0.0477	a

Table 8.2.12 ANOVA: Treatment effects on average Magnesium concentration (%) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.9697	12	1.6830	24.11	2.28e-05***

Table 8.2.13 Treatment effects on average Magnesium concentration (%) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium concentration (%)	Groups
Paper sludge	0.2842	b
Control	0.1620	a
Seaweed	0.1627	a
Digestate	0.1702	a

Table 8.2.14 ANOVA: Treatment effects on average Iron concentration (ppm) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.136	12	1.208	0.4074	0.7505

Table 8.2.15 Treatment effects on average Iron concentration (ppm) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron concentration (ppm)	Groups
Paper sludge	94.990	a
Control	81.8675	a
Seaweed	98.6300	a
Digestate	105.5675	a

Table 8.2.16 ANOVA: Treatment effects on average Manganese concentration (ppm) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	3.364	12	1.2069	14.43	0.00027***

Table 8.2.17 Treatment effects on average Manganese concentration (ppm) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese concentration (ppm)	Groups
Paper sludge	445.0875	c
Control	221.2525	b
Seaweed	197.5175	ab
Digestate	127.2750	a

Table 8.2.18 ANOVA: Treatment effects on average Zinc concentration (ppm) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.5045	12	2.6658	0.6226	0.6139

Table 8.2.19 Treatment effects on average Zinc concentration (ppm) for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc concentration (ppm)	Groups
Paper sludge	19.9450	a
Control	31.5250	a
Seaweed	22.5725	a
Digestate	21.8450	a

8.3 Miscanthus tissue nutrient

Table 8.3.1 ANOVA: Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1.535	12	2.0542	3.467	0.05089

Table 8.3.2 Treatment effects on average Nitrogen yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen yield (kg/ha)	Groups
Paper sludge	12.0100	b
Control	5.1597	a
Seaweed	9.6275	ab
Digestate	7.3357	ab

Table 8.3.2 ANOVA: Treatment effects on Phosphorous yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1.515	12	2.2589	3.153	0.06458

Table 8.3.3 Treatment effects on average Phosphorous yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorous yield (kg/ha)	Groups
Paper sludge	1.00125	b
Control	0.428	a
Seaweed	0.740	ab
Digestate	0.596	ab

Table 8.3.4 ANOVA: Treatment effects on Potassium yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.7473	12	1.6212	2.167	0.145

Table 8.3.5 Treatment effects on average Potassium yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potassium yield (kg/ha)	Groups

Paper sludge	4.0915	a
Control	3.2477	a
Seaweed	5.8755	a
Digestate	4.8077	a

Table 8.3.6 ANOVA: Treatment effects on Calcium yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1.401	12	2.0341	3.538	0.04824

Table 8.3.7 Treatment effects on average Calcium yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium yield (kg/ha)	Groups
Paper sludge	2.3897	b
Control	1.1125	a
Seaweed	1.8820	ab
Digestate	1.3387	ab

Table 8.3.8 ANOVA: Treatment effects on Sodium yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.4788	12	1.7750	0.9327	0.4788

Table 8.3.9 Treatment effects on average Sodium yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium yield (kg/ha)	Groups
Paper sludge	0.1887	a
Control	0.1217	a
Seaweed	0.1852	a
Digestate	0.1762	a

Table 8.3.10 ANOVA: Treatment effects on Magnesium yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	3.273	12	2.4396	6.16	0.00888**

Table 8.3.11 Treatment effects on average Magnesium yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium yield (kg/ha)	Groups
Paper sludge	1.5372	b
Control	0.4705	a
Seaweed	0.8200	ab
Digestate	0.6135	a

Table 8.3.12 ANOVA: Treatment effects on Iron yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1.675	12	4.0179	1.652	0.2297

Table 8.3.13 Treatment effects on average Iron yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron yield (kg/ha)	Groups
Paper sludge	0.0497	a
Control	0.0232	a
Seaweed	0.0560	a
Digestate	0.0385	a

Table 8.3.14 ANOVA: Treatment effects on Manganese yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	6.423	12	3.8197	7.925	0.00352**

Table 8.3.15 Treatment effects on average Manganese yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese yield (kg/ha)	Groups
Paper sludge	0.2415	b
Control	0.0642	a
Seaweed	0.0992	ab
Digestate	0.0477	a

Table 8.3.14 ANOVA: Treatment effects on Zinc yield (kg/ha) for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.000007	12	0.0005	0.06	0.98

Table 8.3.15 Treatment effects on average Zinc yield (kg/ha) in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc yield (kg/ha)	Groups
Paper sludge	0.0102	a
Control	0.0100	a
Seaweed	0.0100	a
Digestate	0.0085	a

8.4 Winter Survival rate, trees 2022

Table 8.4.1 ANOVA: Treatment effects on survival rate for Poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.05912	12	0.0364	6.1	0.009189**

Table 8.4.2 Treatment effects on survival rate for Poplar grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Survival rate	Groups
Paper sludge	0.8575	a
Control	0.9850	b
Seaweed	0.9900	b
Digestate	0.9900	b

Table 8.4.3 ANOVA: Treatment effects on survival rate for Willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.0002	12	0.00228	0.3939	0.7597

Table 8.4.4 Treatment effects on survival rate for Willow grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Survival rate	Groups
Paper sludge	0.9900	a
Control	0.9925	a
Seaweed	0.9875	a

Digestate	0.9825	a

Table 8.4.5 ANOVA: Treatment effects on survival rate for Poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.4773	12	0.77116	3.01	0.0722

Table 8.4.6 Treatment effects on survival rate for Poplar grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Survival rate	Groups
Paper sludge	0.5250	a
Control	0.8300	b
Seaweed	0.7425	ab
Digestate	0.7825	ab

Table 8.4.7 ANOVA: Treatment effects on survival rate for Willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.1484	12	0.7520	1.022	0.4172

Table 8.4.8 Treatment effects on survival rate for Willow grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Survival rate	Groups
Paper sludge	0.7375	a
Control	0.8500	a
Seaweed	0.9250	a
Digestate	0.9450	a

8.5 Winter Survival rate, miscanthus 2022

Table 8.5.1 ANOVA: Treatment effects on survival rate for Miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.05607	12	0.09817	2.284	0.131

Table 8.5.2 Treatment effects on survival rate for Miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Survival rate	Groups
Paper sludge	0.3150	a
Control	0.1550	a
Seaweed	0.2450	a
Digestate	0.2775	a

8.7 Biomass yield, woody crops (Two-way ANOVA) 2021

Table 8.7.1 Two-way ANOVA: Crop, treatment, and interaction effects on yield (kg/ha) for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	56259	56259	70.639	1.82e-08 ***
Treatment	3	23593	7864	9.874	0.000224 ***
Crop:Treatment	3	12680	4227	5.307	0.006288 **

Table 8.7.2 Tukey's test: Treatment effects on yield (kg/ha) for poplar and willow grown in the Falmouth site. Treatments included a no-additives control (CT), anaerobic digestate (DG), paper sludge (PS), and liquid A. nodosum extract (SE). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Difference	Lower	Upper	P-value
DG-CT	19.8300	-19.2182	58.8782	0.5088
PS-CT	71.0225	31.9742	110.0707	0.0002***
SE-CT	11.5562	-27.4919	50.6044	0.8448

8.8 Soil composition analysis 2021 (Falmouth):

Table 8.8.1 ANOVA: Treatment effects on soil pH from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.1826	12	0.3992	1.83	0.195

Table 8.8.2 Treatment effects on soil pH from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.pH	Groups
Anaerobic digestate	5.7775	a
Control	5.6425	a
Paper sludge	5.5350	a

Seaweed extract	5.5050	a

Table 8.8.3 ANOVA: Treatment effects on soil buffer pH from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.009519	12	0.01402	2.715	0.0914

Table 8.8.4 Treatment effects on soil buffer pH from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Buffer pH	Groups
Anaerobic digestate	7.7075	a
Control	7.6925	a
Paper sludge	7.6900	a
Seaweed extract	7.6425	a

Table 8.8.5 ANOVA: Treatment effects on soil organic matter from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.1925	12	0.9050	0.851	0.493

Table 8.8.6 Treatment effects on soil organic matter from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Organic matter (%)	Groups
Anaerobic digestate	4.250	a
Control	4.225	a
Paper sludge	4.100	a
Seaweed extract	3.975	a

Table 8.8.7 ANOVA: Treatment effects on soil nitrogen concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.000725	12	0.00425	0.682	0.58

