Purpose-Grown Biomass Crops: Efficient Production and Real-world Verification

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ABSTRACT

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For Nova Scotia, the adoption of green fuels represents an opportunity to transition away from its high emission, coal-based energy system. Namely, a NS bioindustry could be facilitated by its agricultural expertise and abundant marginal land. The objective of this research was to determine whether bioenergy crops could be established on Nova Scotian marginal land. Two sites were created in East Gore, Hants County and Skye Glen, Inverness County. At these sites, four biomass crops (Miscanthus, switchgrass, poplar, willow) were planted and treated with one of three soil amendments (*Ascophyllum nodosum* seaweed extract, paper mill sludge, anaerobic digestate) or a no-additives control. Growth parameters were measured in the following fall/spring. After analyzing these data through ANOVA, it was found that poplar and Miscanthus treated with paper mill sludge possessed higher growth parameters (relative to other tested crops) consistently across sites. Conversely, switchgrass generally had lower yields in comparison.

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1. INTRODUCTION

1.1 Climate Change and Canada

Climate change is considered to be the most serious modern-day crisis, impacting human wellness around the world (Auditors General 2018). Analysis of the Earth's mean surface temperature has revealed an average increase of nearly 1°C over the last century (Bush and Lemmen 2019). The past five years have been the hottest on record, and on a larger scale, the previous three decades have ranked highest in terms of average temperature (Hartmann et al. 2013). In Canada, changes in precipitation patterns may have led to natural disasters such as the 2013 Alberta floods and the 2016 Fort McMurray wildfire. Combined, these events are responsible for losses worth billions of dollars as well as irreversible natural damage (Bush and Lemmen 2019).

The anthropogenic origin of climate change is indisputable, as natural systems are unlikely to reach such extremes alone (Bush and Lemmen 2019). The "greenhouse effect" caused by the heat-trapping ability of manmade emissions, or "greenhouse gases" (e.g. CO_2, N_2O, CH_4), has been cited as the most likely explanation (Bush and Lemmen 2019). Canada, while having one of the world's lowest populations relative to landmass size, is among the highest for greenhouse gas contributions (Government of Canada 2003). To combat this, the Canadian government has agreed to decrease its emissions to 511 megatonnes of carbon equivalent over the next decade through the Paris Agreement, relative to its 2005 level of 730 Mt CO_2 eq (Environment and Climate Change Canada 2021). Despite this, an average of 720 Mt CO_2 eq was generated annually over the past decade (Government of Canada 2020) because of Canada's dependency on fossil fuels, with over 85% of all primary energy coming from these resources (Natural Resources

Canada 2016). Therefore, to see meaningful reductions in greenhouse gas emissions, this problem needs to be addressed at its source by developing greener alternatives to fossil fuels.

1.2 Biofuels

When once-living matter (biomass) is chemically transformed into energetic compounds in solid, liquid, or gaseous states, biofuels are created (Rodionova et al. 2017). Plants are the preferred source of biomass due to their unique method of obtaining energy (Rodionova et al. 2017) – using energy from the sun to convert atmospheric carbon dioxide into sugars through photosynthesis (Voloshin et al. 2015). The energy stored within biofuels can be used by burning the fuel itself, such as with wood pellets (primary biofuels), or can be fed into a combustion engine like a conventional fuel (secondary biofuels) (Rodionova et al. 2017). Secondary biofuel crops contain two "generations", the first comprised of high sugar and/or starchy food crops (corn, sugarcane), and the second associated with cellulosic, non-food crops (poplar, switchgrass) (Rodionova et al. 2017).

First-generation (or "first-gen") biofuel crops have been largely favoured over second-generation ("second-gen") biofuel crops, though their adoption is not without complications (Scaife et al. 2015). The use of first-generation biofuel crops could impede food supply and impact the economy, as farmers elect to sell their crops for biofuels rather than food as it is more lucrative (the "food versus fuel" debate) (Scaife et al. 2015). Another detriment of first-gen biofuels is that their overall savings in greenhouse gas emissions compared to traditional fossil fuels is limited when considering factors of large-scale production (Havlík et al. 2011). First-gen crops leave a high carbon footprint due to the need for intensive machine applications of fertilizers and water (Scaife et al. 2015).

Contrasting the first generation, second-gen biofuel crops avoid these issues while providing additional benefits to the land they are established on. Second-gen biofuel crops can be grown on soils too poor in nutrients or composition for first-gen crops (Robertson et al. 2017), circumventing the food versus fuel debate (Scaife et al. 2015). Second-gen crops can also have lower requirements for fertilizers (Ruan et al. 2016) and water (Robertson et al. 2017), decreasing the risk of environmental damage through leaching and lowering the need for emission-intensive, vehicle-assisted fieldwork. A reduction in the amount of fertilizer that is applied through these lowered nutrient requirements can likely reduce GHG production as well. For instance, nitrous oxide (N_2O) contributes to global warming to an extent that is over 250 times greater than CO_2 and can be produced through high application rates of nitrogen fertilizers (Xu et al. 2019).

Second generation crops can be converted into many different types of products depending on the method of conversion, such as pyrolysis, gasification, and liquefaction (Fokaides & Christoforou 2016). However, biofuels that are compatible with traditional engines (usually through fossil fuel mixtures such as "gasohol") are extremely relevant in a Canadian context as transportation is a major contributor of greenhouse gases (Islam et al. 2004). Per unit of distance travelled, the use of cellulosic ethanol is predicted to lower the amount of greenhouse gases produced by up to 85% relative to gasoline, though this hypothetical reduction relies on high expected ethanol yields and how the conversion technology is implemented (i.e., utilizing lignin by-products to power ethanol plants) (Schubert 2006). Bioethanol is currently the top biofuel being produced in Canada (Scaife et al. 2015), theoretically satisfying up to 50% of Canada's fuel needs in 2006 through a maximum-efficiency system (Mabee and Saddler 2010). There are already policies in place to guarantee the addition of ethanol to gasoline to reduce greenhouse gases, with most gasses in Canada including at least 5% ethanol (Wolinetz et al. 2019). Biofuel production in Canada has remained relatively stable over time, exemplified by only a one percent increase in ethanol manufacturing (~1,700 million litres) reported by FAS/Ottawa from 2016 to 2017 (Danielson 2017), even though nationwide use of ethanol (litres consumed) has nearly doubled within the last decade (2010-2017) (Wolinetz et al. 2019).

Even with its facilities operating close to maximum efficiency, Canada has been unable to produce ethanol at a volume that would facilitate international trade (Danielson 2017). As a result, nearly half of all ethanol consumed is imported from the United States (Danielson 2017). That is not to say that there is no expansion in this field, as work is being done across Canada to increase its biofuel production capacity, such as the $120 million extensions added to Ontario's IGPC ethanol facility in 2017 (Danielson 2017). However, one region that has seen little activity regarding the biofuel industry is Nova Scotia. While few studies exist that assess Nova Scotia's potential as a biofuel-producing region, current information seems promising. With increasing demands for biofuel nationwide, high profit margins, experience from other provinces, and ample natural resources, Nova Scotia could have the capacity to soon develop a formidable biofuel industry (Atlantic Council for Bioenergy Cooperative 2013).

1.3 Objective

The implementation of second-generation biofuels in Canada not only presents an opportunity for economic growth, but for decreasing the impacts of greenhouse gases. This is especially relevant to the province of Nova Scotia, where coal accounts for nearly 50% of annual electricity generated and is its greatest contributor of emissions (Nova Scotia Power Inc. 2019; Canada Energy Regulator 2020). Therefore, the long-term goal of this project is to determine whether energy crops grown in Nova Scotia can produce significant yields. Our objectives over the short term (i.e. this research paper) is to determine whether certain second-generation biomass crops (poplar, willow, Miscanthus, and switchgrass) can be established on two different marginal sites in Nova Scotia, and whether soil amendments can significantly impact crop establishment. The effects of three soil amendments on crop growth, including seaweed extract, wood fibre residue, and anaerobic digestate will therefore be tested. We hypothesize that plant establishment and yield on these marginal lands in Nova Scotia will differ based on: (i) crop type; (ii) location (i.e. land characteristics and meteorological factors); and (iii) soil amendments (i.e. a seaweed extract, anaerobic digestate, and a paper mill sludge). The results of this research will help identify efficient methods for establishing these crops in Nova Scotia, which will contribute towards lowering the investment risk for the producers and users of these crops. Reducing these uncertainties will further support the utilization of second-generation biofuels in Nova Scotia, along with the economic and environmental benefits they could provide.

2. LITERATURE REVIEW

2.1 Energy in Nova Scotia

The standards of Nova Scotia's energy system remains in the early 20^{th} century, with almost two-thirds of the Province's electricity coming from non-renewable sources (Nova Scotia Power Inc. 2019). Specifically, coal has persisted in Nova Scotia's energy system since the 1970s (Nova Scotia Department of Energy 2015), its use accounting for nearly 50% of electricity generated in 2019 (Nova Scotia Power Inc. 2019). The practicality of maintaining these systems is also dependent on the global price of coal, which has repeatedly fluctuated over the past decade (Natural Resources Canada 2021). On top of economic concerns, there is also the environmental impact of burning coal. Generating nearly 45% of all greenhouse gases (GHGs) in the province, the coal-based energy sector is one of Nova Scotia's greatest contributors to climate change (Canada Energy Regulator 2020).

The distribution of energy use in Nova Scotia is biased towards coal, petroleum, and oil, with only a 30% share in domestic renewable energy (Nova Scotia Power Inc. 2019). Tidal energy is one instance where Nova Scotia is expected to prosper, being almost completely encompassed by the Atlantic Ocean (Nova Scotia Department of Energy 2012). The potential for this industry is exemplified by the Bay of Fundy, which displaces water in volumes of over 160 billion tonnes, four times greater than all freshwater rivers worldwide (Nova Scotia Department of Energy 2012). Solar energy has also received considerable support within the Province through incentivizing strategies such as the Enhanced Net Metering policy (Dunsky Energy Consulting 2019). This allowed surplus renewable energy to be sold back to electricity utilities by individuals in domestic and commercial sectors (Dunsky Energy Consulting 2019). The amount of renewable energy produced from hydroelectric, wind, or biofuel sources varies yearly from factors like price (e.g. bioenergy), availability (e.g. wind), or governmental restrictions (Nova Scotia Department of Energy 2015).

In terms of limiting the production of greenhouse gases, Nova Scotia has been relatively proactive in establishing reduction targets. For example, the Province has complied to lower its energy sector related GHG output to a level 40% less than it was in 2007 (10.15 million tonnes of CO_2 equivalent) by 2030 through an agreement overseen by the federal government (Abreu 2013). Among the three major sources of renewable energy in Nova Scotia that could help reach this target (wind, hydro, and biomass), biomass ranks the lowest (Nova Scotia Power Inc. 2019). Biomass produced only 1% of annual energy in 2019 (Nova Scotia Power Inc. 2019), enough to power roughly 7,500 homes (Nova Scotia Power Inc. 2012). To better understand the potential of biomass use in Nova Scotia, similarly sized regions can be used as reference. Despite its forest cover being drastically less than in Nova Scotia (11% vs. 75%) Denmark has incorporated biomass into roughly 70% of its total renewable energy produced (Danish Energy Agency 2012; Department of Natural Resources 2016). Within Canada, Ontario produced over 500 times the bioenergy that Nova Scotia produced in 2011 (Macgregor et al. 2014).

Globally, current biofuel industries focus on first-generation (or “first-gen”) biofuels (e.g. fuels made from high lipid, sugar, and/or starchy food crops). However, as the technology surrounding second-gen biofuels improves, increased support of this resource will likely occur. For Nova Scotia, its lack of development could be beneficial as it could facilitate the direct implementation of second-gen biofuel infrastructure (ACBC 2013).

According to an assessment done by the Atlantic Council for Bioenergy Cooperative (2013), there has been limited research into a Nova Scotian biofuel industry despite its potential for reducing provincial greenhouse gasses while being monetarily lucrative (e.g. exportation to the United States). From what has been compiled, Nova Scotia has abundant natural, technical, and information resources, and experience in agriculture. These factors could facilitate bioeconomic development, with investments expected to follow once infrastructure is created. However, Nova Scotia’s inexperience in this sector and repeated failures to match the pace of other provinces may dissuade stakeholders. Additionally, there have been few large-scale producers of biofuel established in the Province within the last decade.

2.2 Marginal land

The use of biomass-based energy is expected to undergo significant growth – a near 40% expansion in its use is likely to occur in the next decade (Nakada et al. 2014). Within Canada, this translates to annual ethanol production of around 82 million barrels (Li et al. 2012). Though an abundance of associated energy crops may mitigate emissions through carbon sequestration, there have been rising concerns of environmental harm accompanying this growth. The monetary incentive for using first-gen energy crops for energy production may be higher than that for food (Liu et al. 2017). This could create an artificial "scarcity" on edible crops, translating to higher prices for consumers (Liu et al. 2017). This "food versus fuel" conflict could soon worsen, as it has been predicted that the required space for cultivating energy crops will equal that needed for food crops (Berndes et al. 2003). To counteract these impacts, the use of marginal land for growing energy crops has been increasingly considered in the biofuel sector (Liu et al. 2017).

The most common method of summarizing the agricultural potential of a given region is by implementing the land suitability rating system. A numeric scale determines soil class, from 1 (viable), to 7 (unviable). Land considered "marginal" has a middling score, encompassing soil with a rating from 3 to 4 (Agronomic Interpretation Working Group 1995). The composition of marginal land renders it nonviable for growing food crops due to environmental factors such as poor soil quality, land geometry, or climatic conditions (Aylott et al. 2010; Gelfand et al. 2013). However, the non-food crops used in second-gen biofuels have traits which make them suitable for use on such soils, such as reduced nutritional requirements (Aylott et al. 2010; Gelfand et al. 2013). For Canadian marginal land, it's been calculated that nearly 10 million hectares could be suitable for growing second-gen feedstocks (Liu et al. 2017), with over 400,000 hectares of marginal land (Canadian Land Inventory class 4) in Nova Scotia (Devanney 2010).

A primary concern when establishing any crop is the nutrition of the surrounding soil. This is especially true for energy crops as their final yield is dependent on plant health, which in turn influences the amount of biofuel that can be extracted (Hangs et al. 2014). The overall nutrition of marginal land is determined by anthropogenic and natural factors. For example, rain, dust, and decomposing biomass act to raise or lower the nutrition of the soil (Reynolds et al. 2001; Schroth et al. 2001; Liu et al. 2002). The amount of available nutrients can also vary based on the surrounding plants – woody and herbaceous plants produce differing amounts of leaf litter and provide essential plant nutrients in varying proportions (Holou et al. 2013; Amichev et al. 2014). In an agricultural context, the repeated harvesting of biomass feedstocks from one area can have a significant impact on soil nutrition as well, which can negatively impact future yields (Ge et al. 2015). Information regarding the dynamics of these nutrient inputs on marginal land has been lacking across Canada, not just in Nova Scotia, and have implications for the long-term viability of perennial biomass crops. As such, research conducted by Ashiq et al. (2018) assessed these factors by growing switchgrass and poplar cultivars in three marginal sites across Canada (including one in Nova Scotia) for two years. Researchers found significant differences in yield between crops, consistent with previous experiments carried out on marginal land. It was demonstrated that the amount of nutrients left in these agricultural systems would be insufficient for sustainability, with fertilization required to support further harvesting. The amount of essential nutrients that remained in the soil was dependent on the type of poplar that was planted, with increased uptake creating higher end yields. This implies that the choice of energy crop used for marginal soil must be carefully considered, the selection depending on whether the grower desires a short-term high yield or a long-term sustained yield. Switchgrass was reported to be a suitable choice overall due to its low nutrient requirements.

2.3 Crop selection and favourable plant traits

When cultivating on marginal land it is important to consider that there is no singular crop that excels in every environment (Robertson et al. 2017). Crop selection is a balance of different benefits and trade-offs; for instance, an introduced cultivar may perform well, but negatively impact the local biodiversity where it is planted (Robertson et al. 2017). Plant characteristics desirable for marginal land can include their physiological needs (e.g. nutrient requirements) and final yield. Crops commonly used on marginal land usually have low nitrogen needs, allowing for production using minimal fertilizers, only as much as what was lost during the previous harvest (Davis et al. 2015). Compared to a first-gen feedstock (maize), Smith et. al (2013) demonstrated that the amount of soil nitrogen lost was significantly lower when growing switchgrass or Miscanthus cultivars. Energy feedstocks can also beneficially have evapotranspiration equivalent to rainfall, maintaining the natural water balance of their surroundings (Robertson et al. 2017).

While choosing the most productive biomass feedstocks is advantageous for maximizing biofuel production, there are other benefits of high-yielding plants. For example, poorly managed harvesting strategies can degrade agricultural systems by introducing erosion and decreased soil organic matter through the removal of residues (Kludze et al. 2013). Many regions in Nova Scotia that could be suitable for agriculture (such as vineyards) are characterized by low soil organic matter, exacerbating this issue (Messiga et al. 2015). A study by Sharifi et al. (2019), however, showed that certain biomass crops (e.g. switchgrass) could be established to mitigate this issue. Plant tissues contain nutrients that are vital for growth, which are returned to the soil through residues. In their absence, negative impacts on future yields can develop (Kludze et al. 2013). The extent of land degradation is site-specific, dependent on climate, soil composition, terrain geometry, and other natural factors (Blanco-Canqui 2010). While these factors can be addressed through strategic biomass collection, crop selection also plays a role in mitigating the side-effects of harvesting. The amount of above- and belowground biomass left after harvesting depends on the yield of the feedstock (Kludze et al. 2013). Therefore, a high-yield crop with a continuous presence in the site (e.g. perennial plants) would be preferential to maintain acceptable soil quality. High yields can also indicate that the energy crop is competitive, such as with the wheat-rye hybrid triticale (Beres et al. 2010; Goyal et al. 2011). This can beneficially increase the chances of successful establishment by allowing the crop to combat weed pressure (Beres et al. 2010). However, it is also important to consider the possibility of over-competition and its impacts on surrounding plant life, especially if the introduced feedstock is not native to the area (Barney and Ditomaso 2008; Simerloff 2008).

At the most rudimentary level, an energy crop should be compatible with the environment it is established on. Sugarcane, for example, produces favorably high yields (Głowacka et al. 2015) and is used extensively in Brazil to produce bioethanol for transportation (MAPA 2018). However, its survival is limited to low-altitude regions with temperatures consistently above 10°C, geographically restricting its cultivation (Allison et al. 2007). To circumvent this issue, plant scientists have developed hybridizations that expand the low-temperature tolerance of sugarcane, usually with the cold-resistant (and genetically similar) Miscanthus grasses. In an experiment by Kar et al. (2019), several crossbreeds of sugarcane and Miscanthus were grown in temperate Japan. Due to the novelty of their research, they were unable to definitively conclude the potential viability of the hybrids in winter conditions. Nevertheless, their research yielded a (possibly) cold-adapted hybridization with high photosynthetic performance, robust dimensions (i.e. leaf/stem size), and final yields unheard of from any prior Miscanthus/sugarcane crossbreed.

By examining trends in hybridization for agriculture, traits that are deemed desirable for energy crop production can be identified. For example, *Miscanthus sinensis* A. is a popular subject for hybridization as it allows for increased leaf longevity without interfering with shoot or root growth (Clifton-Brown 2000). Hybridization can also result in plants with larger leaves and taller, thicker stems (Głowacka et al. 2010a, b). The use of hybrids in agriculture can help garner support for novel crop types by making them more appealing to their potential users (Glowacka 2011). These factors, however, will vary depending on how the feedstocks are utilized. For direct combustion, hybrids that maximize yield (Glowacka 2011) and mineral content (which influences combustion) will be preferred (Nunes et al. 2016). In the future, bioethanol crops may be hybridized to increase yield and modify the cell wall, maximizing cellulose content or granting easier access to biomolecules by changing lignin composition (Glowacka 2011).

The cost of producing energy crops must be kept in check as not to offset the profits made from biofuels. This is an important consideration for establishing a Nova Scotian bioindustry, as monetary incentives will likely help convince farmers to contribute their resources for the development of this sector. However, some expenses can have marked effects on final yields, such as soil amendments stimulating cell division (Zhao et al. 2005). Sorghum growth, for instance, is influenced by soil nitrogen amount. Too little nitrogen lowers stored chlorophyll, retarding photosynthesis and leading to underdeveloped leaves (Zhao et al. 2005). Inversely, overuse of fertilizers can lead to environmental side-effects, such as the eutrophication of water bodies by nitrogen leached from agricultural sites (Ramu et al. 2012).

The amount of resources needed for a satisfactory product is crop-dependent (Smith and Buxton 1993), with a plant's ability to absorb nutrients and convert them into biomass being known as physiological use efficiency (Good et al. 2004). Feedstocks that are particularly efficient at utilizing macronutrients (e.g. N, P, K) are highly desirable for cultivation on marginal lands. Understanding the optimal amount of field fertilizers added relative to a crop's physiological use efficiency is crucial for ensuring high yields and low production costs (Ameen et al. 2016). Another benefit of low nutrient requirements is to preserve the symbioses between plants and belowground microbes (bacteria and fungi). Feedstocks such as switchgrass benefit from the presence of soil microbes that make nutrients more accessible, especially on marginal land where these resources can be scarce (Revillini et al. 2019). Plant performance and nutrient cycling are highly influenced by soil microbes, ultimately affecting final yield (Bakker et al. 2018).

In terms of life cycle, crops which persist for over one year (perennial crops) are favourable for biomass production over those that do not (annual crops) due to several reasons. Perennial crops can provide greater reductions in carbon emissions through sequestration due to their longer lifespans (West & Post 2002), can produce relatively lower amounts of nitrous oxide pollutants (Robertson et al. 2000), and, without soil amendments, offer comparable yields to annuals grown under high N fertilization (Robertson et al. 2017). Because perennials do not require complete harvesting and reestablishment every year, the cost of fertilization and site maintenance is also reduced (Robertson et al. 2017).

Relative to annual crops, perennials are more efficient at utilizing nitrogen for several reasons. Due to their presence early in the spring and winter, feedstocks are afforded extra time to absorb soil nitrogen (Robertson et al. 2017). This also enhances the crop's conversion efficiency of sunlight due to having more time available for photosynthesis (Roozeboom et al. 2018). The lower frequency of anthropogenic disruption prevents nitrogen loss during harvesting (West & Post 2002). This is also due to the type of plant material being collected – annual seeds rich in starch or oils also contain large amounts of nitrogen, whereas perennial biomass (e.g. plant tissue, wood) has a comparatively lower N content (Robertson et al. 2017). Depending on the time of year, perennial crops can also be harvested at a point where most plant nitrogen has been relocated to the roots, further reducing losses (Jach-Smith and Jackson 2015).

The hardy root system created by perennials allows them to persist in areas vulnerable to erosion and are often better suited to drier or nutrient-poor environments (Gelfand et al. 2013). It also helps to prevent the erosion of topsoil and mitigate water runoff. Emission savings by these crops relies on a balance of carbon production and storage, with the carbon-storing ability of the newly established feedstocks needing to exceed that of pre-existing vegetation (Gelfand et al. 2011). Miscanthus, for example, is a popular perennial feedstock that's been reported to sequester 92 tonnes of carbon per hectare over a nine-year period (Hansen et al. 2004).

2.4 Miscanthus

Perennial feedstocks, especially those of grasses, are notable for their volume. The warm-season hybrid *Miscanthus* x *giganteus* cultivated in the United States can produce an average yield of 14,000-40,000 kg/ha annually (Mcgowan et al. 2019). In a comparative growth experiment that included sorghum, perennial grasses (Miscanthus, switchgrass), and corn in Kansas, sweet sorghum consistently generated more biomass and had higher potential ethanol yield relative to corn and the perennial grasses over the 11-year long study. However, while Miscanthus underperformed in terms of yield and possible ethanol content relative to annual crops in the beginning, it gradually became more comparable. This allowed for similar biomass outputs while maintaining lower fertilization requirements (Roozeboom et al. 2018).

Compared to prairie tallgrasses such as switchgrass, Miscanthus has demonstrated superior yields through experimentation in Canada, the United States, France and Italy (Ercoli et al. 1999; Clifton-Brown et al. 2004; Heaton et al. 2008; Tubeileh et al. 2014; Tubeileh et al. 2015). As is the case with most second-gen feedstocks, these yields can significantly differ between sites through variations in genetics (Tubeileh et al. 2015) and environmental conditions (temperature, precipitation, etc.) (Richter et al. 2008). After a 3-5-year long period of cultivation following establishment, the productivity of a Miscanthus plantation typically culminates as rhizomes are dispersed to their maximum extent (Miguez et al. 2008). During growth, the hybrid *Miscanthus x giganteus* produces broad leaves that can retain leaf chlorophyll for an extended period before senescence (staygreen trait), increasing its exposure to light (and therefore its photosynthetic potential) to a greater extent than that of switchgrass (Tubeileh et al. 2016). In a direct comparison, *M. x giganteus* has over twice the solar conversion efficiency of switchgrass, at 2% and 0.9%, respectively (Dohleman et al. 2012). Miscanthus can maintain its photosynthetic rate under low soil nitrogen conditions (Tubeileh et al. 2016). It has also been reported that relatively high treatments of nitrogen (200 kilograms per hectare) can enhance this ability, while lower applications (100 kg/h) do not, relative to other Miscanthus species (Beale et al. 1996).

Relative to other cellulosic crops, the dry weight composition of Miscanthus is made up of less ash content and has lower moisture (Lewandowski and Kicherer 1997). This is beneficial for thermochemical conversion processes that are otherwise impeded by the presence of feedstock moisture (Tubeileh et al. 2016). When averaged across yields from different parts of the world, and at different times (fall and winter harvest) the cellulose content (the compound used to create biofuels) of *M. x giganteus* is the highest amongst commercial Miscanthus cultivars (Lee and Kuan 2015). Arundale et al. (2015) documented how growing *M. x giganteus* clones under different environmental conditions (amount of N fertilizer applied, soil quality, etc.) in Illinois had little effect on the cellulose, hemicellulose, and lignin content of its harvested biomass, differing no more than 6%. While yield quantity was impacted by environmental conditions, this experiment emphasized the importance of Miscanthus genetics on biomass quality. With concerns of maximizing the land-use efficiency of energy crops on marginal soils, there are few plant families better suited for occupying these areas than grasses, including Miscanthus and switchgrass cultivars.

2.5 Switchgrass

The warm season switchgrass (*Panicum virgatum* L.) is particularly well-adapted to growing under poor environmental conditions, such as those found in marginal areas (Ameen et al. 2019). This is due in part to its root system, which works to elevate soil quality by increasing the amount of organic carbon in the soil (Bonin et al. 2012). The roots accomplish this by decomposing previous root matter and producing exudates (Bonin et al. 2012). Because of this versatility, switchgrass has been the subject of numerous studies assessing its performance both as a feedstock and an ecological aid on acidic, dry, and eroded soils such as those found within urbanized areas, mining sites, and underused farmland (Blanco-Canqui 2016). Additionally, these root systems have the capacity to diminish the amount of nitrate leeching from fertilization by 50 kg/ha on average (Brandes et al. 2017).

The quantity and quality of switchgrass yield is seasonally variable. In terms of highest potential yield, harvesting late into the summer results in maximal biomass content overall, though this also increases its ash content to the point of being unusable for biofuels (Wilson et al 2012). Feedstock composition optimal for biofuels occurs late in the fall, and numerous studies have shown that switchgrass harvested in the spring suffers from comparatively lower yields, such as a decrease of ~25% in Quebec (Goel et al. 2000) and a near 40% reduction in Iowa from November to April (Wilson et al. 2012). The annual amount of harvested switchgrass can vary from several to over twelve thousand kilograms of dry matter per hectare, influenced by factors like the environment, age of the feedstock, and agricultural techniques used. In certain situations, yields can even reach up to 20 or 30 thousand kg/ha/y (Gunderson et al. 2008; Smeets et al. 2009; Hattori and Morita 2010).

As is the case with many perennial feedstocks, the nutritional requirements of switchgrass are minimal, and it can function sufficiently on soils with saline, alkaline, or acidic properties (Evanylo et al. 2005; Quinn et al. 2015). Therefore, the volume of chemical fertilizers applied relative to existing soil macronutrients is given greater importance due to the efficient metabolization of switchgrass (Brodowska et al. 2018). For example, the response of switchgrass to the addition of phosphorous is positive when initial soil phosphorous is low (Brodowska et al. 2018). Additionally, fertilizers containing a combination of macronutrients (N, P, K) may enhance switchgrass growth further. In experiments by Mohammed et al. (2015) and Ameen et al. (2018), the former researcher found switchgrass treated with an N, P, K fertilizer had yields that were nearly 50% greater than the control, with the highest yields reported by the latter researcher being the result of applying all three major macronutrients together rather than in combinations of two (e.g. N and K). With these needs in mind, sustainable harvesting would likely involve the retention of some biomass onsite, minimizing the amount of soil nutrients lost and maintaining suitable yields over time (Goel et al. 2000).