Table 8.8.8 Treatment effects on soil nitrogen concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups

Anaerobic digestate	0.19	a
Control	0.1875	a
Paper sludge	0.2025	a
Seaweed extract	0.1850	a

Table 8.8.9 ANOVA: Treatment effects on soil phosphate concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	202.2	12	454.2	1.798	0.201

Table 8.8.10 Treatment effects on soil phosphate concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Phosphate conc. (%)	Groups
Anaerobic digestate	41	a
Control	34.25	a
Paper sludge	34.25	a
Seaweed extract	31.25	a

Table 8.8.11 ANOVA: Treatment effects on soil potash concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	4814	12	7890	2.441	0.115

Table 8.8.12 Treatment effects on soil potash concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Potash conc. (%)	Groups
Anaerobic digestate	183.75	a
Control	170	a
Paper sludge	150.5	a
Seaweed extract	138.75	a

Table 8.8.13 ANOVA: Treatment effects on soil calcium concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	551310	12	1823335	1.209	0.348

Table 8.8.14 Treatment effects on soil calcium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium conc. (%)	Groups
Anaerobic digestate	2156.25	a
Control	1777.50	a
Paper sludge	1729.75	a
Seaweed extract	1692.50	a

Table 8.8.15 ANOVA: Treatment effects on soil magnesium concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	5271	12	10816	1.949	0.176

Table 8.8.16 Treatment effects on soil magnesium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium conc. (%)	Groups
Anaerobic digestate	292.25	a
Control	264.0	a
Paper sludge	254.5	a
Seaweed extract	243.25	a

Table 8.8.17 ANOVA: Treatment effects on soil sodium concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.307	12	0.1901	6.592	0.00699**

Table 8.8.18 Treatment effects on soil sodium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium conc. (%)	Groups
Anaerobic digestate	142.0	b
Control	108.75	a
Paper sludge	102.25	a
Seaweed extract	104.25	a

Table 8.8.19 ANOVA: Treatment effects on soil sulfur concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	41.19	12	61.25	2.69	0.0933

Table 8.8.20 Treatment effects on soil sulfur concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sulfur conc. (%)	Groups
Anaerobic digestate	25.5	a
Control	25.25	a
Paper sludge	27.25	a
Seaweed extract	22.75	a

Table 8.8.21 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	18219	12	44741	1.629	0.235

Table 8.8.22 Treatment effects on soil aluminum concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Anaerobic digestate	905.25	a
Control	886.25	a
Paper sludge	971.25	a
Seaweed extract	893.25	a

Table 8.8.23 ANOVA: Treatment effects on soil copper concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.5334	12	2.0303	1.051	0.406

Table 8.8.24 Treatment effects on soil copper concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Anaerobic digestate	2.7425	a
Control	2.4350	a
Paper sludge	2.2725	a
Seaweed extract	2.3225	a

Table 8.8.25 ANOVA: Treatment effects on soil iron concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	2143	12	3878	2.21	0.14

Table 8.8.26 Treatment effects on soil iron concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Anaerobic digestate	281.25	a
Control	272.25	a
Paper sludge	259.75	a
Seaweed extract	251.0	a

Table 8.8.27 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1323	12	8820	0.6	0.627

Table 8.8.28 Treatment effects on soil manganese concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. manganese conc. (ppm)	Groups
Anaerobic digestate	87.75	a
Control	70.25	a
Paper sludge	75.0	a
Seaweed extract	62.75	a

Table 8.8.29 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.2905	12	3.134	0.3294	0.8042

Table 8.8.30 Treatment effects on soil zinc concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. zinc conc. (ppm)	Groups
Anaerobic digestate	1.855	a

Control	1.725	a
Paper sludge	1.5175	a
Seaweed extract	2.2	a

8.9 Soil composition analysis (Chegoggin Point)

Table 8.9.1 ANOVA: Treatment effects on soil pH from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.3668	12	0.2708	5.419	0.0137*

Table 8.9.2 Treatment effects on soil pH from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg.pH	Groups
Anaerobic digestate	5.6325	a
Control	5.3550	ab
Paper sludge	5.2125	b
Seaweed extract	5.4250	ab

Table 8.9.3 ANOVA: Treatment effects on soil buffer pH from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	4.06e-05	12	0.0003218	0.5031	0.6873

Table 8.9.4 Treatment effects on soil buffer pH from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Buffer pH	Groups
Anaerobic digestate	7.5775	a
Control	7.5650	a
Paper sludge	7.57	a
Seaweed extract	7.5450	a

Table 8.9.5 ANOVA: Treatment effects on soil organic matter from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.945	12	1.265	2.988	0.0734

Table 8.9.6 Treatment effects on soil organic matter from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Organic matter (%)	Groups
Anaerobic digestate	5.775	a
Control	5.850	a
Paper sludge	6.400	a
Seaweed extract	6.075	a

Table 8.9.7 ANOVA: Treatment effects on soil nitrogen concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.003019	12	0.004375	2.76	0.0881

Table 8.9.8 Treatment effects on soil nitrogen concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Anaerobic digestate	0.3250	a
Control	0.3400	a
Paper sludge	0.3625	a
Seaweed extract	0.3500	a

Table 8.9.9 ANOVA: Treatment effects on soil phosphate concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.4866	12	0.1998	11.02	0.00091***

Table 8.9.10 Treatment effects on soil phosphate concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphate conc. (%)	Groups
Anaerobic digestate	73.0	a
Control	59.5	a
Paper sludge	94.5	b
Seaweed extract	66	a

Table 8.9.11 ANOVA: Treatment effects on soil potash concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	8767	12	9890	3.546	0.048

Table 8.9.12 Treatment effects on soil potash concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potash conc. (%)	Groups
Anaerobic digestate	198.75	a
Control	147.25	ab
Paper sludge	138.0	b
Seaweed extract	153.25	ab

Table 8.9.13 ANOVA: Treatment effects on soil calcium concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	9187	12	95911	0.383	0.767

Table 8.9.14 Treatment effects on soil calcium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium conc. (%)	Groups
Anaerobic digestate	967.75	a
Control	911	a
Paper sludge	909	a
Seaweed extract	939	a

Table 8.9.15 ANOVA: Treatment effects on soil magnesium concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	4434	12	30453	0.582	0.638

Table 8.9.16 Treatment effects on soil magnesium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium conc. (%)	Groups
Anaerobic digestate	426.5	a
Control	412.25	a
Paper sludge	386.25	a
Seaweed extract	427.5	a

Table 8.9.17 ANOVA: Treatment effects on soil sodium concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.3904	12	0.07475	20.67	4.94e-05***

Table 8.9.18 Treatment effects on soil sodium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium conc. (%)	Groups
Anaerobic digestate	314	b
Control	218.5	a
Paper sludge	223.25	a
Seaweed extract	221.75	a

Table 8.9.19 ANOVA: Treatment effects on soil sulfur concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	38.25	12	83.5	1.832	0.195

Table 8.9.20 Treatment effects on soil sulfur concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sulfur conc. (%)	Groups
Anaerobic digestate	32.5	a
Control	33.25	a
Paper sludge	34.5	a
Seaweed extract	30.25	a

Table 8.9.21 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	19808	12	50243	1.577	0.246

Table 8.9.22 Treatment effects on soil aluminum concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. aluminium conc. (ppm)	Groups
Anaerobic digestate	952.75	a
Control	1009.5	a
Paper sludge	940.75	a
Seaweed extract	911.5	a

Table 8.9.23 ANOVA: Treatment effects on soil copper concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.02745	12	0.09205	1.193	0.354

Table 8.9.24 Treatment effects on soil copper concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Anaerobic digestate	0.5100	a
Control	0.4125	a
Paper sludge	0.4425	a
Seaweed extract	0.4050	a

Table 8.9.25 ANOVA: Treatment effects on soil iron concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1004	12	1880	2.136	0.149

Table 8.9.26 Treatment effects on soil iron concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Anaerobic digestate	384.25	a
Control	406.00	a
Paper sludge	397.25	a
Seaweed extract	399.75	a

Table 8.9.27 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	1.614	12	0.4173	16.3	0.00015***

Table 8.9.28 Treatment effects on soil manganese concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. manganese conc. (ppm)	Groups
Anaerobic digestate	5	a
Control	5.25	a
Paper sludge	10.5	b
Seaweed extract	5.5	a