The harvest rate of switchgrass can be flexible based on the needs of the producers, as it can be collected altogether once the growing season is complete or at multiple points throughout (Brodowska et al. 2018). However, harvesting multiple times in one year can generate greater overall costs through the repeated fertilization as well as the cost of collecting and transporting biomass (Christensen and Koppenjan 2010). Additionally, the ability for switchgrass to overwinter may be impaired due to the decreased amount of nutrients for root allocation at the end of the growing season (Mitchell and Schmer 2012). Switchgrass varieties can be selected for the production of specific types of bioenergy based on their composition at harvest. Compositional analysis by Min et al. (2017) revealed that the biomass of genotype SWG 2007-2 had lower lignin concentration while also containing a large quantity of carbohydrates, making it an ideal feedstock for sugar-based biofuels. Similarly, the greater overall amount of carbohydrates, starch, and cellulose relative to hemicellulose in the stems of switchgrass make it a potential resource for liquid biofuels. As cellulose is also a prominent component of wood tissue, tree genera such as poplar and willow represent another potential source of these organic compounds.

2.6 Poplar

Although tree species may not be thought of as a typical energy crop, they are considered to be among the best lignocellulose resources for biofuel production (Dou et al. 2019). To satisfy yield demands poplar can be crossbred to create hybrids that develop and accumulate biomass quickly, such as NM6 (an interspecific cross between *Populus nigra* and *Populus maximowiczii*) (Labrecque and Teodorescu 2005). This modified growth rate is also beneficial for the environment, as plantations can more quickly reach the stage at which remediation and ecosystem services are provided (Perry et al 2001; Fortier et al 2010). While the majority of Canadian land can support the growth of hybrid poplar (Liu et al. 2017), the performance of this feedstock is still heavily influenced by the environment, through elevation, fertility, accessibility of water, and many other factors (Tabbush and Beaton 1998; Coleman et al. 2006; Bergante et al. 2010; Truax et al. 2012). Fortunately, potentially harmful environmental effects can be lessened by selecting an appropriate hybrid (after assessing trade-offs). For example, while NM6 is among the quickest developing hybrids, it has difficulty growing in soil with a pH above 7.5 (Pearson et al. 2010). In a nearly fifteen year long agricultural experiment, Truax et al. (2014) discovered that the most productive land for cultivating poplar in Quebec was fertile, low-lying, post-farmland areas. Additionally, differences in the performance of poplar clones were pronounced across different regions, demonstrating the limits of hybrid traits.

In terms of yield, short-rotation poplar can produce 9,000 to 13,000 kg/ha each year on average (Laureysens et al. 2004; Dillen et al 2013). The logistics of supplying biorefineries with a constant supply of wood biomass may be questionable given lignocellulose’s low energy density (Richard 2010). However, the “coppice” method has been developed to allow these crops to generate significantly more wood biomass than normal. By scaling back the stems of a developing woody crop cutting, stem regrowth becomes robust and dense, its morphology resembling that of a shrub. Though created with the intention of facilitating higher wood yields for direct combustion, this method, when combined with extensive, large scale plantations (2,000-20,000 plants per hectare), allows for utilization of land to its fullest extent to produce lignocellulosic biomass over a 2- or 3-year cycle (Dou et al. 2019). Machine harvesting of poplar is expedited by its smaller stems, resulting in residues of wood, bark, and branch fragments that can compete with other well-established energy crops (Santangelo et al. 2015; Dou et al. 2017). The use of this feedstock for bioenergy can result in high economic returns, with harvesting costs of only $60 per tonne in certain North American regions (Dou et al. 2017).

Outside of growth characteristics, the composition of poplar has been found to be beneficial for biofuel production. Its ash content can be highly dissimilar between poplar species, from 0.6 to nearly 3 percent (Sannigrahi et al 2010). However, this is minimal compared to feedstocks like stover and switchgrass (Brown and Brown 2014). Experimental assessments of hybrid poplar's biomass content have determined that cellulose can account for up to almost 50% of dry weight, as with NM6 (48.95%) (Sannigrahi et al. 2010). The potential of this hybrid was similarly shown in Zamora et al. (2013), as though the cellulose content of NM6 grown for 13 years in Minnesota was comparable to other clones (D105 and DN34; ~39% of dry matter), the combined amount of biomass produced (11,460 kg/ha) was significantly higher.

2.7 Willow

Another woody crop that has been extensively studied in the context of biofuels are willow trees, especially in northeastern North America, where it has been used as an experimental subject for over two decades around the New York area (Kopp et al. 2001). Tests have shown that this region (Northeastern America) is particularly well suited for growing willow due to its climatic and soil characteristics (Kopp et al. 2001). Some aspects that make willow an appealing option for biofuels include its biomass characteristics, which is akin to typical wood sources that take longer to establish (willow can be harvested every 3-4 years) (Volk and Harlow 2014). Willow's genetics also offers great potential for hybridization due to how easily it can be crossbred and its high degree of genetic variation (Volk and Harlow 2014). For example, commercial cultivars of the Japanese willow *Salix miyabeana*, such as 'SX61', 'SX64', and 'SX67', are used for their high yields and cellulose content (Ray et al. 2012). Moving forward, future hybrids can be expected to generate yields that are up to 40% greater than what is currently produced (Serapiglia et al. 2012).

At planting, 13,500 willow cuttings per hectare is typical (Volk et al. 2016). After the first harvest, producers can expect their willow plantation to last for seven or more harvests, each typically yielding 8,000 to 12,000 kg/ha of dry biomass per year (Volk et al. 2016). Brereton et al. (2016) performed a comparative growth analysis of *Salix* cultivars in Quebec which demonstrated a wide variation in the amount of phenolic by-products extracted from its biomass. The greatest of these yields came from the *S. miyabeana* 'SX67', which generated almost 6 kg/ha of phenolics. These results present a potential revenue stream for willow that could run parallel to its use as a cellulosic biofuel feedstock.

In turn, this could increase the profitability of cultivating willow by further offsetting the price of establishment and harvesting. Currently, these costs are among the biggest impediments to the widespread adoption of willow as a feedstock, and extensive research has been done to minimize them (Volk et al. 2016).

As woody feedstocks are managed using a coppice system, cultivars that can produce high numbers of advantageous buds will be the preferred choice for maximizing yield (Karp et al. 2011). Following this logic, a cultivar such as *S. amygdaloides* would be a comparatively less appealing option than *S. viminalis*, as a stem of the former will have only half as many buds as the latter (Karp et al. 2011). An advantage of the coppice system is that it can produce higher yields over time, as the portion of the tree that remains after cutting will become increasingly denser with each rotation (Karp et al. 2011). This extends to the root system, as larger willows will sequester more resources to their roots to be later used during spring regrowth (Verwijst 1996). The characteristic increase in plant growth hormones and the rapid growth of willow stems during regrowth creates a dense leaf system with sizable leaves, benefiting growth and eventual yield (Sennerby-Forsse and Zsuffa 1995). Classifying the canopy structure and leaf area optimal for willow development is made somewhat difficult due to variations between cultivars (Karp et al. 2011). For example, an experiment by Weih and Ronnberg-Wastljung (2007) found the cultivar Tora (*S. viminalis* × *S. schwerinii*) generated comparatively greater yields than *S. viminalis* despite the former having a smaller leaf area index and sparser canopy cover.

Overall, the composition of willow biomass is better suited for thermochemical processes such as gasification and pyrolysis rather than as a resource for biochemical methods (Karp et al. 2011). This is due to willow containing more lignin and ash, less cellulose/hemicellulose, and a greater energy value when compared to herbaceous feedstocks such as wheat straw or Miscanthus (Karp and Shield 2008). An experiment by Adler et al. (2006) showed that the quality of their willow biomass for combustion (low concentration of N, P, and K) was strongly determined by fertilizer type (mineral/sludge/ash), site layout, and the age of the feedstock. The wastewater sludge and wood ash combination used in their assessment was able to produce willow yields similar to that of mineral fertilizers, though it had higher phosphorous and potassium content.

Soil amendments, such as the aforementioned sludge, can improve the economic feasibility of cultivating feedstocks on marginal land by using a low-input design (Terres et al. 2008). Low-input agriculture usually refers to methods which minimize the amount of field additives (e.g. fertilizers, pesticides) used for crop production (Fess et al. 2014). Through this method, the investment and environmental risks associated establishing feedstocks are reduced (Terres et al. 2008). As plant productivity on marginal soils is markedly decreased in terms of yield and quality (compared to agricultural soils), the need for such soil amendments is emphasized.

2.8 Paper mill sludge

To lessen the adverse conditions typical of marginal land, soil amendments can be introduced. However, these treatments must be economical for the final biofuel product to be profitable. Utilizing waste products for these purposes is therefore logical due to their abundance and low value. As one of the greatest industrial sources of wastewater and sludge in the world (Ashrafi et al. 2015), the production of paper persistently demands an end use for its waste material. This issue is exasperated by the volume of its output, creating nearly half a ton of waste for each ton of paper made (Toczyłowska-Mamińska 2017). The removal of wastewater can be done through combination with paper mill sludge (Stoica et al. 2009), making its composition high in water (≥50%) (Joshi et al. 2017). It is also rich in organic materials (Fierro et al 1999) and contains cellulose and negligible amounts of heavy metals (Joshi et al. 2017), low enough to not pose a threat to the environment (Boni 2004). In fact, paper mill sludge contains significantly fewer heavy metals than sewage sludge, a typical soil amendment (Fierro et al. 1999).

There are various options available for the removal of paper mill sludge, including costly measures such as landfilling (Bravo et al. 2015). One field that has benefitted from the use of paper mill sludge is environmental remediation (Calace et al. 2005). Its addition has been reported to raise soil pH to acceptable levels and lessen the presence of mobile soil metals, as reported by Calance et al. (2002). The high amounts of organic matter present in paper mill sludge also allows it to counteract nutrient deficits (Fierro et al. 1999) and treat soils that are abundant in heavy metals by chemically binding to several different metals via absorption (Calance et al. 2005). Additionally, the water holding capacity of paper mill sludge is considerable (65%), improving water retention where it is distributed (Fierro et al. 1997).

The benefits of paper mill sludge extend into the agricultural sector. While the composition of paper mill sludge can vary significantly, the improvements in soil condition it can confer are enduring. As paper mill sludge contains high amounts of carbon, one treatment can increase organic carbon in the soil for up to five years, though this differs based on application rate (Zibilske et al. 2000). This relationship can be seen in an experiment by Zibilske et al. (2000), wherein the highest application rate (225 thousand kg/ha annually) resulted in a final soil carbon amount greater than twice its starting value. These lasting effects arise from the slow decomposition rate of paper mill sludge due to its lignin content (Chantigny et al. 2000a). Two years after application, Chantigny et al. (1999)

and Fierro et al. (2000) found that nearly half of the initial paper mill sludge still remained in the soil. Importantly, experiments have shown that paper mill sludge can increase the activity of soil microbes, such as through increasing the productivity of multiple enzymes by over 50% (Lalande et al., 2003), or more commonly by elevating microbial biomass (Chantigny et al., 2000b; Lalande et al., 2003). Finally, as mentioned prior, paper mill sludge can improve the water holding capacity of soils. However, this characteristic is not conducive to plant growth unless it also improves the availability of said water, as demonstrated an experiment by Zibilske et al. (2000) in which plant water content from a paper mill sludge treatment was nearly double that of the control. Its also important to consider that soil amendments produced closer to an agricultural site may help to further reduce costs. In this sense, waste resources high in organic matter that are plentiful on farmlands are likely to come from livestock.

2.9 Anaerobic digestate

In an agricultural context no soil amendment is more coincident than manure, or more specifically, its derived digestates. Anaerobic digestion is a process in which organic materials (substrate) are broken down by bacteria in an environment without air to produce biogas and carbon dioxide (Lozano et al. 2009). The use of manure as a component of anaerobic digestate rather than as a direct soil amendment is typically preferred due to its more robust benefits (Podmirseg et al. 2019). Anaerobic digestion eliminates a large amount of carbon present in the provided substrate while maintaining its nitrogen and phosphorous content, modifying these macronutrients into forms that can be more easily absorbed by crops (Möller and Müller 2012). This process also produces a digestate by-product that has applications as a biofertilizer (Lozano et al. 2009).

Biomass digestates have been found to contain high amounts of important plant micro- and macronutrients, including N, P, K, Fe, and Mn, (Möller and Müller 2012) and can be produced as either a liquid or solid amendment (Manyi-Loh et al. 2019). The extent of these beneficial characteristics can differ significantly between digestates based on the biomass material used to produce them as well as production techniques (Al-Seadi and Lukehurst 2012). Beyond providing nutrients, the addition of digestates to the soil can increase water holding capacity (Risberg 2015) and reduce the presence of soil-borne plant pathogens (Lukehurst et al. 2010). Critically, the fertilizing characteristics of digestates can sustain existing soil microorganisms by providing them with organic substances (Manyi-Loh et al. 2019). The nature of digestate's effects on microbe activity and biomass (including beneficial microorganisms like nitrogen-fixing bacteria) is not completely known (Podmirseg et al. 2019) and has been shown to be variable, likely due to differences in substrate quality (Abubaker et al. 2013) and root exudate interactions (Hartmann et al. 2009). In an experiment by García-Sánchez et al. (2012), the addition of anaerobic digestates to the soil resulted in favourable changes to the soil microbiome, improving the biomass and diversity for both bacteria and fungi.

In terms of synergy with biofuel feedstocks, the use of anaerobic digestate as soil amendments may increase the ability of an entire field site to sequester carbon. The ability of soil to absorb atmospheric carbon dioxide can be influenced by the stability of its fertilizing organic materials, more specifically, how long these components can persist in the soil following treatment (Béghin-Tanneau et al. 2019). Consequently, anaerobic digestates fall under this categorization due to their high organic matter content. While studies have reported contradictory evidence regarding this potential, an experiment by Béghin-Tanneau et al. (2019) demonstrated that a digestate treatment heightened the stability of the soil, enhancing its sequestration capabilities and lowering the amount of carbon it produced by over a quarter.