Table 8.9.29 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.0970	12	0.3921	0.989	0.431

Table 8.9.30 Treatment effects on soil zinc concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. zinc conc. (ppm)	Groups
Anaerobic digestate	1.4500	a
Control	1.5175	a
Paper sludge	1.5350	a
Seaweed extract	1.6650	a

8.10 Soil heavy metal analysis (Falmouth):

Table 8.10.1 ANOVA: Treatment effects on soil Aluminum from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	442319	12	6027925	0.294	0.829

Table 8.10.2 Treatment effects on soil Aluminum from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc (mg/kg)	Groups
Anaerobic digestate	9922.5	a
Control	9887.5	a
Paper sludge	10112.5	a
Seaweed extract	9645	a

Table 8.10.3 ANOVA: Treatment effects on soil Arsenic from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	8.19	12	40.75	0.804	0.516

Table 8.10.4 Treatment effects on soil Arsenic from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc (mg/kg)	Groups
Anaerobic digestate	10	a
Control	9	a
Paper sludge	10.25	a
Seaweed extract	11	a

Table 8.10.5 ANOVA: Treatment effects on soil Barium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	46.25	12	135.5	1.365	0.3

Table 8.10.6 Treatment effects on soil Barium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc (mg/kg)	Groups
Anaerobic digestate	27	a
Control	28.75	a
Paper sludge	26.75	a
Seaweed extract	24	a

Table 8.10.7 ANOVA: Treatment effects on soil Chromium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	5.187	12	11.250	1.844	0.193

Table 8.10.8 Treatment effects on soil Chromium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc (mg/kg)	Groups
Anaerobic digestate	13.5	a
Control	13.75	a
Paper sludge	14.75	a
Seaweed extract	13.25	a

Table 8.10.9 ANOVA: Treatment effects on soil Cobalt from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.18	12	13.50	1.158	0.366

Table 8.10.10 Treatment effects on soil Cobalt from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc (mg/kg)	Groups
Anaerobic digestate	6.5	a
Control	7.75	a
Paper sludge	8.25	a
Seaweed extract	6.50	a

Table 8.10.11 ANOVA: Treatment effects on soil Copper from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	2.69	12	37.75	0.285	0.835

Table 8.10.12 Treatment effects on soil Copper from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc (mg/kg)	Groups
Anaerobic digestate	13.5	a
Control	13.5	a
Paper sludge	14.5	a
Seaweed extract	13.75	a

Table 8.10.13 ANOVA: Treatment effects on soil Iron from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	4201875	12	19272500	0.872	0.482

Table 8.10.14 Treatment effects on soil Iron from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc (mg/kg)	Groups
Anaerobic digestate	13875	a
Control	14475	a
Paper sludge	15275	a
Seaweed extract	14250	a

Table 8.10.15 ANOVA: Treatment effects on soil Lead from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	41.2	12	198.2	0.832	0.502

Table 8.10.16 Treatment effects on soil Lead from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc (mg/kg)	Groups
Anaerobic digestate	19.9	a
Control	16.625	a
Paper sludge	19.375	a
Seaweed extract	20.975	a

Table 8.10.17 ANOVA: Treatment effects on soil Lithium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	9.5	12	15.5	2.452	0.114

Table 8.10.18 Treatment effects on soil Lithium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc (mg/kg)	Groups
Anaerobic digestate	19.25	a
Control	19.75	a
Paper sludge	21	a

Seaweed extract	19.0	a

Table 8.10.19 ANOVA: Treatment effects on soil Manganese from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.2642	12	0.9189	1.184	0.3569

Table 8.10.20 Treatment effects on soil Manganese from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc (mg/kg)	Groups
Anaerobic digestate	604.5	a
Control	567.25	a
Paper sludge	567.5	a
Seaweed extract	430.25	a

Table 8.10.21 ANOVA: Treatment effects on soil Nickel from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.06032	12	0.151	2.021	0.1647

Table 8.10.22 Treatment effects on soil Nickel from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc (mg/kg)	Groups
Anaerobic digestate	11.75	a
Control	11.0	a
Paper sludge	12	a
Seaweed extract	10.25	a

Table 8.10.23 ANOVA: Treatment effects on soil Strontium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.133	12	0.2515	2.823	0.0838

Table 8.10.24 Treatment effects on soil Strontium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Strontium conc (mg/kg)	Groups
Anaerobic digestate	8	b
Control	7.25	ab
Paper sludge	6.75	ab
Seaweed extract	6.25	a

Table 8.10.25 ANOVA: Treatment effects on soil Uranium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.01307	12	0.1833	0.2875	0.8336

Table 8.10.26 Treatment effects on soil Uranium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Uranium conc (mg/kg)	Groups
Anaerobic digestate	0.450	a
Control	0.425	a
Paper sludge	0.450	a
Seaweed extract	0.425	a

Table 8.10.27 ANOVA: Treatment effects on soil Vanadium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	24.75	12	37	2.676	0.0944

Table 8.10.28 Treatment effects on soil Vanadium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Vanadium conc (mg/kg)	Groups
Anaerobic digestate	27	a
Control	26.5	a
Paper sludge	29.5	a
Seaweed extract	26.5	a

Table 8.10.27 ANOVA: Treatment effects on soil Zinc from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	47.69	12	196.25	0.972	0.438

Table 8.10.28 Treatment effects on soil Zinc from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc (mg/kg)	Groups
Anaerobic digestate	37.25	a
Control	36.25	a
Paper sludge	38.75	a
Seaweed extract	34	a

8.11 Soil heavy metal analysis (Chegoggin Point):

Table 8.11.1 ANOVA: Treatment effects on soil Aluminum from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	3316219	12	5860225	2.264	0.133

Table 8.11.2 Treatment effects on soil Aluminum from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc (mg/kg)	Groups
Anaerobic digestate	8417.5	a
Control	7590	a
Paper sludge	7582.5	a
Seaweed extract	7162.5	a

Table 8.11.3 ANOVA: Treatment effects on soil Arsenic from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.05212	12	0.21517	0.9519	0.4465

Table 8.11.4 Treatment effects on soil Arsenic from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc (mg/kg)	Groups
Anaerobic digestate	23.5	a
Control	20.5	a
Paper sludge	21	a
Seaweed extract	20.5	a

Table 8.11.5 ANOVA: Treatment effects on soil Barium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	10.69	12	14.25	3	0.0728

Table 8.11.6 Treatment effects on soil Barium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc (mg/kg)	Groups
Anaerobic digestate	9.75	a
Control	8.25	a
Paper sludge	10	a
Seaweed extract	8.25	a

Table 8.11.7 ANOVA: Treatment effects on soil Chromium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	11.5	12	30.5	1.508	0.263

Table 8.11.8 Treatment effects on soil Chromium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc (mg/kg)	Groups
Anaerobic digestate	15.75	a
Control	14.75	a
Paper sludge	14.0	a
Seaweed extract	13.5	a

Table 8.11.9 ANOVA: Treatment effects on soil Cobalt from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.07813	12	0.29466	1.16	0.3652

Table 8.11.10 Treatment effects on soil Cobalt from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc (mg/kg)	Groups
Anaerobic digestate	3.25	a
Control	3	a
Paper sludge	2.75	a
Seaweed extract	2.75	a

Table 8.11.11 ANOVA: Treatment effects on soil Copper from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.1505	12	37.75	1.455	0.2759

Table 8.11.12 Treatment effects on soil Copper from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc (mg/kg)	Groups
Anaerobic digestate	8.5	a
Control	8.5	a
Paper sludge	7	a
Seaweed extract	7	a

Table 8.11.13 ANOVA: Treatment effects on soil Iron from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	8373800	12	31436200	10.65	0.4

Table 8.11.14 Treatment effects on soil Iron from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc (mg/kg)	Groups
Anaerobic digestate	14375	a
Control	13275	a
Paper sludge	12600	a
Seaweed extract	12610	a

Table 8.11.15 ANOVA: Treatment effects on soil Lead from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.01226	12	0.0813	0.5909	0.6327

Table 8.11.16 Treatment effects on soil Lead from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc (mg/kg)	Groups
Anaerobic digestate	9.150	a
Control	8.5	a
Paper sludge	8.675	a
Seaweed extract	8.650	a

Table 8.11.17 ANOVA: Treatment effects on soil Lithium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	9.5	12	15.5	2.452	0.114

Table 8.11.18 Treatment effects on soil Lithium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc (mg/kg)	Groups
Anaerobic digestate	13.75	a
Control	13	a
Paper sludge	12.25	a
Seaweed extract	11.5	a

Table 8.11.19 ANOVA: Treatment effects on soil Manganese from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.07319	12	0.180	1.519	0.26

Table 8.11.20 Treatment effects on soil Manganese from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc (mg/kg)	Groups
Anaerobic digestate	146.75	a
Control	126.0	a
Paper sludge	139.5	a
Seaweed extract	125.25	a

Table 8.11.21 ANOVA: Treatment effects on soil Nickel from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.06032	12	0.151	2.021	0.1647

Table 8.11.22 Treatment effects on soil Nickel from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc (mg/kg)	Groups
Anaerobic digestate	11.75	a
Control	11.0	a
Paper sludge	12	a
Seaweed extract	10.25	a

Table 8.11.23 ANOVA: Treatment effects on soil Strontium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.06534	12	0.2285	1.116	0.3812

Table 8.11.24 Treatment effects on soil Strontium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Strontium conc (mg/kg)	Groups
Anaerobic digestate	15.75	a
Control	13.5	a
Paper sludge	13.5	a
Seaweed extract	14	a

Table 8.11.25 ANOVA: Treatment effects on soil Uranium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.03309	12	0.09969	1.326	0.3116

Table 8.11.26 Treatment effects on soil Uranium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Uranium conc (mg/kg)	Groups
Anaerobic digestate	0.575	a
Control	0.525	a
Paper sludge	0.575	a
Seaweed extract	0.525	a

Table 8.11.27 ANOVA: Treatment effects on soil Vanadium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	0.05631	12	0.118	1.915	0.181

Table 8.11.28 Treatment effects on soil Vanadium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Vanadium conc (mg/kg)	Groups
Anaerobic digestate	21.75	a
Control	19.5	a
Paper sludge	19.5	a
Seaweed extract	18.5	a

Table 8.11.27 ANOVA: Treatment effects on soil Zinc from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	3	14.19	12	89.25	0.636	0.606

Table 8.11.28 Treatment effects on soil Zinc from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc (mg/kg)	Groups
Anaerobic digestate	27.25	a
Control	25.50	a
Paper sludge	25.25	a
Seaweed extract	24.75	a

8.12 Biomass yield (2022)

Table 8.12.1 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	5229683	18	2762968	6.814	0.00099 ***

Table 8.12.2 Effect of soil amendments on Switchgrass yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	2664	a
Control	2065.8	ab
Seaweed-1	1367.8	b
Seaweed-2	1253.3	b
Digestate-1	1950.2	ab
Digestate-2	1843.6	ab

Table 8.12.3 ANOVA: Treatment effects on yield (kg/ha) for miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	397787	18	860626	1.664	0.194

Table 8.12.4 Effect of soil amendments on miscanthus yield (kg/ha) from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	684.8	a
Control	294	a
Seaweed-1	349	a
Seaweed-2	412.2	a

Digestate-1	360.7	a
Digestate-2	496.2	a

Table 8.12.5 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	9741758	18	6546003	5.358	0.00345**

Table 8.12.6 Effect of soil amendments on Switchgrass yield (kg/ha) from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	4033.5	a
Control	2188.8	b
Seaweed-1	2875.8	ab
Seaweed-2	2803.3	ab
Digestate-1	3713	a
Digestate-2	3639.5	a

8.13 Moisture content (2022)

Table 8.13.1 ANOVA: Treatment effects on percent moisture content for switchgrass grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05)

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1742	18	0.35619	1.643	0.1994

Table 8.13.2 Treatment effects on moisture content (%) for switchgrass grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Paper sludge	38.3	a
Control	45.2	a
Seaweed-1	49.7	a

Seaweed-2	44.2	a
Digestate-1	41.2	a
Digestate-2	47.2	a

Table 8.13.3 ANOVA: Treatment effects on percent moisture content for miscanthus grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05)

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	226	18	516.1	1.576	0.217

Table 8.13.4 Treatment effects on moisture content (%) for miscanthus grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

ANOVA: Treatment effects on average stem length (cm) for poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

Soil amendment	Moisture content (%)	Groups
Paper sludge	45.7	a
Control	47	a
Seaweed-1	46.4	a
Seaweed-2	44.9	a
Digestate-1	45.1	a
Digestate-2	37.9	a

Table 8.13.5 ANOVA: Treatment effects on percent moisture content for switchgrass grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05)

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	207.5	18	999.5	0.747	0.599

Table 8.13.6 Treatment effects on moisture content (%) for switchgrass grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Paper sludge	57.9	a

Control	60	a
Seaweed-1	51.4	a
Seaweed-2	51.4	a
Digestate-1	58.6	a
Digestate-2	61	a

8.14 Poplar average stem length (2022)

Table 8.14.1 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	1195	18	4890	0.88	0.514

Table 8.14.2 Treatment effects on average stem length (cm) for poplar grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	55.5	a
Control	46	a
Seaweed-1	38.4	a
Seaweed-2	38.4	a
Digestate-1	47.4	a
Digestate-2	58	a

Table 8.14.3 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	703	18	1276	1.984	0.13

Table 8.14.4 Treatment effects on average stem length (cm) for poplar grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	54.3	a
Control	37.6	a
Seaweed-1	42.5	a
Seaweed-2	38.9	a
Digestate-1	44.9	a
Digestate-2	44.1	a

8.15 Willow average stem length (2022)

Table 8.15.1 ANOVA: Treatment effects on average stem length (cm) for willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	5013	18	5214	3.461	0.0229*

Table 8.15.2 Treatment effects on average stem length (cm) for willow grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	63	a
Control	38.9	a
Seaweed-1	31.4	a
Seaweed-2	33.2	a
Digestate-1	60.7	a
Digestate-2	65	a

Table 8.15.3 ANOVA: Treatment effects on average stem length (cm) for willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	582.7	18	1374.9	1.526	0.231

Table 8.15.4 Treatment effects on average stem length (cm) for willow grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	83.1	a
Control	69.2	a
Seaweed-1	78.8	a
Seaweed-2	73.4	a
Digestate-1	73.4	a
Digestate-2	81.4	a

8.16 Poplar average stem diameter (2022)

Table 8.16.1 ANOVA: Treatment effects on average stem diameter (mm) for poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.3355	18	0.70735	1.488	0.2427

Table 8.16.2 Treatment effects on average stem length (cm) for poplar grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem diameter (mm)	Groups
Paper sludge	4.9	a
Control	4.3	a
Seaweed-1	3.7	a
Seaweed-2	3.9	a
Digestate-1	4.4	a
Digestate-2	5.2	a

Table 8.16.3 ANOVA: Treatment effects on average stem diameter (mm) for poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of	Deviance	Residual	Residual	F-value	P-value

	freedom		df	deviance		
Treatment	5	5.655	18	6.059	3.36	0.0256*

Table 8.16.4 Treatment effects on average stem diameter (mm) for poplar grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem diameter (mm)	Groups
Paper sludge	5.7	a
Control	4.2	b
Seaweed-1	4.6	ab
Seaweed-2	4.4	b
Digestate-1	4.8	ab
Digestate-2	4.7	ab

8.17 Willow average stem diameter (2022)

Table 8.17.1 ANOVA: Treatment effects on average stem diameter (mm) for willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.5688	18	1.1800	1.637	0.2009

Table 8.17.2 Treatment effects on average stem length (cm) for willow grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem diameter (mm)	Groups
Paper sludge	5.8	a
Control	4.8	a
Seaweed-1	4.3	a
Seaweed-2	4.3	a
Digestate-1	5.9	a
Digestate-2	6.4	a

Table 8.17.3 ANOVA: Treatment effects on average stem diameter (mm) for willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.07711	18	0.1875	1.919	0.1409

Table 8.17.4 Treatment effects on average stem length (cm) for willow grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem diameter (mm)	Groups
Paper sludge	5.9	ab
Control	5.4	a
Seaweed-1	6.1	ab
Seaweed-2	5.7	ab
Digestate-1	5.9	ab
Digestate-2	6.5	b

8.18 Poplar total stem length (2022)

Table 8.18.1 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.5619	18	1.567	1.147	0.3723

Table 8.18.2 Treatment effects on total stem length (cm) for poplar grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	444.5	a
Control	374.3	a
Seaweed-1	307.5	a
Seaweed-2	318.3	a
Digestate-1	379.7	a
Digestate-2	464.5	a

Table 8.18.3 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	44891	18	81708	1.978	0.131