2.10 *Ascophyllum nodosum* extract

The most efficient strategy for establishing energy crops in Nova Scotia will likely capitalize on the Province's unique characteristics, such as its natural resources. *Ascophyllum nodosum*, also known as rockweed, is a plentiful seaweed resource found throughout the Nova Scotian coastline (Ugarte et al. 2010). In the west, the commercial collection of this resource started in Nova Scotia around the 1940s, representing almost 80 years of experience (Monagail et al. 2017). Agriculturally, *A. nodosum* extracts (ANE) are among the most commonly applied biostimulants (Xu and Leskovar 2015), which are organic substances used to increase plant performance by improving environmental stress tolerances, nutrient acquisition, and overall growth (Drobek et al. 2019). While this definition is broad, it is important to consider that biostimulants do not inherently possess fertilizing capabilities (Bulgari et al. 2019). Instead, they support plant processes through metabolic and physiological pathways (Bulgari et al. 2014) even when applied in extremely small amounts (micromolar concentrations) (Wally et al. 2012). *Ascophyllum nodosum* extract as a soil amendment compliments the production of second-gen biofuel feedstocks, providing a renewable, eco-friendly alternative to chemical stimulants that can be added to fertilizers (Renaut et al. 2019). The use of these extracts can augment the effects of subsequent chemical fertilizers, lowering fertilization requirements and thus reducing costs (Shukla et al. 2019).

Abiotic stresses imposed by the environment are detrimental to plant productivity as it diverts resources away from primary yield and/or decreases the efficiency of plant metabolic processes (Drobek et al. 2019). For example, high salinity environments can impair cell membrane functioning by interfering with the osmotic balance of intracellular ions, which can eventually lead to the death of the plant (Yadav et al. 2012). Research has shown that *A. nodosum* can alleviate this salinity induced stress, as demonstrated in a study by Jitesh et al. (2019). In this experiment, thale cress exposed to a saline environment under an ANE treatment had higher final fresh weights when compared to the untreated control by approximately 50%. Through gene expression analysis, these researchers ultimately concluded that this effect was the result of ANE's ester content which changed the expression of genes involved in stress response pathways, increasing salinity tolerance.

Under a changing climate, plant diseases are expected to become more prevalent as plant vulnerabilities increase (Elad and Pertot 2014). While the mechanics underlying these effects are not yet fully understood, there is evidence that applying *A. nodosum* extracts may influence the dynamics of microbe communities in the rhizosphere in a manner that reduces the presence of pathogens (Renaut et al. 2019). The effects of *A. nodosum* extract was explored by Fei et al. (2017) on biofuel feedstocks. Between switchgrass and poplar cultivars, their results showed a greater growth response to ANE from the 'Walker' poplar clone, which had significantly higher biomass than the no additives control. Additionally, greenhouse experiments on the 'Okanese' poplar clone demonstrated that ANE had a positive effect on leaf potassium content.

2.11 Conclusion

From this literature review, several key points arise about the current state of Nova Scotia's energy sector and the potential of biofuel resources therein. While Nova Scotia has made progress in reducing greenhouse gas emissions over the last decade, it is still dependent on an outdated, pollutant-forming source of energy, coal (Nova Scotia Power Inc. 2019). Increasing the presence of renewables within Nova Scotia presents an opportunity not only for economic growth, but also for reducing the amount of greenhouse gasses produced province-wide. Along with solar and wind-based energy, Nova Scotia may have the capacity for cultivating second-gen biofuel crops, which will avoid negatively impacting food production (Liu et al. 2017) and existing ecosystems (Barney and Ditomaso 2008; Simerloff 2008). While this resource is currently underutilized within Nova Scotia, the significant amount of available marginal land (Devanney 2010) and agricultural expertise therein supports its application (ACBC 2013).

Efficient utilization of marginal land will likely require the cultivation of perennial, second-generation biofuel crops, which offer advantages over first-gen crops. Second-generation energy crops are usually more resistant to environmental stressors, allowing them to grow in a variety of adverse conditions (Aylott et al. 2010; Gelfand et al. 2013). Over their lifetime, these crops can naturally produce yields comparable to first-gen crops grown using nitrogen fertilizer (Robertson et al. 2017) and can sequester a notable amount of carbon dioxide emissions, such as 92 tonnes per hectare by Miscanthus over nine years (Hansen et al. 2004). Among these second-generation energy feedstocks, trees and grasses are chosen due to several desirable traits for biofuel production, such as having high quality biomass (i.e. high in cellulose/carbohydrates, low ash/lignin content) (Min et al. 2017). For example, Miscanthus is efficient at intercepting sunlight and can retain leaf chlorophyll for long periods before senescence, enhancing its productivity and therefore the quality and quantity of its biomass (Tubeileh et al. 2016).

In order to ensure the successful establishment of these feedstocks, soil amendments are typically introduced to lessen the adverse conditions of marginal land. Soil amendments can be inexpensive industrial by-products that would otherwise be landfilled, making them an economic choice. They can provide numerous benefits to feedstocks, such as increasing available water (Zibilske et al. 2000), stimulating soil microbiota communities (Manyi-Loh et al. 2019), and enhancing the carbon sequestration ability of the soil (Béghin-Tanneau et al. 2019). The combination of abundant available marginal land, extensive local agricultural knowledge and infrastructure, robust feedstock characteristics, and impactful soil amendments create an ideal formula for a potential bioindustry in Nova Scotia, entailing numerous environmental and economic benefits.

3.0 MATERIALS AND METHODS

3.1 Planting materials

The plant materials used in this experiment included poplar (*Populus nigra* × *Populus maximowiczii* 'NM-6'), willow (*Salix miyabeana* 'SX67'), switchgrass (*Panicum virgatum* 'Cave-in-Rock'), and Miscanthus (*Miscanthus* × *giganteus* 'Nagara') crops. Miscanthus plantlets were generated in lab as per the methods in Fei et al. (2019). Switchgrass seeds came from Ferme Norac, Inc., Saint-Timothée, QC and were not treated with pesticide or other seed treatments prior to planting. Poplar cuttings originated from nursery stocks grown at the Agriculture and Agri-Food Canada (AAFC) research farm in Nappan, NS and were obtained on April 13th, 2019. Trees grown in a plantation near Mr. Rick Corradini's Farmstead, Falmouth, NS (45°00'24.1"N 64°09'56.8"W) were the source of willow cuttings, being collected in April 2019 for the East Gore site and the week prior to planting for the Skye Glen site. Cuttings were 25-30 cm long and were stored in freezers set to 0 °C before planting.

3.2 Amendment materials

One of the three soil amendments used in this experiment was a paper mill "sludge" (i.e. a wood fibre residue from the milling process; fig 3.1; table 3.1) from the Port Hawkesbury pulp and paper mill in Port Hawkesbury, NS. The liquid fraction of an anaerobic digestate was sourced from T.E. Boyle Farm & Forestry Limited, Antigonish, NS, and was derived from feedstocks of dairy manure and crop residues. An analysis of digestate composition can be seen in table 3.2, done by the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS. For each site, 1000 L of liquid *Ascophyllum nodosum* solution was prepared by diluting the seaweed extract (Stella Maris™ aquatic plant extract; Acadian Seaplants Ltd., Dartmouth, NS) with water (1 millilitre of extract per litre) in a high-density polyethylene (HDPE) bulk container.

3.3 Experimental design

To assess the performance of biomass crops on Nova Scotia's marginal land, five experimental growing sites were established across the Province. Two of these five sites were the focus of this research, at East Gore, Hants County, NS (45°06'14.7"N 63°40'58.4"W), and Skye Glen, Inverness County, NS (46°03'30.0"N 61°12'17.1"W). The site at East Gore was at the top of a steep hill (fig. 3.2), whereas the site at Skye Glen was surrounded by forest (fig. 3.3, 3.4). Both sites were roughly 4,250 m^2 large and were arranged into a randomized block design, with four replicate blocks (20 × 49 m including pathways; fig. 3.5). These blocks contained plots for each of the four test biomass crops. Every individual plot was divided into four subplots (10 m × 4 m) to test each soil amendment plus a control without amendments (fig. 3.5). The site in East Gore was too narrow for this exact layout, thus requiring modification (fig. 3.6). In each subplot, 90

Miscanthus plantlets, 65 poplar/willow cuttings, or 160 spots for switchgrass seeds were planted (see details below). Miscanthus and switchgrass were distributed evenly within subplots as seen in figures 3.7 and 3.8. Poplar and willow cuttings were arranged into five double-rows per subplot to maximize space without hindering plant performance (relative to a single-row design; fig. 3.9) (Lewis et al. 1985). Spacing between crops was designed to reduce competition and allow for safe access to the plants without risking damage (e.g. during weeding).

3.4 Site characterization

In order to assess soil quality, two 1 kg samples of topsoil were collected at each site using a soil core sampler, with 1 kg from a soil depth of 0-15 cm, and the other 15-30 cm deep. Soil cores were collected at random locations across the field site before planting. Soil cores were sent to the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS for compositional analysis of several macro- and micronutrients (table 3.3). After the first winter (spring 2020), soil cores in and around the subplots were collected using the same methodology to capture the overall soil characteristics of the site. This was done to explore the effects of our soil amendments on soil quality.

Other site characterization included soil classification (table 3.4) which was determined by locating the position of each site on a Canada Land Inventory map of Nova Scotia, produced by the Canadian Soil Information Service (CanSIS 2013). To monitor soil temperature and moisture at a 15 cm depth, a soil moisture smart sensor (S-SMx-M005) and 12-bit temperature smart sensor (S-TMB-M0xx) were installed to a HOBO® Micro Station (H21-USB; Onset Computer Corporation, Bourne, MA) set up at the periphery of each site shortly after planting (~1-2 weeks), which collected data hourly. However, malfunction of East Gore's soil moisture smart sensor led to data loss from August 29th, 2020 onwards. Weather station data (e.g. daily temperatures, precipitation, snowfall, etc.) were taken from the Halifax Stanfield International Airport and Cheticamp Highlands National Park weather stations (via the Government of Canada's environment resources website), located roughly 28 and 69 kilometers from the East Gore and Skye Glen sites (respectively). These databases did not include entries for each day of the year – an average of 16 entries were missing for Stanfield Airport data, with Cheticamp Park missing an average of 8 entries per year. These measures offered an assessment of the surrounding environment throughout the experiment. Seven weeks after planting, weeds at the East Gore site were photographed for later identification. First-year weed composition for the East Gore site can be seen in table 3.5.

3.5 Site history

East Gore

The site in East Gore was previously host to a variety of wild grasses until the fall of 2015, when it began its conversion into a barley field with a liquid spray application of Roundup® herbicide (Monsanto Company, Creve Coeur MO). A year later, the site was adapted into a soybean field using Roundup-ready bean seeds and a Roundup® herbicide application of 1 L per acre. The site would contain soybean up until the spring of 2019, when it was disked and leveled in preparation for this experiment.

Skye Glen

The plot in Skye Glen was an unimproved hay field for the 15 years leading up to 2019, during which no fertilizers were applied. In the spring of 2019, two tonnes per acre of lime was applied as well as one litre per acre of Roundup® herbicide (10 gallons of water as a carrier for 1 gallon of herbicide) via a field sprayer. To further prepare the site for this experiment, it was plowed as deep as possible (12 inches), being passed over twice with a minimal till disc.

3.6 Planting

Planting of all materials was done by hand and occurred from June 19 to 24, 2019 at East Gore and from July 9 to 12, 2019 in Skye Glen. Miscanthus plantlets were delivered to the Skye Glen site 5 days prior and were watered daily before planting. The remaining planting materials arrived on the day of planting. The wood cuttings used in East Gore were soaked in water a day prior to planting. Miscanthus were planted by plunging a shovel vertically into the ground and then moving the shovel backwards. Plants were then inserted into the space left when the shovel was removed, so that the soil reached the point where the blades began. The root system already established in the soil of the trays was not tampered with to avoid damage. In each designated subplot 90 plantlets were set up (22,500 plantlets/hectare). Miscanthus tillers were cut to half its original length, approximately 20 cm long.

Three separate methods were used to plant the poplar and willow cuttings into the soil. If the soil was soft enough, the cuttings could be pushed into the ground by hand, or through light taps with a hammer. Alternatively, the cuttings could be placed into holes (~2.5 cm wide) formed using a metal pole and hammer. Cuttings were oriented with buds facing upwards at an intended depth of ~8 cm. The planting density of woody energy crops was 65 cuttings/subplots, or 16,250 cuttings per hectare. Switchgrass seeds were sown by hand onto the soil surface, with ~0.2 g of seeds being deposited into 160 preplanned locations within each subplot (~32 g of seeds/subplot; 40,000 seed spots/hectare). A lawn roller was rolled across the subplots to compact seeds into the soil.

3.7 Amendment application (2019)

Paper mill sludge was delivered to the sites in bulk bags (fig. 3.10), arriving on June 17th for East Gore and on July 3rd for Skye Glen. During planting, paper mill sludge was applied by digging holes in the intended position of the seeds/cutting/plantlet and filling it with residue. Holes were dug to accommodate 2, 3.5, and 5 litres of paper mill sludge for switchgrass, Miscanthus, and poplar/willow, respectively, equivalent to an application rate of 12,047 kg/ha for all crops. After this, these holes were filled with topsoil to create a uniform surface. Aforementioned planting methods were used on the covered holes filled with paper mill sludge. For both sites, the application of paper mill sludge was completed on the day of planting.

Treatments of the remaining soil amendments (seaweed extract, anaerobic digestate) occurred roughly 7 weeks after establishment for both sites. Anaerobic digestate was usually obtained a maximum of two days before application, being transported in an HDPE bulk container (fig. 3.11). This same container (after washing) was used for the diluted seaweed extract, which was applied on the same day of its dilution. Subplots containing woody crops (willow or poplar) were treated with anaerobic digestate using measuring cups, with 1 L of digestate poured onto the area surrounding each cutting (16,250 L/ha). The same technique was used for Miscanthus subplots, at a rate of 500 mL per plant (11,250 L/ha). For switchgrass, anaerobic digestate was diluted into a 50/50 water/digestate mix, with around 16 L of the diluted digestate being dispersed onto each subplot. The longest period between procurement and application for digestate was overnight. Subplots were treated with *A. nodosum* seaweed extract using the same methods and application rates used for the anerobic digestate, the only exception being that the seaweed extract was not diluted prior to switchgrass subplot application.

3.8 Site maintenance (2019)

Eight weeks after the East Gore site was established, weeding was required to reduce competition and maintain crop performance. A Certified™ 174cc 3-in-1 self-propelled RWD lawnmower (Certified Lawnmowers Inc., Charlotte NC; 59 cm wide deck) was used to mow weeds growing in the walkways. To cut weeds at a height that would not interfere with developing switchgrass (3-10 cm), a handheld gasoline-powered weed trimmer was employed in these plots.

Weeds immediately surrounding the Miscanthus, willow, and poplar were removed by hand to increase the visibility of these plants. This ensured that the weed trimmer could be used to safely remove the remaining weeds. Depending on the amount of space between crop rows, a mower, weed trimmer, or wheel hoe was utilized. The site at Skye Glen possessed negligible weed pressure, and therefore did not require site maintenance.

3.9 Subsample collection (2019)

The sample size (n) used for each crop was 4 (one sample per replicate), with the number of subsamples taken per sample varying by crop. On October 1st, 2019, four Miscanthus plants were taken per subplot in East Gore and stored in microperforated polypropylene bags for future nutrient analysis. Miscanthus were randomly selected by picking the first four entries in a randomized list of 1 to 90, which corresponded to the position of Miscanthus in each subplot. This was repeated in the Skye Glen site in the same week (October 7th, 2019), with subsamples being randomly collected by picking a random direction without looking.

Plant subsamples from each subplot were collected on November 12th and 16th, 2019 for East Gore and Skye Glen, respectively. Survival counts were made prior to subsample collection in poplar and willow subplots. “Survival” was a yes/no evaluation, with empty spots counting as a plant that did not survive. Per woody crop subplot, 20 individual plants were randomly selected, their branches being cut 5 cm from the base with pruning shears to enable regrowth the following spring. Branches were pooled into individual microperforated polypropylene bags that were labeled corresponding to their subplot of origin. Miscanthus subsamples were collected by cutting the plant down to the soil surface using shears, with 8 plants from each subplot pooled into two microfibre bags. Switchgrass was gathered into single bags using the same methods as Miscanthus.

Plants were randomly selected to avoid biasing the results. After harvesting, the stems and branches of all woody crops were cut to a length of 3-5 cm to facilitate a coppice system during spring regrowth, and the remaining Miscanthus and switchgrass were cut with a string trimmer (~5 cm height). All plant subsamples were placed into ovens located in the AAFC Research Farm in Nappan, NS until dried.

3.10 Subsample analysis (2019)

Dry weights of the crop samples from the first harvest were obtained by weighing the microperforated polypropylene bags and their dried contents. The weight of the plastic bag was subtracted from the resulting values to determine dried subsample weight. A Denver Instrument PK-352 laboratory scale (Denver Instrument; Bohemia, NY) or Taylor® glass kitchen scale (Taylor Holdco; Oak Brook, IL) was used depending on the size of the subsample. Miscanthus samples were sent to the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS. At this facility tissue samples were grinded to a powder and analyzed for their nutrient concentrations through use of a 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). These results were then multiplied by dry weight and plant count data to obtain nutrient yield per hectare. As data was collected shortly after the plants were harvested, a survival rate of 100% was assumed.

3.11 Weeding and herbicide application (summer 2020)

At the earliest opportunity, the two sites were weeded using the same methodology as 2019. This was done to lessen the weed pressure that had developed since spring re-emergence, which threatened the performance of the developing energy crops. For the East Gore site, weeding was done from the 23rd to the 25th of June, and from the 13th to the 14th of July for the Skye Glen site. Unlike the previous year, where the presence of weeds at the Skye Glen site was virtually nonexistent, the weed pressure had developed considerably in the summer of 2020. The species of weeds present at both sites can be seen in table 3.5.

Due to the relative abundance and persistence of broadleaf weeds in the switchgrass plots at both sites, it was decided that an application of herbicide was necessary in the switchgrass subplots. This was due to the difficulty in removing them completely by hand without interfering with the established switchgrass. The most plentiful broadleaf weed at both sites was *Trifolium repens* (white clover). The herbicide "Weed B Gon® MAX" (active ingredient: chelated iron (FeHEDTA); Scotts Miracle-Gro Company, Maryville

OH) was diluted to a 1:8 ratio with water (one litre of herbicide mixed with eight litres of water). Nine litres of this diluted mixture were distributed onto switchgrass subplots using pump backpack sprayers, focusing the application on any visible weeds. This occurred on the 30th of July at the East Gore site, and the 13th of August at the Skye Glen site.

3.12 Second amendment application (summer 2020)

In 2019, the application of soil amendments after planting occurred relatively late in the season. Thus, it was decided that a second application of the digestate and seaweed extract treatments earlier in the following season would be carried out using a split plot design. The new application was applied to one half of each subplot (each split plot being 2 × 10 m) which received amendments in 2019. Application rates were identical to those done a year earlier, with woody crops receiving one litre of *Ascophyllum nodosum* extract/digestate per plant, Miscanthus 500 mL per plant, and switchgrass having eight litres of seaweed extract or diluted digestate applied per split plot. Anaerobic digestate treatments occurred on the 22nd and 28th of July for the East Gore and Skye Glen sites (respectively), while liquid seaweed extract treatments were done on the 24th and 29th of July for East Gore and Skye Glen subplots.

3.13 August data collection (2020)

Data collection in the summer of 2020 occurred from August 13th to the 18th at the Skye Glen site, and from August 19th to the 20th at the East Gore site. Measurements were taken from 10 randomly selected plants (subsamples) in each Miscanthus, poplar, or willow subplot. This was achieved by throwing 10 plastic discs in random directions and marking the plants nearest to where the hoops landed. However, as the height of the Miscanthus in

Skye Glen interfered with this strategy (fig. 3.12), individual plants were instead chosen by throwing the hoops from the long (10 m) side of the subplots.

The plant parameters that were measured varied among crops, with switchgrass being omitted due to the prevalence of weed growth (fig. 3.13). For poplar, stem count, total stem length (a combination stem lengths from one tree), leaf count, and leaf area were obtained. Total stem length and stem count of select willow trees were determined with the same methods as poplar, but due to willow's abundance of leaves, leaf count and leaf area was only collected from the tallest stem.

Length measurements were taken using a meter stick or measuring tape, starting from the origin point of the stem from the original cutting for poplar and willow, or from the base of the tiller at ground level for Miscanthus. The leaf areas of woody crops were acquired through the use of a portable leaf area meter (LI-3000C; LI-COR Biosciences, Lincoln NE), with willow leaves being subsampled destructively. From the middle of the tallest stem of each tree, 10 willow leaves were collected in microperforated polypropylene bags and stored in a cooler with ice (later a refrigerator). A week after collection, these leaves were measured in lab.

Willow leaf area was not recorded in East Gore due to the small size of the trees, as destructive subsampling would likely impact performance. For these same reasons, Miscanthus leaf area was taken from the tallest tiller of a living plant (East Gore), or from a destructive subsample (Skye Glen). Specifically, the Skye Glen Miscanthus tillers were harvested in the morning and then later quantified offsite that same day. This method involved inserting multiple leaves into a bag clip and measuring them at once with the leaf area meter (fig. 3.14). While this was more time efficient than measuring the leaves one at a time, it required the number of leaves per clip to be separately documented, as the leaf area meter would interpret multiple leaves in one clip as a single wide “leaf”.

Soil subsamples were collected at the same time as the plant growth parameters. From each subplot, five soil cores were randomly obtained at a depth of 15 cm. These subsamples were pooled in accordance with their crop and treatment type (e.g. willow treated with anerobic digestate). While soil from grass subplots could be taken from any spot within the rows, subsamples from the woody crop subplots were taken in alternating positions. For example, five soil subsamples from one woody subplot could be comprised of two subsamples from the 0.75-meter-wide rows and 3 subsamples from the 1.5-meter-wide rows, while another could be the opposite (3 narrow-row subsamples and 2 wide-row subsamples). These soil subsamples were later sent to the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS for the compositional analysis of nutrients and heavy metals (section 4.20 and 4.21).

3.14 End of season data collection (fall 2020)

Collection of plant subsamples and measurements occurred in Fall 2020 in order to assess end-of-season growth. In poplar, willow, and Miscanthus subplots individual plants had already been selected and marked during August data collection. These plants were again subsampled to obtain data – ten trees per woody subplot, or six Miscanthus plants per subplot. The randomization strategy for August data collection was used again, with the same number of plants being subsampled regardless of whether it was a split plot or subplot (e.g. 10 trees subsampled per subplot or split plot).

For woody crops, selected trees were measured for stem length and diameter using a meter stick and caliper, respectively. Length measurements began from the stem’s origin point and ended at the tip of the stem, with width measurements starting 5 cm from the base of the stem. “Secondary” (stems growing from the original cutting, the “primary” stem) and “tertiary” stems (growing from stems previously coppiced) were selected for measurement. As a time-saving measure, poplar stems were measured up to a maximum of eight (per plant) at the Skye Glen site. Stems that exceeded this limit had a negligible contribution to biomass and overall growth. All results were rounded to the nearest unit of measurement (mm or cm). Average measures of stem length and diameter were integrated into a modified cylinder volume formula $(\pi r^2)/2 \times l$ (where "r" is the radius at the base of the stem, and "l" is stem length) to obtain a conservative estimate of stem volume. As stem diameter was measured from the base of each stem, the area of a circle (πr^2) was halved to give a general measure for the entire stem.

Grass crops were destructively subsampled to ascertain fresh weight in the field. The total biomass associated with six of the established Miscanthus plantlets (including tillers emerged from rhizomes) from each subplot were cut 5 cm from the base of the stalk. A scale was used to determine the collective fresh weight of these six subsamples. Roughly 150 grams were taken from these subsamples and placed into labeled microperforated bags. These smaller subsamples would be later desiccated in heating ovens, with dry weights being recorded thereafter. Using these measurements, moisture content and dry biomass per hectare could be calculated. The same methodology was applied to switchgrass, with some modification. Eight plastic discs were tossed throughout the subplots, with all biomass (switchgrass or otherwise) within these rings (an area of ~416 cm^2) being cut (5 cm from the ground), collected, and weighed to simulate a machine harvest. These subsamples were again lessened (~100 grams), stored in labeled bags, and put in an oven to ultimately determine dry weight. After the relevant field measurements had been recorded, all subplots containing grass crops were mowed using a handheld weed trimmer to approximately 5 cm in height. As our designated indicator species, a nutrient analysis of plant tissue was also carried out by the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS on the dried Miscanthus samples. Nutrient yield was obtained by calculating dry weight per subplot, multiplying it by nutrient concentration, then converting the units of measurement to kilograms per hectare, as seen in the results section.

3.15 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. However, this method may require data transformation to satisfy assumptions of homoscedasticity and normality. Such transformations can be difficult to find as it must be applicable to multiple datasets. Additionally, interpretation errors can arise from back-transforming the data after analysis of variance is complete, and can introduce bias to the results (Rothery 1988). Therefore, we used a generalized linear model (GLM) in these scenarios, which does not rely on assumptions of homoscedasticity and normality (Crawley 2007).

Generalized linear models can incorporate a variety of statistical tests (including ANOVA) (Agresti 2007). Unlike linear regression, the GLM involves changing components of the model itself (e.g. distribution family, link function) to best suit the distribution of response data, rather than transforming the data to satisfy the assumptions of the model (as is true with ANOVA) (Fox 2008). For our purposes, a gamma distribution was chosen as data were continuous (Crawley 2007). Similarly, a log link was chosen as the data analyzed was nonnegative and likely positively skewed. Probability plots were created to verify that the gamma distribution was a better overall fit for the data than the gaussian (normal) distribution (as would be used in an ANOVA). This allowed for direct comparison of both histogram distribution curves.

Pairwise comparison of two independent variables on a single dependent variable can be achieved through post-hoc analysis of a two-way ANOVA. Such methods were therefore employed to evaluate comparable growth parameters of crops similar in morphology and establishment procedure (i.e. the woody crops poplar and willow). With these results, a non-significant interaction effect indicates that a narrower analysis is required (e.g. one-way analysis of variance). While two-way ANOVAs can reveal overarching patterns, combining poplar and willow data into a single dataset can potentially mask trends that occur on a per-crop basis. Therefore, one-way ANOVAs were computed regardless of a nonsignificant interaction effect to ensure comprehensive results.

Analysis of variance tests with Tukey-Kramer post-hoc analyses were performed using the R programming language (R Core Team) with the "car" (Fox et al. 2020), and "multcomp" packages (Hothorn et al. 2020) alongside stock R functions. The results were then visualized using the "ggplot2" (Wickam et al. 2020a) and "dplyr" packages (Wickham et al. 2020b). Probability plots comparing gaussian and gamma distributions were achieved without the use of external packages.

Figure 3.1. Paper mill sludge soil amendment.

Figure 3.2. Location of the East Gore site, with plot highlighted. Scalebar represents 20 meters.

Figure 3.3. Location of the Skye Glen site, with plot highlighted. Scalebar represents 20 meters.