Table 8.18.4 Treatment effects on total stem length (cm) for poplar grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	434.5	a
Control	300.6	a
Seaweed-1	340.1	a
Seaweed-2	311.8	a
Digestate-1	359.1	a
Digestate-2	353.3	a

8.19 Willow total stem length (2022)

Table 8.19.1 ANOVA: Treatment effects on total stem length (cm) for willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	329629	18	334168	3.551	0.0208*

Table 8.19.2 Treatment effects on total stem length (cm) for willow grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	504.3	a
Control	311.1	a
Seaweed-1	251.3	a
Seaweed-2	257	a
Digestate-1	485.9	a
Digestate-2	520.4	a

Table 8.19.1 ANOVA: Treatment effects on total stem length (cm) for willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	37103	18	88049	1.517	0.234

Table 8.19.2 Treatment effects on total stem length (cm) for willow grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem length (cm)	Groups
Paper sludge	664.8	a
Control	553.6	a
Seaweed-1	631	a
Seaweed-2	586.9	a
Digestate-1	588.9	a
Digestate-2	651.2	a

8.20 Poplar total stem volume (2022)

Table 8.20.1 ANOVA: Treatment effects on total stem volume (cm3) for poplar grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	6.414	18	11.305	1.627	0.2036

Table 8.20.2 Treatment effects on total stem length (cm3) for poplar grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem volume (cm3)	Groups
Paper sludge	85.48	a
Control	81.82	a
Seaweed-1	89.25	a
Seaweed-2	59.39	a
Digestate-1	168.81	a
Digestate-2	258.09	a

Table 8.20.3 ANOVA: Treatment effects on total stem volume (cm3) for poplar grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	2455	18	19453	0.454	0.805

Table 8.20.4 Treatment effects on total stem length (cm3) for poplar grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem volume (cm3)	Groups
Paper sludge	74.68	a
Control	49.33	a
Seaweed-1	65.25	a
Seaweed-2	51.77	a
Digestate-1	63.5	a
Digestate-2	77.55	a

8.21 Willow total stem volume (2022)

Table 8.21.1 ANOVA: Treatment effects on total stem volume (cm3) for willow grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	12.92	18	14.536	7.036	0.00083***

Table 8.21.2 Treatment effects on total stem volume (cm3) for willow grown in the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.stem volume (cm3)	Groups
Paper sludge	258.73	ab
Control	100.93	bc
Seaweed-1	50.59	c
Seaweed-2	53.33	c
Digestate-1	255.45	ab
Digestate-2	346.33	a

Table 8.21.3 ANOVA: Treatment effects on total stem volume (cm3) for willow grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	1.736	18	6.221	1.229	0.3362

Table 8.21.4 Treatment effects on total stem volume (cm3) for willow grown in the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg.stem volume (cm3)	Groups
Paper sludge	232.39	a
Control	179.23	a
Seaweed-1	212.27	a
Seaweed-2	176.38	a
Digestate-1	269.54	a
Digestate-2	377.94	a

8.22 Survival rate, woody crops (2022)

Table 8.22.1 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	0.00845	0.008450	7.198	0.01328*
Treatment	3	0.02474	0.008246	7.024	0.00161**
Crop:Treatment	3	0.02690	0.008967	7.638	0.00102**

Table 8.22.2 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	0.1668	0.16675	6.754	0.0161*
Treatment	3	0.2803	0.09343	3.784	0.0242*
Crop:Treatment	3	0.0438	0.01459	0.591	0.6271

8.23 Biomass yield, woody crops (2021)

Table 8.23.1 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	29342	29342	70.641	1.82e-08***
Treatment	3	42304	4101	9.874	0.000225***
Crop:Treatment	3	6611	2204	5.305	0.006296**

Table 8.23.2 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	1386	1386.3	4.995	0.035
Treatment	3	1599	533	1.920	0.153
Crop:Treatment	3	1381	460.2	1.658	0.203

8.24 Average stem length, woody crops (2022)

Table 8.24.1 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	8	709	0.027	0.86970
Treatment	3	5305	1061	3.676	0.00887**
Crop:Treatment	3	903	180.6	0.626	0.68111

Table 8.24.2 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	12956	12956	183.767	1.71e-15***
Treatment	3	1147	229	3.254	0.0162*
Crop:Treatment	3	139	28	0.394	0.8499

8.25 Total stem length, woody crops (2022)

Table 8.25.1 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	567	567	0.031	0.8621
Treatment	3	353855	70771	3.825	0.0072**
Crop:Treatment	3	57242	11448	0.619	0.6863

Table 8.25.2 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	828661	828661	183.543	1.74e-15***
Treatment	3	73122	14624	3.239	0.0166*
Crop:Treatment	3	8872	1774	0.393	0.8502

8.26 Average stem diameter, woody crops (2022)

Table 8.26.1 Two-way ANOVA: Crop, treatment, and interaction effects on average stem diameter (mm) for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	9.05	9.048	8.288	0.006762 **
Treatment	3	20.69	4.138	3.791	0.007556 **
Crop:Treatment	3	1.43	0.287	0.263	0.930278

Table 8.26.2 Two-way ANOVA: Crop, treatment, and interaction effects on average stem diameter (mm) for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	17.041	17.041	54.889	1.14e-08***
Treatment	3	5.482	1.096	3.532	0.0109*
Crop:Treatment	3	2.898	0.580	1.867	0.1254

8.27 Total stem volume, woody crops (2022)

Table 8.27.1 Two-way ANOVA: Crop, treatment, and interaction effects on total stem volume (cm3) for woody crops (poplar, willow) grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	953	953	1.231	0.2748
Treatment	3	12795	2559	3.304	0.0151*
Crop:Treatment	3	775	155	0.200	0.0125*

Table 8.27.2 Two-way ANOVA: Crop, treatment, and interaction effects on total stem volume (cm3) for woody crops (poplar, willow) grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Sum of squares	Mean squares	F-value	P-value
Crop	1	19586	19586	98.275	1.06e-11***
Treatment	3	3853	771	3.866	0.0068 **
Crop:Treatment	3	1711	342	1.717	0.1564

8.28 Soil composition analysis 2022 (Falmouth)

Table 8.28.1 ANOVA: Treatment effects on soil pH from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.09184	18	0.29031	1.139	0.376

Table 8.28.2 Treatment effects on soil pH from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.pH	Groups
Digestate-1	5.79	a
Digestate-2	5.84	a
Control	5.74	a
Paper sludge	5.686	a
Seaweed extract-1	5.66	a
Seaweed extract-2	5.74	a

Table 8.28.3 ANOVA: Treatment effects on soil buffer pH from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment						

Table 8.28.4 Treatment effects on soil buffer pH from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Buffer pH	Groups
Anaerobic digestate-1	7.778	a
Anaerobic digestate-2	7.761	a
Control	7.771	a
Paper sludge	7.748	a
Seaweed extract-1	7.757	a
Seaweed extract-2	7.75	a

Table 8.28.5 ANOVA: Treatment effects on soil organic matter from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1972	18	0.8769	0.81	0.558

Table 8.28.6 Treatment effects on soil organic matter from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Organic matter (%)	Groups
Anaerobic digestate -1	4.45	a
Anaerobic digestate -1	4.26	a
Control	4.15	a
Paper sludge	4.27	a
Seaweed extract-1	4.25	a
Seaweed extract-2	4.22	a

Table 8.28.7 ANOVA: Treatment effects on soil nitrogen concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.0218	18	0.05674	1.361	0.2849

Table 8.28.8 Treatment effects on soil nitrogen concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Anaerobic digestate -1	0.218	a
Anaerobic digestate -2	0.208	a
Control	0.197	a
Paper sludge	0.205	a
Seaweed extract-1	0.208	a
Seaweed extract-2	0.207	a

Table 8.28.9 ANOVA: Treatment effects on soil phosphate concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	81.05	18	301.69	0.967	0.464

Table 8.28.10 Treatment effects on soil phosphate concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphate conc. (kg/ha)	Groups
Anaerobic digestate-1	32.7	a
Anaerobic digestate-2	34.87	a
Control	29.62	a
Paper sludge	33.3	a
Seaweed extract-1	30.87	a
Seaweed extract-2	30.37	a

Table 8.28.11 ANOVA: Treatment effects on soil potash concentration (kg/ha) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	4930	18	12348	1.437	0.259

Table 8.28.12 Treatment effects on soil potash concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potash conc. (kg/ha)	Groups
Anaerobic digestate-1	189	a
Anaerobic digestate-2	196.37	a
Control	158.3	a
Paper sludge	158.37	a
Seaweed extract-1	180.75	a
Seaweed extract-2	173.87	a

Table 8.28.13 ANOVA: Treatment effects on soil calcium concentration (kg/ha) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	308721	18	1083259	1.026	0.432

Table 8.28.14 Treatment effects on soil calcium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium conc. (kg/ha)	Groups
Anaerobic digestate-1	1977.5	a
Anaerobic digestate-2	1875.87	a
Control	1745	a
Paper sludge	1716.62	a
Seaweed extract-1	1714.12	a
Seaweed extract-2	1971	a

Table 8.28.15 ANOVA: Treatment effects on soil magnesium concentration (kg/ha) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	2114	18	10352	0.735	0.607

Table 8.28.16 Treatment effects on soil magnesium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium conc. (kg/ha)	Groups
Anaerobic digestate-1	266.25	a
Anaerobic digestate-2	259.62	a
Control	256	a
Paper sludge	243	a
Seaweed extract-1	250	a
Seaweed extract-2	270.87	a

Table 8.28.17 ANOVA: Treatment effects on soil sodium concentration (kg/ha) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	3897	18	2268	6.184	0.00167**

Table 8.8.18 Treatment effects on soil sodium concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium conc. (%)	Groups
Anaerobic digestate-1	85.62	ab
Anaerobic digestate-2	109.97	a
Control	73.75	b
Paper sludge	77.75	b
Seaweed extract-1	71.62	b
Seaweed extract-2	81.25	b

Table 8.8.19 ANOVA: Treatment effects on soil sulfur concentration (%) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	1.83	18	112.5	0.059	0.997

Table 8.8.20 Treatment effects on soil sulfur concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Sulfur conc. (%)	Groups
Anaerobic digestate-1	20.12	a
Anaerobic digestate-2	19.25	a
Control	19.37	a
Paper sludge	19.62	a
Seaweed extract-1	19.62	a
Seaweed extract-2	19.5	a

Table 8.8.21 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	8584	18	76862	0.402	0.841

Table 8.8.22 Treatment effects on soil aluminum concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Anaerobic digestate-1	831.87	a
Anaerobic digestate-2	830.5	a
Control	822.37	a
Paper sludge	839.62	a
Seaweed extract-1	868.37	a
Seaweed extract-2	871.12	a

Table 8.8.23 ANOVA: Treatment effects on soil copper concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1345	18	0.48367	0.046	0.4216

Table 8.8.24 Treatment effects on soil copper concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Anaerobic digestate-1	1.906	a
Anaerobic digestate-2	2.285	a
Control	2.377	a
Paper sludge	2.340	a
Seaweed extract-1	2.361	a
Seaweed extract-2	2.301	a

Table 8.8.25 ANOVA: Treatment effects on soil iron concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	648.2	18	3097.3	0.753	0.595

Table 8.8.26 Treatment effects on soil iron concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Anaerobic digestate-1	219.75	a
Anaerobic digestate-2	217.75	a
Control	228.62	a
Paper sludge	223.125	a
Seaweed extract-1	211.75	a
Seaweed extract-2	222.62	a

Table 8.8.27 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1345	18	0.48367	1.046	0.4216

Table 8.8.28 Treatment effects on soil manganese concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. manganese conc. (ppm)	Groups
Anaerobic digestate-1	64.25	a
Anaerobic digestate-2	68.25	a
Control	57.75	a
Paper sludge	54.87	a
Seaweed extract-1	54.25	a
Seaweed extract-2	63.75	a

Table 8.8.29 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1345	18	0.48367	1.046	0.4216

Table 8.8.30 Treatment effects on soil zinc concentration from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. zinc conc. (ppm)	Groups
Anaerobic digestate-1	4.55	a
Anaerobic digestate-2	2.711	a
Control	2.89	a
Paper sludge	1.235	a
Seaweed extract-1	2.75	a
Seaweed extract-2	3.377	a

8.30 Soil composition analysis (Chegoggin Point)

Table 8.30.1 ANOVA: Treatment effects on soil pH from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.2119	12	0.09283	5.479	0.00745**

Table 8.30.2 Treatment effects on soil pH from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.pH	Groups
Anaerobic digestate-1	5.6466	ab
Anaerobic digestate-2	5.778	a
Control	5.0505	b
Paper sludge	5.501	b
Seaweed extract-1	5.501	b
Seaweed extract-2	5.481	b

Table 8.30.3 ANOVA: Treatment effects on soil buffer pH from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of	Deviance	Residual	Residual	F-value	P-value

	freedom		df	deviance		
Treatment	5	0.004561	12	0.01448	0.756	0.598

Table 8.30.4 Treatment effects on soil buffer pH from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.BpH	Groups
Anaerobic digestate-1	7.551	a
Anaerobic digestate-2	7.580	a
Control	7.57	a
Paper sludge	7.53	a
Seaweed extract-1	7.551	a
Seaweed extract-2	7.550	a

Table 8.9.5 ANOVA: Treatment effects on soil organic matter from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.0611	12	0.7967	0.184	0.963

Table 8.9.6 Treatment effects on soil organic matter from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.Organic matter (%)	Groups
Anaerobic digestate-1	5.4166	a
Anaerobic digestate-2	5.3500	a
Control	5.466	a
Paper sludge	5.45	a
Seaweed extract-1	5.316	a
Seaweed extract-2	5.33	a

Table 8.9.7 ANOVA: Treatment effects on soil nitrogen concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.00024	12	0.006867	0.085	0.993

Table 8.9.8 Treatment effects on soil nitrogen concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.Nitrogen conc. (%)	Groups
Anaerobic digestate-1	0.2883	a
Anaerobic digestate-2	0.2883	a

Control	0.29	a
Paper sludge	0.291	a
Seaweed extract-1	0.2883	a
Seaweed extract-2	0.280	a

Table 8.9.9 ANOVA: Treatment effects on soil phosphate concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.03217	12	0.3226	0.2314	0.9414

Table 8.9.10 Treatment effects on soil phosphate concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.Phosphate conc. (kg/ha)	Groups
Anaerobic digestate-1	58.66	a
Anaerobic digestate-2	62.33	a
Control	59.833	a
Paper sludge	60.166	a
Seaweed extract-1	57.166	a
Seaweed extract-2	54.5	a

Table 8.9.11 ANOVA: Treatment effects on soil potash concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.408	12	0.166	5.896	0.005611

Table 8.9.12 Treatment effects on soil potash concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.Potash conc. (kg/ha)	Groups
Anaerobic digestate-1	173	bc
Anaerobic digestate-2	210.5	c
Control	150	ab
Paper sludge	152.3	ab
Seaweed extract-1	130.166	a
Seaweed extract-2	153.166	ab

Table 8.9.13 ANOVA: Treatment effects on soil calcium concentration (kg/ha) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	58567	12	86427	1.626	0.227

Table 8.9.14 Treatment effects on soil calcium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.Calcium conc. (kg/ha)	Groups
Anaerobic digestate-1	1021.833	a
Anaerobic digestate-2	958.33	a
Control	957.16	a
Paper sludge	925.5	a
Seaweed extract-1	868.5	a
Seaweed extract-2	854.16	a

Table 8.9.15 ANOVA: Treatment effects on soil magnesium concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	9912	12	15060	1.58	0.239

Table 8.9.16 Treatment effects on soil magnesium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.magnesium conc. (kg/ha)	Groups
Anaerobic digestate-1	446.5	a
Anaerobic digestate-2	433.0	a
Control	415.0	a
Paper sludge	398.3	a
Seaweed extract-1	386.6	a
Seaweed extract-2	382.83	a

Table 8.9.17 ANOVA: Treatment effects on soil sodium concentration (%) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1526	12	3.435	3.435	0.03708*

Table 8.9.18 Treatment effects on soil sodium concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. sodium conc. (kg/ha)	Groups

Anaerobic digestate-1	258.3	ab
Anaerobic digestate-2	286.3	b
Control	230.3	ab
Paper sludge	236.5	ab
Seaweed extract-1	225.5	a
Seaweed extract-2	220.16	a

Table 8.9.19 ANOVA: Treatment effects on soil sulfur concentration (kg/ha) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	82.46	12	185.17	1.069	0.424