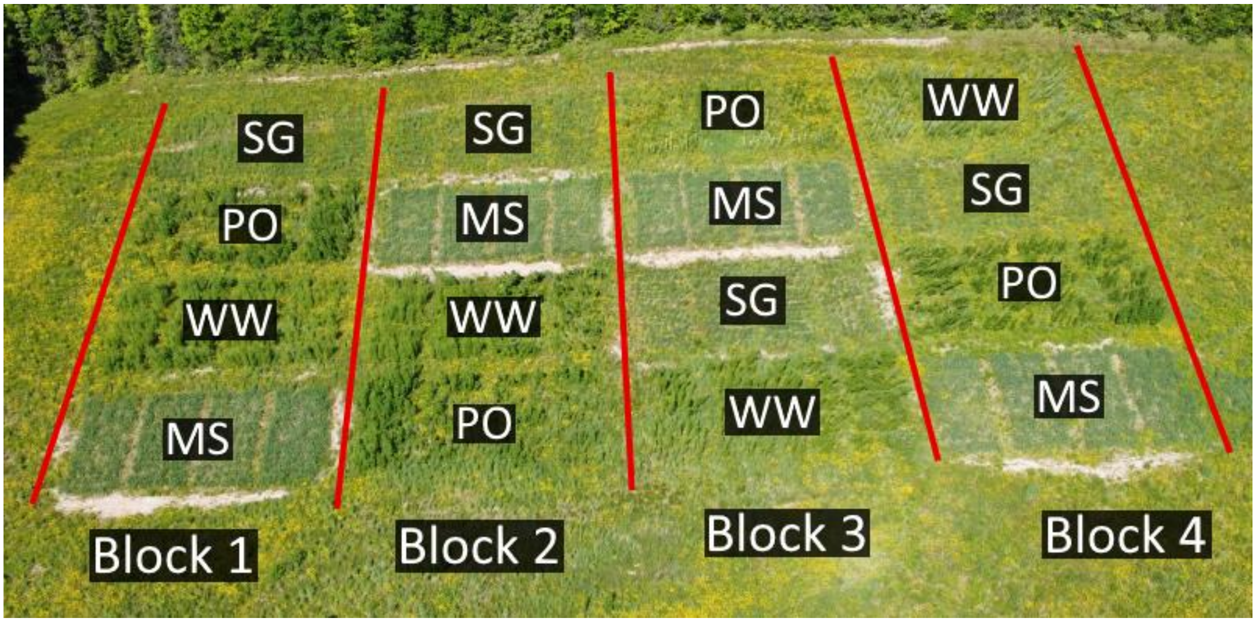


Figure 3.4. Aerial photograph of the Skye Glen site, including the randomized block design and arrangement of the tested energy crops (poplar (PS), willow (WW), switchgrass (SG), and Miscanthus (MS)).

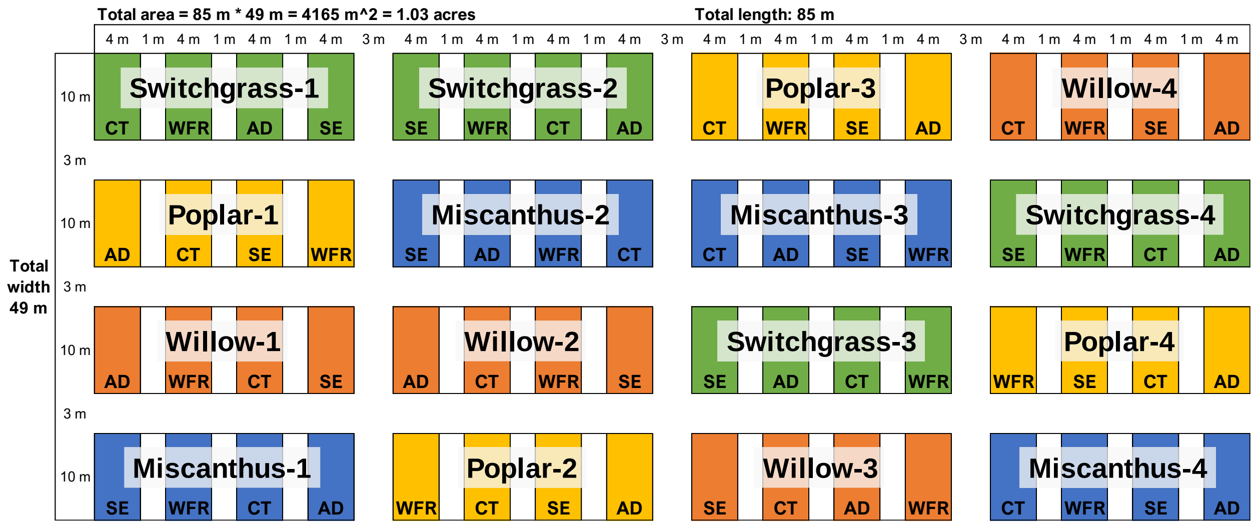


Figure 3.5. Design for the site in Skye Glen.

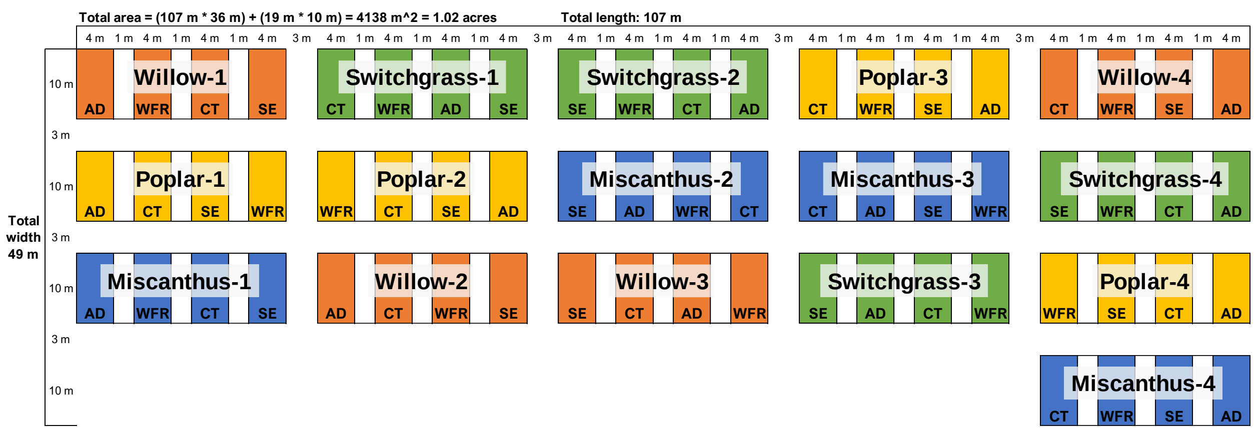


Figure 3.6. Modified design for the site in East Gore.

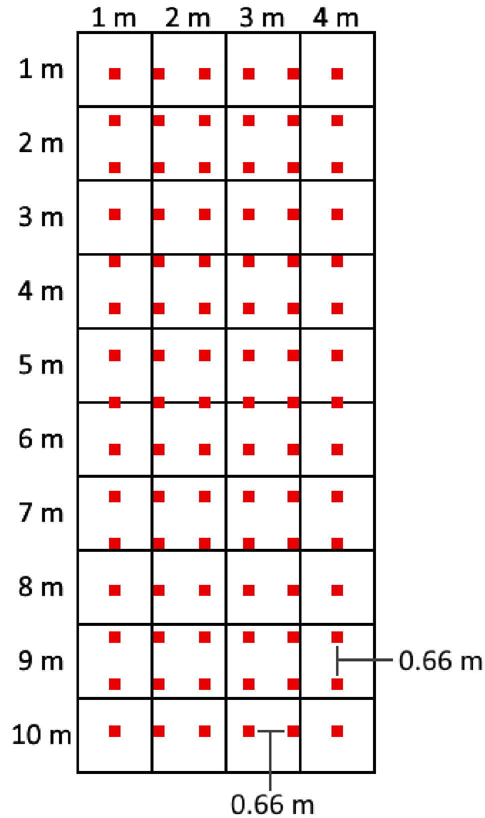


Figure 3.7. Planting design for Miscanthus subplots.

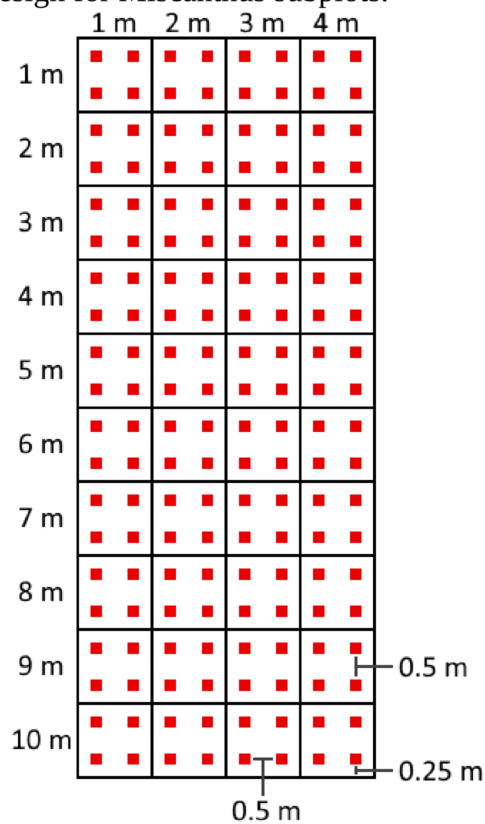


Figure 3.8. Planting design for switchgrass subplots.

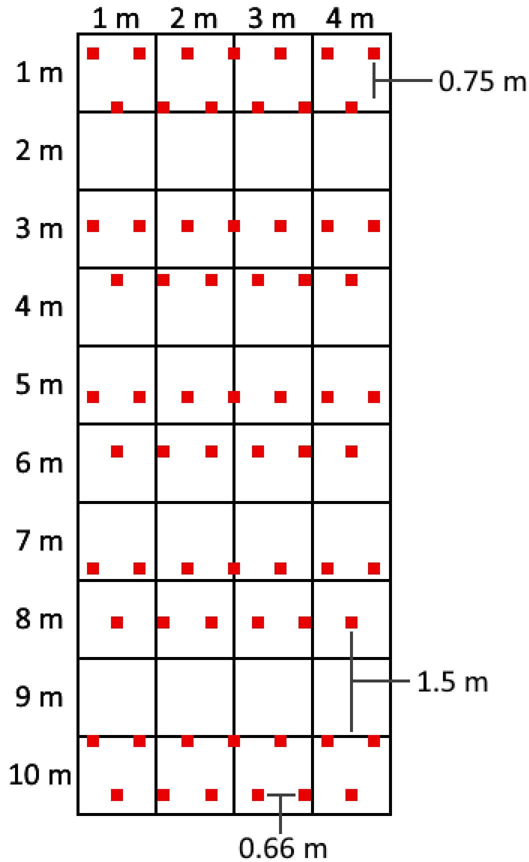


Figure 3.9. "Double row" planting design for poplar and willow subplots.

Figure 3.10. Bulk bags used to transport paper mill sludge.

Figure 3.11. Bulk container (left) used to transport anaerobic digestate.

Figure 3.12. Miscanthus growth at the Skye Glen site by mid August 2020.

Figure 3.13. Weed pressure at the East Gore site during the summer of 2020.

Figure 3.14. Method used to measure multiple Miscanthus blades using the leaf area meter.

Table 3.1. The typical composition of paper mill sludge produced at the Port Hawkesbury pulp and paper mill in Port Hawkesbury, NS. Total organic carbon, pH, total inorganic carbon, and the carbon to nitrogen ratio is on a dry weight basis.

Moisture content (%)	~70
Total organic carbon (%)	42.7
pH	6.15
Total inorganic carbon (%)	3.9
Carbon to nitrogen ratio	2241.9

Table 3.2. Chemical analysis of anaerobic digestate samples taken in 2019 and 2020. 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 or parts per million (ppm) of the dry matter fraction of the liquid digestate.

	DG-2019	DG1-2020	DG2-2020
Dry matter (%)	9.4	7.4	8.2
Nitrogen (%)	2.3	2.2	1.9
Calcium (%)	1.9	2.6	2.4
Potassium (%)	3.0	4.0	3.7
Magnesium (%)	0.7	0.8	0.8
Phosphorus (%)	0.8	0.8	0.8
Sodium (%)	3.3	5.8	5.4
Boron (ppm)	40.5	42.0	41.4
Copper (ppm)	182.5	490.2	438.8
Iron (ppm)	5005.8	2216.2	2363.1
Manganese (ppm)	318.7	256.1	249.8
Zinc (ppm)	154.9	212.5	196.9

Table 3.3. Chemical analysis of site soil samples at two different depths. These samples were collected in the summer of 2019 prior to site establishment.

	East Gore, 1-15 cm	East Gore, 16-30 cm	Skye Glen, 1-15 cm	Skye Glen, 16-30 cm
pH (pH units)	6.75	6.9	5.45	5.58
Buffer pH (pH units)	7.77	7.79	7.54	7.5
Nitrogen (%)	0.17	0.2	0.14	0.13
Nitrate-N (ppm)	7.93	6.26	1.4	1.08
Organic matter (%)	3.3	3.1	2.9	3.1
P_2O_5 (kg/ha)	558	546	22	22
K_2O (kg/ha)	97	95	96	115
Calcium (kg/ha)	3176	2894	1836	1893
Magnesium (kg/ha)	197	231	465	446
Sodium (kg/ha)	< 16	< 16	51	57
Sulfur (kg/ha)	16	13	5	7
Aluminum (ppm)	1241	1175	947	1083

Boron (ppm)	0.57	0.56	< 0.50	< 0.50
Copper (ppm)	1	0.82	0.41	0.61
Iron (ppm)	286	272	306	282
Manganese (ppm)	64	59	67	87
Zinc (ppm)	1.06	1.06	0.58	0.71

Table 3.4. Soil characteristics of the East Gore and Skye Glen sites (P = stoniness; D = undesirable soil structure and/or low permeability; T = adverse relief due to steepness or pattern of slope; W = excessive soil moisture).

Site	Soil series/type	Canada Land Inventory (CLI)
East Gore	Barney	3P
Skye Glen	Westbrook	3DT – 4W

Table 3.5. Composition of weeds at the East Gore (EG) and Skye Glen (SG) sites in 2019 and 2020.

Weed species (EG 2019)	Weed species (EG 2020)	Weed species (SG 2020)
Amaranthus retroflexus	*Achillea millefolium*	*Cirsium vulgare*
Chenopodium album	*Barbarea vulgaris*	*Panicum capillare*
Persicaria maculosa	*Equisetum arvense*	*Ranunculus repens*
Plantago lanceolata	*Erysimum cheiranthoides*	*Setaria viridis*
Raphanus raphanistrum	*Leucanthemum vulgare*	*Solidago* spp.
Setaria viridis	*Prunella vulgaris*	*Trifolium repens*
Stellaria graminea	*Ranunculus repens*	*Vicia cracca*
	Setaria viridis	
	Solidago spp.	
	Stellaria graminea	
	Trifolium repens	
	Vicia cracca	

3.16 Weather data

Data obtained from the Halifax Stanfield International Airport and Cheticamp Highlands National Park weather stations characterized the environmental conditions of the East Gore and Skye Glen sites, respectively.