Table 8.9.20 Treatment effects on soil sulfur concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. sulphur conc. (kg/ha)	Groups
Anaerobic digestate-1	47.83	a
Anaerobic digestate-2	44.33	a
Control	49.5	a
Paper sludge	45.66	a
Seaweed extract-1	45	a
Seaweed extract-2	43.166	a

Table 8.9.21 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	29240	12	147971	0.474	0.789

Table 8.9.22 Treatment effects on soil aluminum concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg.aluminum conc. (ppm)	Groups
Anaerobic digestate-1	1149.5	a
Anaerobic digestate-2	1052.83	a
Control	1160.167	a
Paper sludge	1100	a
Seaweed extract-1	1068.667	a
Seaweed extract-2	1078	a

Table 8.9.23 ANOVA: Treatment effects on soil copper concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.5179	12	1.098	1.082	0.4182

Table 8.9.24 Treatment effects on soil copper concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. copper conc. (ppm)	Groups
Anaerobic digestate-1	0.366	a
Anaerobic digestate-2	0.385	a
Control	0.291	a
Paper sludge	0.273	a
Seaweed extract-1	0.378	a
Seaweed extract-2	0.250	a

Table 8.9.25 ANOVA: Treatment effects on soil iron concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.05275	12	0.14747	0.858	0.536

Table 8.9.26 Treatment effects on soil iron concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Anaerobic digestate-1	0.366	a
Anaerobic digestate-2	0.385	a
Control	0.291	a
Paper sludge	0.273	a
Seaweed extract-1	0.378	a
Seaweed extract-2	0.250	a

Table 8.9.27 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.01812	12	0.02441	1.826	0.1822

Table 8.9.28 Treatment effects on soil manganese concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. manganese conc. (ppm)	Groups
Anaerobic digestate-1	463.3	a
Anaerobic digestate-2	427.6	a
Control	460.83	a
Paper sludge	473.3	a
Seaweed extract-1	460.5	a
Seaweed extract-2	463.6	a

Table 8.9.29 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.09988	12	0.5746	0.3942	0.8435

Table 8.9.30 Treatment effects on soil zinc concentration from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. zinc conc. (ppm)	Groups
Anaerobic digestate-1	11.66	a
Anaerobic digestate-2	10.83	a
Control	11.3	a
Paper sludge	13.3	a
Seaweed extract-1	11.166	a
Seaweed extract-2	10.66	a

8.10 Soil heavy metal analysis (Falmouth):

Table 8.11.1 ANOVA: Treatment effects on soil Aluminum from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.03239	18	0.1654	0.6894	0.6378

Table 8.11.2 Treatment effects on soil Aluminum from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc (mg/kg)	Groups
Anaerobic digestate-1	10373.75	a
Anaerobic digestate-2	10078.75	a

Control	10627.5	a
Paper sludge	10876.25	a
Seaweed extract-1	9795.0	a
Seaweed extract-2	9962.5	a

Table 8.10.3 ANOVA: Treatment effects on soil Arsenic from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	19.08	54.25	18	1.266	0.321

Table 8.10.4 Treatment effects on soil Arsenic from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc (mg/kg)	Groups
Anaerobic digestate-1	12.125	a
Anaerobic digestate-2	11.5	a
Control	12.375	a
Paper sludge	11.625	a
Seaweed extract-1	14	a
Seaweed extract-2	11.375	a

Table 8.10.5 ANOVA: Treatment effects on soil Barium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	72.96	18	104.38	2.516	0.0678

Table 8.10.6 Treatment effects on soil Barium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc (mg/kg)	Groups
Anaerobic digestate-1	39	a
Anaerobic digestate-2	39.125	a
Control	40.75	a
Paper sludge	41.87	a
Seaweed extract-1	37.25	a
Seaweed extract-2	37	a

Table 8.10.7 ANOVA: Treatment effects on soil Chromium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	5.052	18	23.688	0.768	0.585

Table 8.10.8 Treatment effects on soil Chromium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc (mg/kg)	Groups
Anaerobic digestate-1	14.125	a
Anaerobic digestate-2	14.625	a
Control	14.875	a
Paper sludge	15.25	a
Seaweed extract-1	14.375	a
Seaweed extract-2	13.875	a

Table 8.10.9 ANOVA: Treatment effects on soil Cobalt from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	9.833	18	16.625	2.129	0.109

Table 8.10.10 Treatment effects on soil Cobalt from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc (mg/kg)	Groups
Anaerobic digestate-1	7.625	a
Anaerobic digestate-2	6.750	a
Control	8.250	a
Paper sludge	7.375	a
Seaweed extract-1	7	a
Seaweed extract-2	6.250	a

Table 8.10.11 ANOVA: Treatment effects on soil Copper from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	14.88	18	249.75	0.214	0.952

Table 8.10.12 Treatment effects on soil Copper from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc (mg/kg)	Groups
Anaerobic digestate-1	11.25	a
Anaerobic digestate-2	10.62	a
Control	12.25	a
Paper sludge	11.87	a
Seaweed extract-1	10.87	a
Seaweed extract-2	9.87	a

Table 8.10.13 ANOVA: Treatment effects on soil Iron from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	5219271	18	20853125	0.901	0.502

Table 8.10.14 Treatment effects on soil Iron from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc (mg/kg)	Groups
Anaerobic digestate-1	15200	a
Anaerobic digestate-2	15225	a
Control	15637	a
Paper sludge	16262.5	a
Seaweed extract-1	15537.5	a
Seaweed extract-2	14750	a

Table 8.10.15 ANOVA: Treatment effects on soil Lead from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	37.04	18	212.26	0.628	0.681

Table 8.10.16 Treatment effects on soil Lead from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc (mg/kg)	Groups
Anaerobic digestate-1	23.1875	a
Anaerobic digestate-2	21.33	a

Control	21.16	a
Paper sludge	20.5	a
Seaweed extract-1	23.8	a
Seaweed extract-2	20.78	a

Table 8.10.17 ANOVA: Treatment effects on soil Lithium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.1958	18	1.385	0.5452	0.7398

Table 8.10.18 Treatment effects on soil Lithium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc (mg/kg)	Groups
Anaerobic digestate-1	17.125	a
Anaerobic digestate-2	15.875	a
Control	19.125	a
Paper sludge	20.5	a
Seaweed extract-1	16.625	a
Seaweed extract-2	16.625	a

Table 8.11.21 ANOVA: Treatment effects on soil Manganese from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	66404	18	410189	0.583	0.713

Table 8.11.22 Treatment effects on soil Manganese from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc (mg/kg)	Groups
Anaerobic digestate-1	626.5	a
Anaerobic digestate-2	673.75	a
Control	712.0	a
Paper sludge	649.625	a
Seaweed extract-1	585.25	a
Seaweed extract-2	554.87	a

Table 8.10.21 ANOVA: Treatment effects on soil Nickel from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	2.25	18	14.38	0.563	0.727

Table 8.10.22 Treatment effects on soil Nickel from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc (mg/kg)	Groups
Anaerobic digestate-1	11	a
Anaerobic digestate-2	11	a
Control	11.125	a
Paper sludge	11.750	a
Seaweed extract-1	11.125	a
Seaweed extract-2	10.750	a

Table 8.10.23 ANOVA: Treatment effects on soil Strontium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	6.375	18	24.75	0.927	0.486

Table 8.10.24 Treatment effects on soil Strontium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Strontium conc (mg/kg)	Groups
Anaerobic digestate-1	7	a
Anaerobic digestate-2	7	a
Control	6.5	a
Paper sludge	7.25	a
Seaweed extract-1	6.25	a
Seaweed extract-2	5.75	a

Table 8.10.25 ANOVA: Treatment effects on soil Uranium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.0289	18	0.1762	0.5942	0.7047

Table 8.10.26 Treatment effects on soil Uranium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Uranium conc (mg/kg)	Groups
Anaerobic digestate-1	0.45	a
Anaerobic digestate-2	0.4375	a
Control	0.45	a
Paper sludge	0.475	a
Seaweed extract-1	0.4375	a
Seaweed extract-2	0.4250	a

Table 8.10.27 ANOVA: Treatment effects on soil Vanadium from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	33.83	18	73.63	1.654	0.197

Table 8.10.28 Treatment effects on soil Vanadium from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Vanadium conc (mg/kg)	Groups
Anaerobic digestate-1	27.62	a
Anaerobic digestate-2	28.25	a
Control	28	a
Paper sludge	29.75	a
Seaweed extract-1	28.37	a
Seaweed extract-2	25.75	a

Table 8.10.27 ANOVA: Treatment effects on soil Zinc from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	14.24	12	225.67	0.151	0.976

Table 8.10.28 Treatment effects on soil Zinc from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc (mg/kg)	Groups
Anaerobic digestate-1	22	a
Anaerobic digestate-2	24.66	a
Control	24.16	a
Paper sludge	24.33	a
Seaweed extract-1	23.5	a
Seaweed extract-2	23.166	a

8.11 Soil heavy metal analysis (Chegoggin Point):

Table 8.10.1 ANOVA: Treatment effects on soil Aluminum from the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	1663257	12	29625083	0.135	0.981

Table 8.10.2 Treatment effects on soil Aluminum from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc (mg/kg)	Groups
Anaerobic digestate-1	7041.66	a
Anaerobic digestate-2	7963.33	a
Control	7856.66	a
Paper sludge	7801.66	a
Seaweed extract-1	7533.33	a
Seaweed extract-2	7545.0	a

Table 8.11.3 ANOVA: Treatment effects on soil Arsenic from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	28.61	12	153.67	0.447	0.808

Table 8.11.4 Treatment effects on soil Arsenic from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc (mg/kg)	Groups
Anaerobic digestate-1	17.66	a
Anaerobic digestate-2	20.66	a
Control	21	a
Paper sludge	21.166	a
Seaweed extract-1	20	a
Seaweed extract-2	18.83	a

Table 8.11.5 ANOVA: Treatment effects on soil Barium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	4.625	12	16	0.694	0.638

Table 8.11.6 Treatment effects on soil Barium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc (mg/kg)	Groups
Anaerobic digestate-1	10.66	a
Anaerobic digestate-2	10.83	a
Control	11.66	a
Paper sludge	11.66	a
Seaweed extract-1	11.33	a
Seaweed extract-2	10.33	a

Table 8.11.7 ANOVA: Treatment effects on soil Chromium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	13.33	12	109.67	0.292	0.908

Table 8.11.8 Treatment effects on soil Chromium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc (mg/kg)	Groups
Anaerobic digestate-1	13	a
Anaerobic digestate-2	14.66	a
Control	15.66	a
Paper sludge	14.33	a
Seaweed extract-1	13.83	a
Seaweed extract-2	13.5	a

Table 8.11.9 ANOVA: Treatment effects on soil Cobalt from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.02932	12	0.5386	0.1373	0.9803

Table 8.11.10 Treatment effects on soil Cobalt from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc (mg/kg)	Groups
Anaerobic digestate-1	2.66	a
Anaerobic digestate-2	3.166	a
Control	3	a
Paper sludge	3.166	a
Seaweed extract-1	2.833	a
Seaweed extract-2	2.66	a

Table 8.11.11 ANOVA: Treatment effects on soil Copper from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	2.90	12	35.33	0.197	0.958

Table 8.11.12 Treatment effects on soil Copper from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc (mg/kg)	Groups
Anaerobic digestate-1	6.33	a
Anaerobic digestate-2	7.66	a
Control	7.166	a
Paper sludge	7	a
Seaweed extract-1	6.83	a
Seaweed extract-2	7.16	a

Table 8.11.13 ANOVA: Treatment effects on soil Iron from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	10029574	12	101898483	0.236	0.939

Table 8.11.14 Treatment effects on soil Iron from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc (mg/kg)	Groups
Anaerobic digestate-1	11895	a
Anaerobic digestate-2	14016.67	a
Control	13926.67	a
Paper sludge	13816.67	a
Seaweed extract-1	13383.33	a
Seaweed extract-2	12863.33	a

Table 8.11.15 ANOVA: Treatment effects on soil Lead from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	3.033	12	10.230	0.712	0.626

Table 8.11.16 Treatment effects on soil Lead from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc (mg/kg)	Groups
Anaerobic digestate-1	7.416	a
Anaerobic digestate-2	7.150	a
Control	8.45	a
Paper sludge	7.916	a
Seaweed extract-1	7.733	a
Seaweed extract-2	7.9	a

Table 8.11.17 ANOVA: Treatment effects on soil Lithium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	16.61	12	98.5	0.405	0.836

Table 8.11.18 Treatment effects on soil Lithium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc (mg/kg)	Groups
Anaerobic digestate-1	12.166	a
Anaerobic digestate-2	15.33	a
Control	14.166	a
Paper sludge	13.833	a
Seaweed extract-1	13.66	a
Seaweed extract-2	13.166	a

Table 8.11.19 ANOVA: Treatment effects on soil Manganese from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	725	12	5765	0.302	0.902

Table 8.11.20 Treatment effects on soil Manganese from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc (mg/kg)	Groups
Anaerobic digestate-1	111.833	a
Anaerobic digestate-2	129.833	a
Control	127.66	a
Paper sludge	126.66	a
Seaweed extract-1	122.5	a
Seaweed extract-2	117.0	a

Table 8.11.21 ANOVA: Treatment effects on soil Nickel from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	10.67	12	71.83	0.356	0.868

Table 8.11.22 Treatment effects on soil Nickel from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc (mg/kg)	Groups
Anaerobic digestate-1	8.66	a
Anaerobic digestate-2	10.66	a
Control	10.83	a
Paper sludge	9.166	a
Seaweed extract-1	9.66	a
Seaweed extract-2	10	a

Table 8.11.23 ANOVA: Treatment effects on soil Strontium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	7.778	12	19.83	0.941	0.489

Table 8.11.24 Treatment effects on soil Strontium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Strontium conc (mg/kg)	Groups
Anaerobic digestate-1	9.33	a
Anaerobic digestate-2	9.166	a
Control	11	a

Paper sludge	10.16	a
Seaweed extract-1	9.83	a
Seaweed extract-2	9.16	a

Table 8.11.25 ANOVA: Treatment effects on soil Uranium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	0.06027	12	0.1217	1.22	0.357

Table 8.11.26 Treatment effects on soil Uranium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Uranium conc (mg/kg)	Groups
Anaerobic digestate-1	0.45	a
Anaerobic digestate-2	0.466	a
Control	0.516	a
Paper sludge	0.516	a
Seaweed extract-1	0.4833	a
Seaweed extract-2	0.450	a

Table 8.11.27 ANOVA: Treatment effects on soil Vanadium from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	15.57	12	114.83	0.325	0.888

Table 8.11.28 Treatment effects on soil Vanadium from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Vanadium conc (mg/kg)	Groups
Anaerobic digestate-1	16.5	a
Anaerobic digestate-2	17.66	a
Control	18.33	a
Paper sludge	19.33	a
Seaweed extract-1	18.66	a
Seaweed extract-2	17.83	a

Table 8.11.27 ANOVA: Treatment effects on soil Zinc from the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	459	18	3696	0.447	0.81

Table 8.11.28 Treatment effects on soil Zinc from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Zinc conc (mg/kg)	Groups
Anaerobic digestate-1	52.25	a
Anaerobic digestate-2	46	a
Control	42.25	a
Paper sludge	44.37	a
Seaweed extract-1	39.375	a
Seaweed extract-2	39.75	a

8.12 Switchgrass yield (2022)

Table 8.12.1 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	5229683	18	2762968	6.814	0.000995 ***

Table 8.12.2 Treatment effects on yield (kg/ha) for switchgrass from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Anaerobic digestate-1	1950.175	ab
Anaerobic digestate-2	1843.65	ab
Control	2065.8	ab
Paper sludge	2664.0	a
Seaweed extract-1	1367.82	b
Seaweed extract-2	1253.325	b

Table 8.12.3 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Chegoggin Point site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value

Treatment	5	9741758	18	6546003	5.358	0.00345 **

Table 8.12.4 Treatment effects on yield (kg/ha) for switchgrass from the Chegoggin Point site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Anaerobic digestate-1	3713	a
Anaerobic digestate-2	3639.475	a
Control	2188.825	b
Paper sludge	4033.500	a
Seaweed extract-1	2875.825	ab
Seaweed extract-2	2803.350	ab

8.13 Miscanthus yield (2022)

Table 8.13.1 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Falmouth site. Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Degrees of freedom	Deviance	Residual df	Residual deviance	F-value	P-value
Treatment	5	397787	18	860626	1.664	0.194

Table 8.13.2 Treatment effects on yield (kg/ha) for switchgrass from the Falmouth site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Anaerobic digestate-1	360.725	a
Anaerobic digestate-2	496.25	a
Control	294.025	a
Paper sludge	684.850	a
Seaweed extract-1	349.050	a
Seaweed extract-2	412.200	a