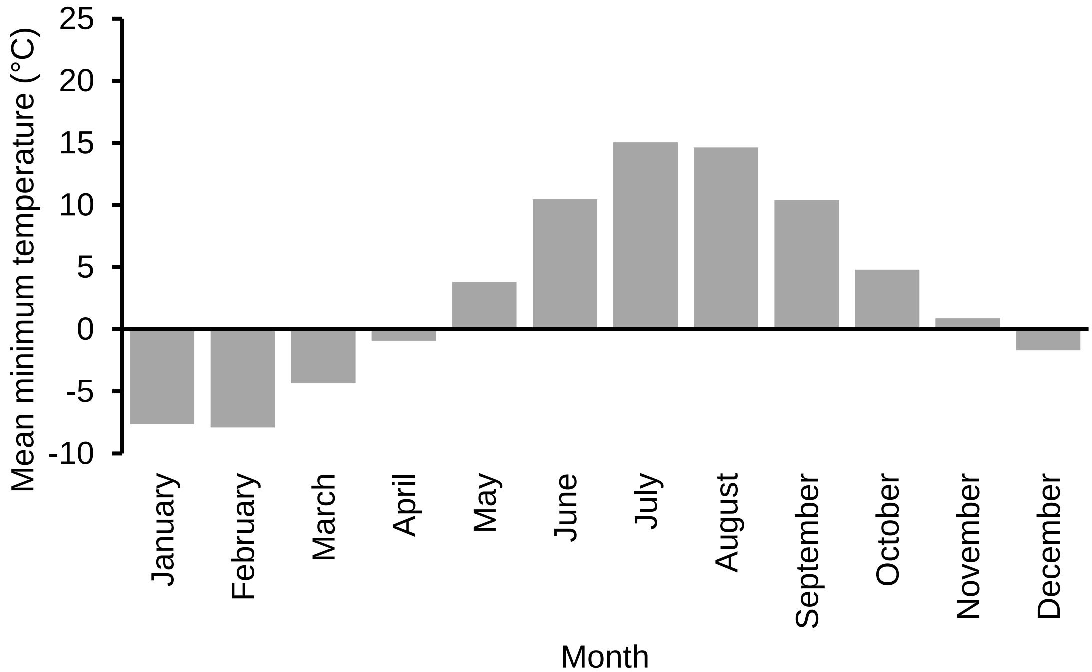


Figure 3.16.1 Monthly minimum temperature conditions at the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

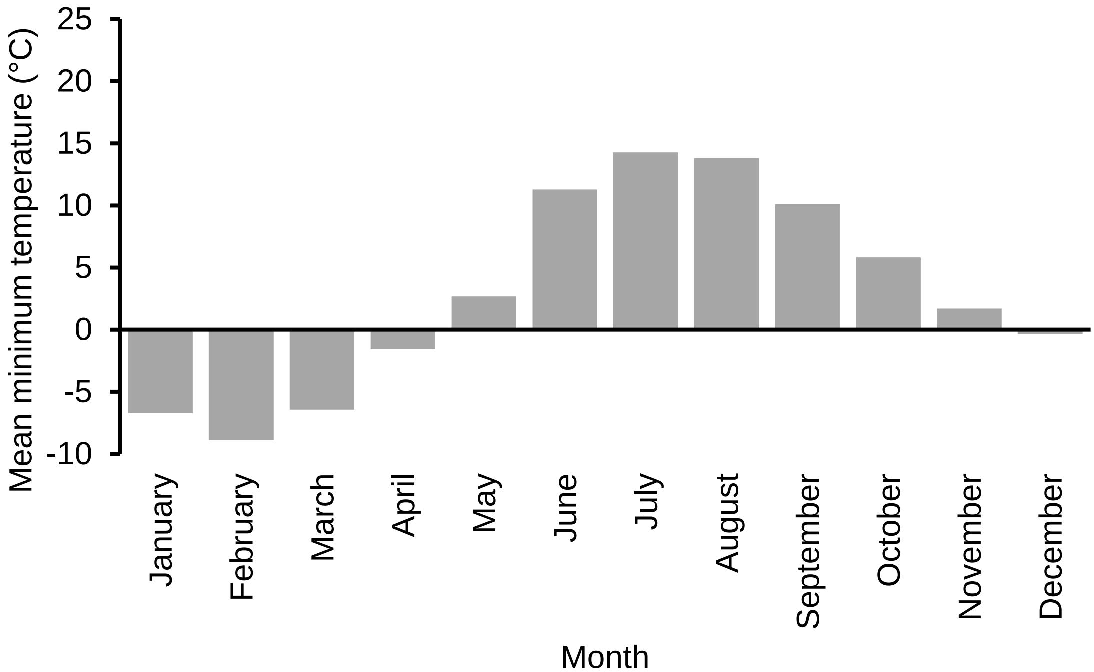


Figure 3.16.2 Monthly minimum temperature conditions near the Cheticamp Highlands National Park weather station (located approximately 69 kilometers from the Skye Glen site) during 2020.

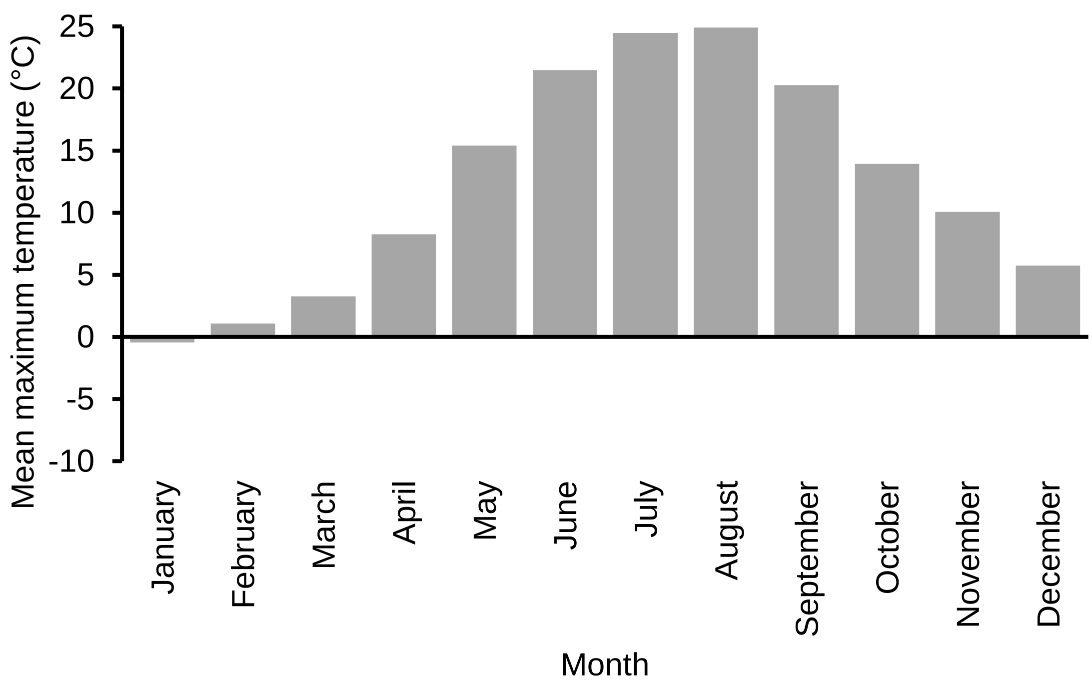


Figure 3.16.3 Monthly maximum temperature conditions near the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

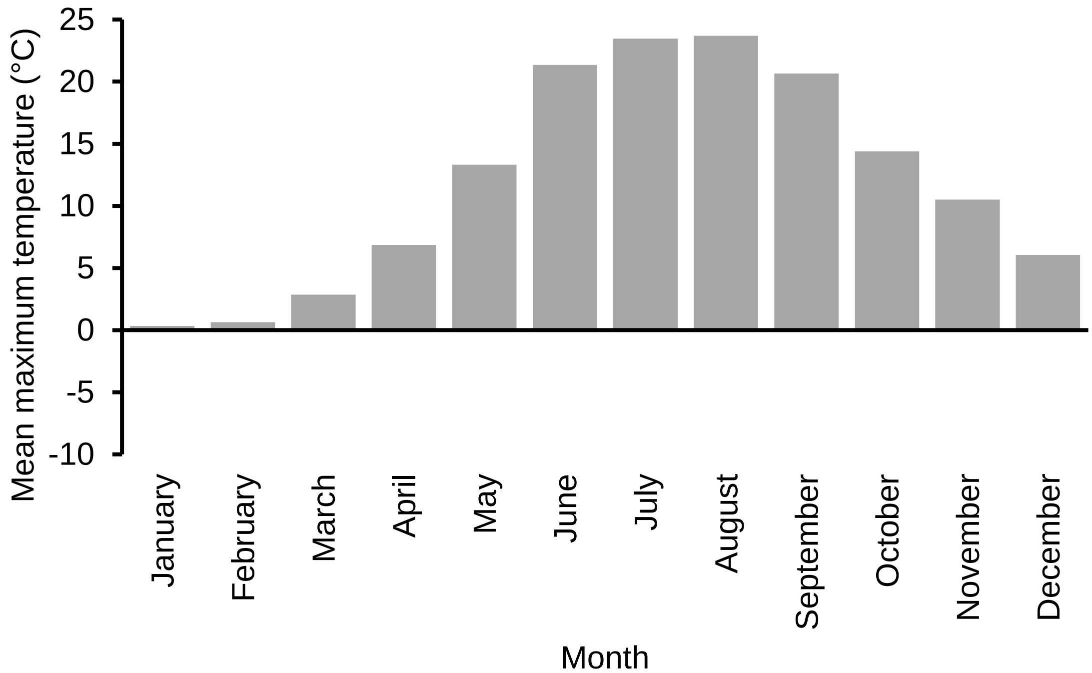


Figure 3.16.4 Monthly maximum temperature conditions near the Cheticamp Highlands National Park weather station (located approximately 69 kilometers from the Skye Glen site) during 2020.

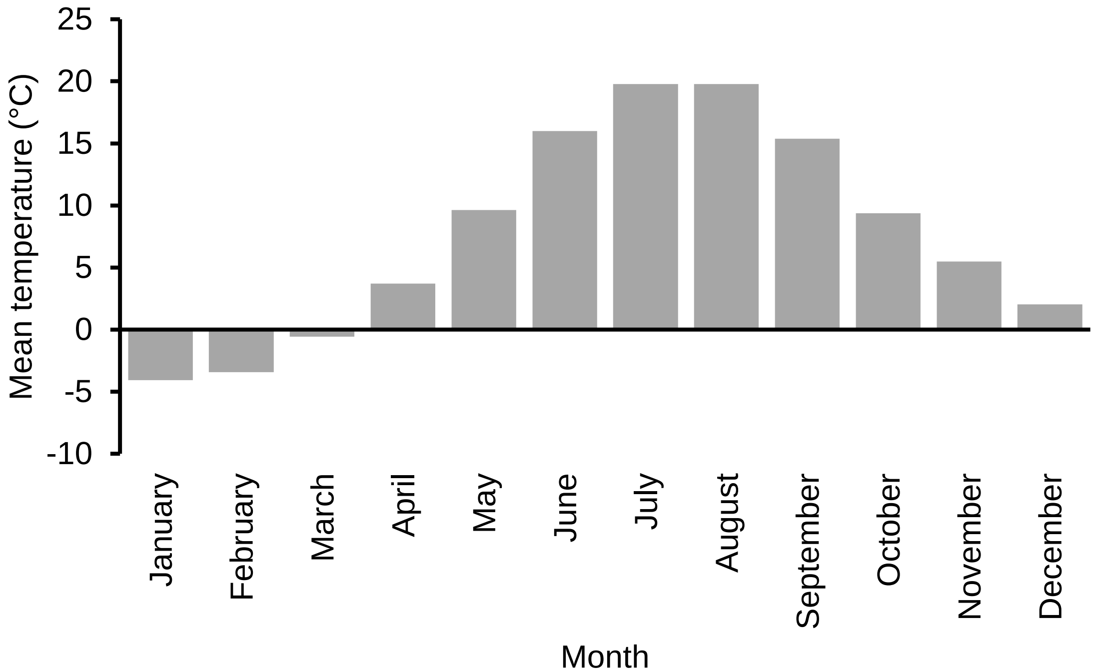


Figure 3.16.5 Monthly temperature conditions near the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

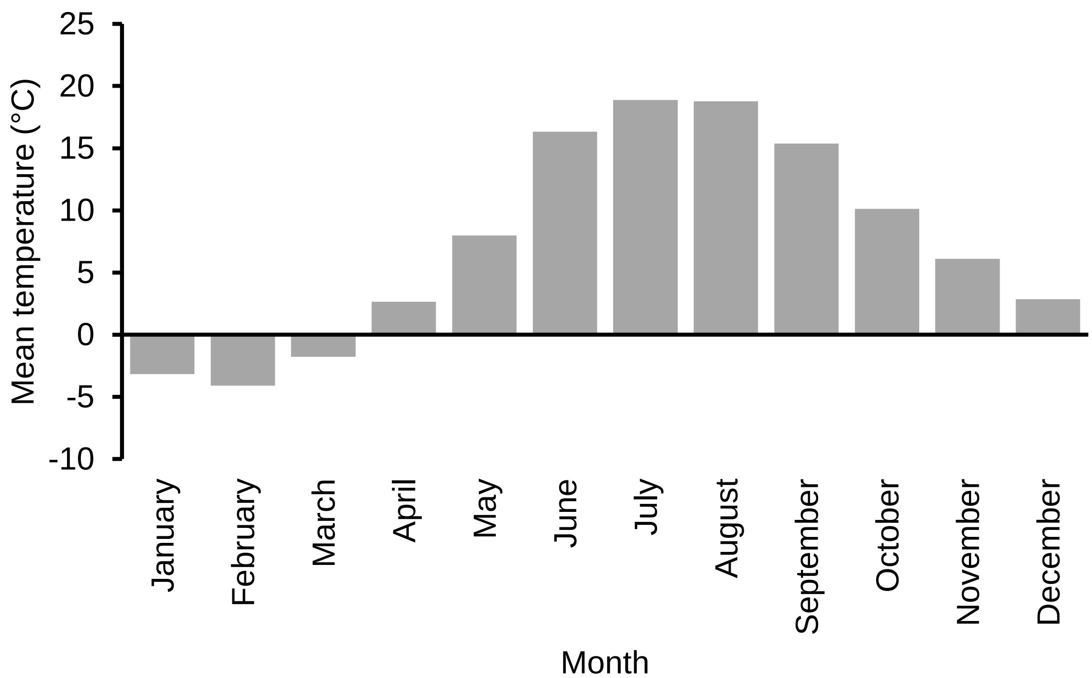


Figure 3.16.6 Monthly temperature conditions near the Cheticamp Highlands National Park weather station (located approximately 69 kilometers from the Skye Glen site) during 2020.

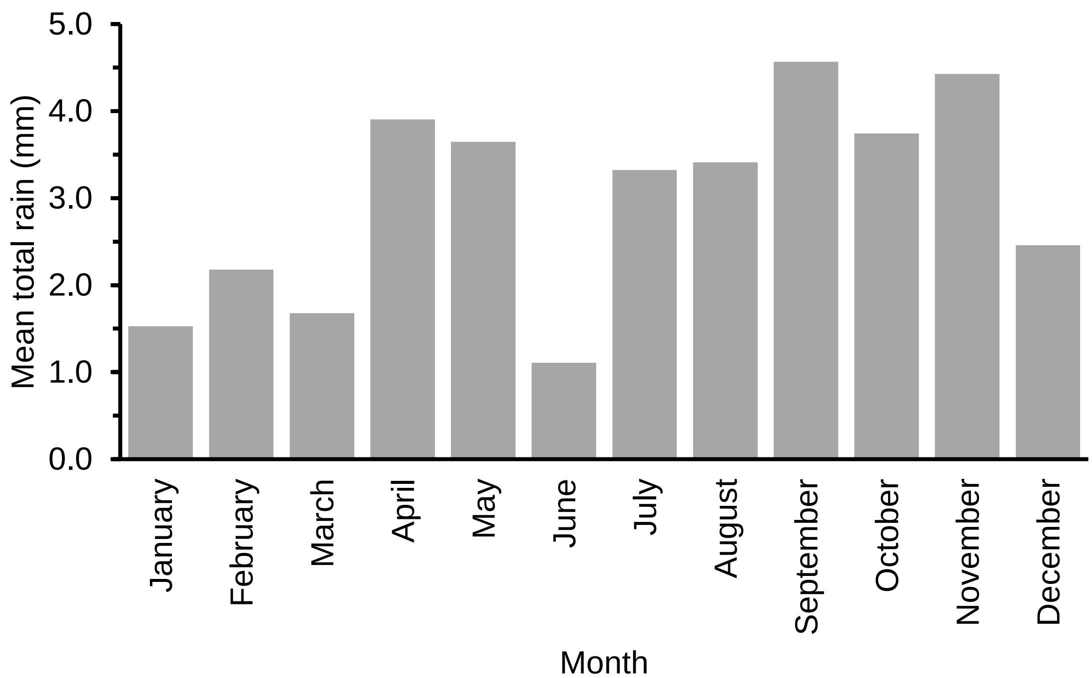


Figure 3.16.7 Monthly total rainfall near the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

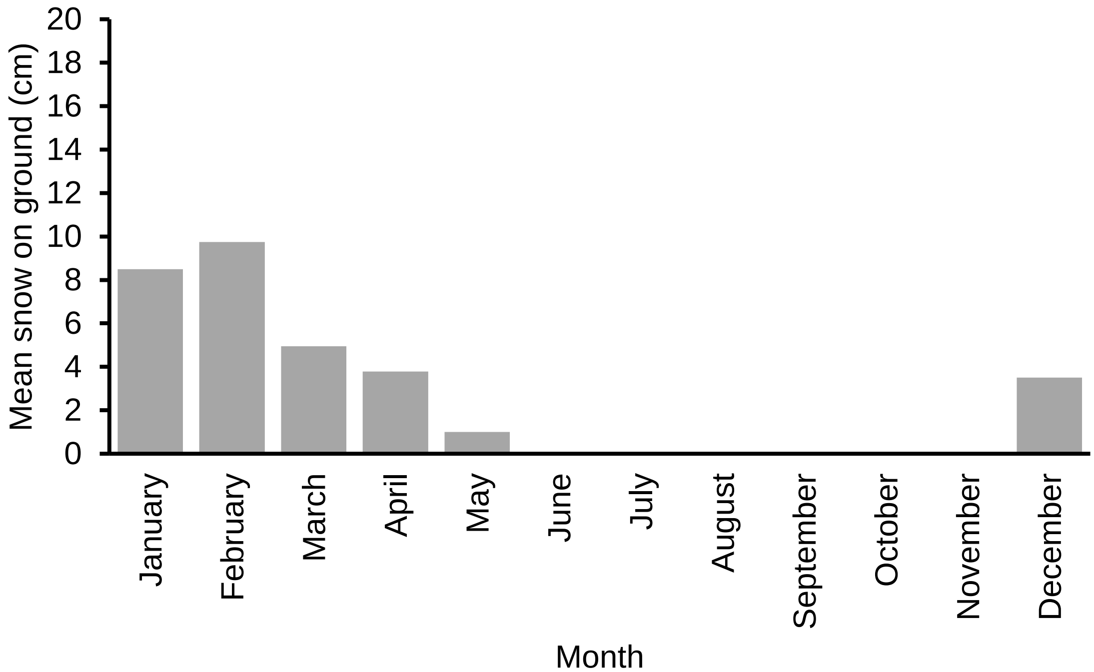


Figure 3.16.8 Monthly snow on ground near the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

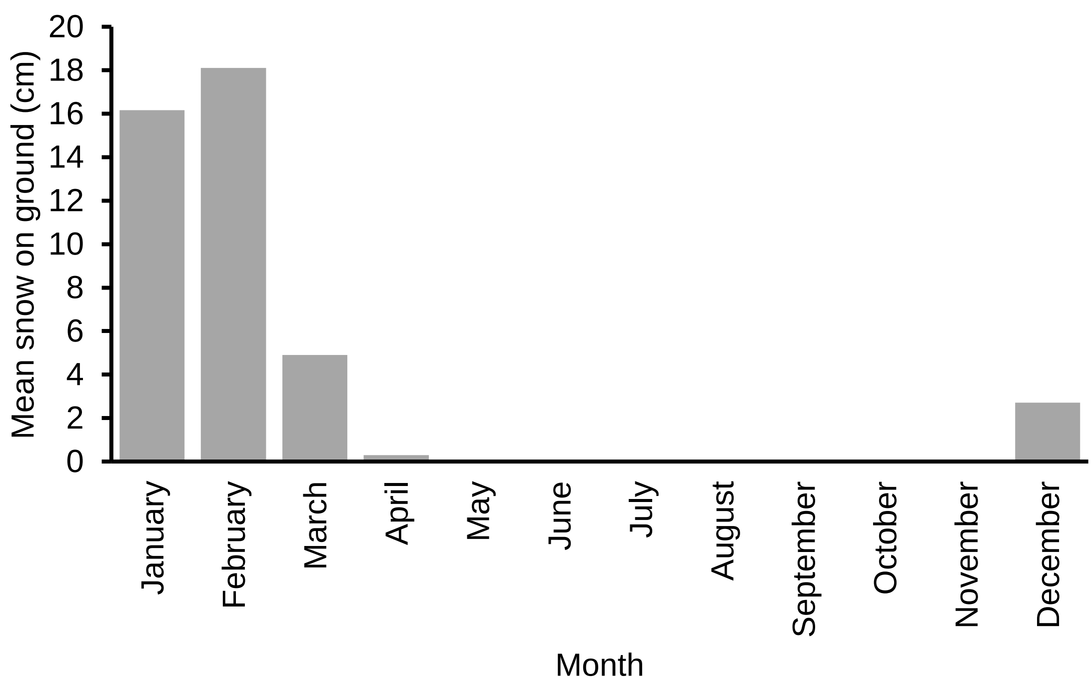


Figure 3.16.9 Monthly snow on ground near the Cheticamp Highlands National Park weather station (located approximately 69 kilometers from the Skye Glen site) during 2020.

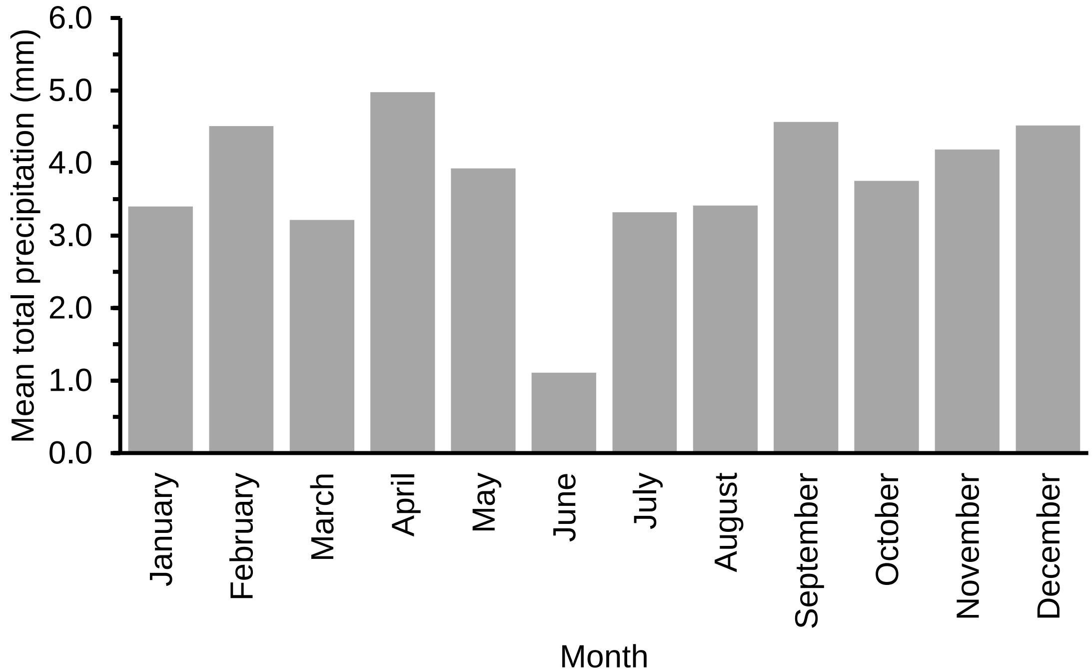


Figure 3.16.10 Monthly total precipitation near the Halifax Stanfield International Airport weather station (located approximately 28 kilometers from the East Gore site) during 2020.

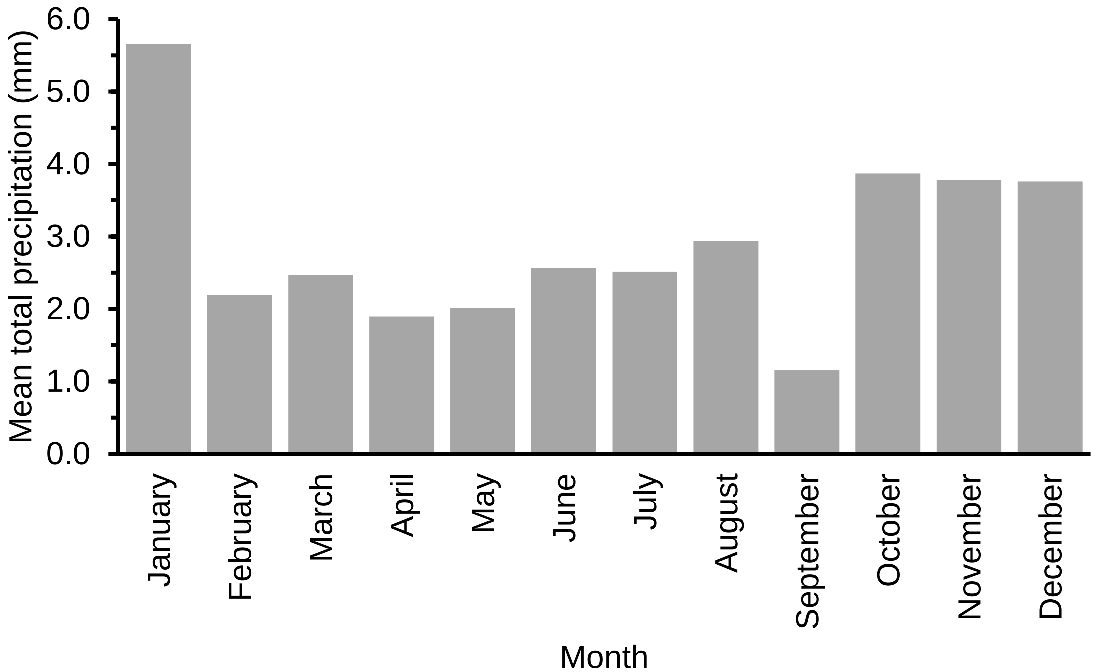


Figure 3.16.11 Monthly total precipitation near the Cheticamp Highlands National Park weather station (located approximately 69 kilometers from the Skye Glen site) during 2020.

The maximum daily temperature around the Stanfield International Airport occurred on the 20th of June at 31.9 °C, with the minimum on February 15th at -20.3 °C. Cheticamp Highlands National park experienced its hottest day on the 20th of July at 31.5 °C, while the coldest was on February 21st at -18.4 °C. Snow was reported at the Stanfield Airport station (fig. 3.16.8) for a longer duration of time than the Cheticamp Park station (fig. 3.16.9), though the latter had greater amounts of snowfall on average. The lowest amount of total precipitation happened over June for the Stanfield Airport station (1.1 mm; fig. 3.16.10) and September for the Cheticamp Park station (1.2 mm; fig. 3.16.11). Conversely, the greatest total precipitation was reported during the months of April (5.0 mm) for the Stanfield Airport station and January (5.7 mm) for the Cheticamp Park station.

At the Stanfield Airport station, average rainfall was most abundant in September (4.6 mm) and least abundant in June (1.1 mm; fig. 3.16.7).

4.0 RESULTS

To assess the establishment potential of four biomass crops treated with locally-sourced soil amendments on Nova Scotian marginal land, two growing sites were set up in East Gore, Hants County and Skye Glen, Inverness County. At these sites, four biomass crops (Miscanthus, switchgrass, coppiced poplar, and coppiced willow) were planted and treated with one of three soil amendments (*Ascophyllum nodosum* seaweed extract, paper mill sludge, anaerobic digestate) or a no-additives control. After one year, digestate and seaweed extract subplots received an additional application of their respective treatment using a split plot design. Parameters such as tissue nutrient concentration, plant height, and dry weight were collected at different times throughout the experiment to assess growth. The sample size (n) used for each crop was 4 (one sample per replicate), with the number of subsamples taken per sample varying by crop.

4.1 Biomass yield (2019)

In November of 2019, the aboveground biomass of all four energy crops were sampled from every subplot at both sites. The resulting dry weights of these samples were converted into dry weight per hectare and evaluated using analysis of variance through a normal or gamma model, as seen below.

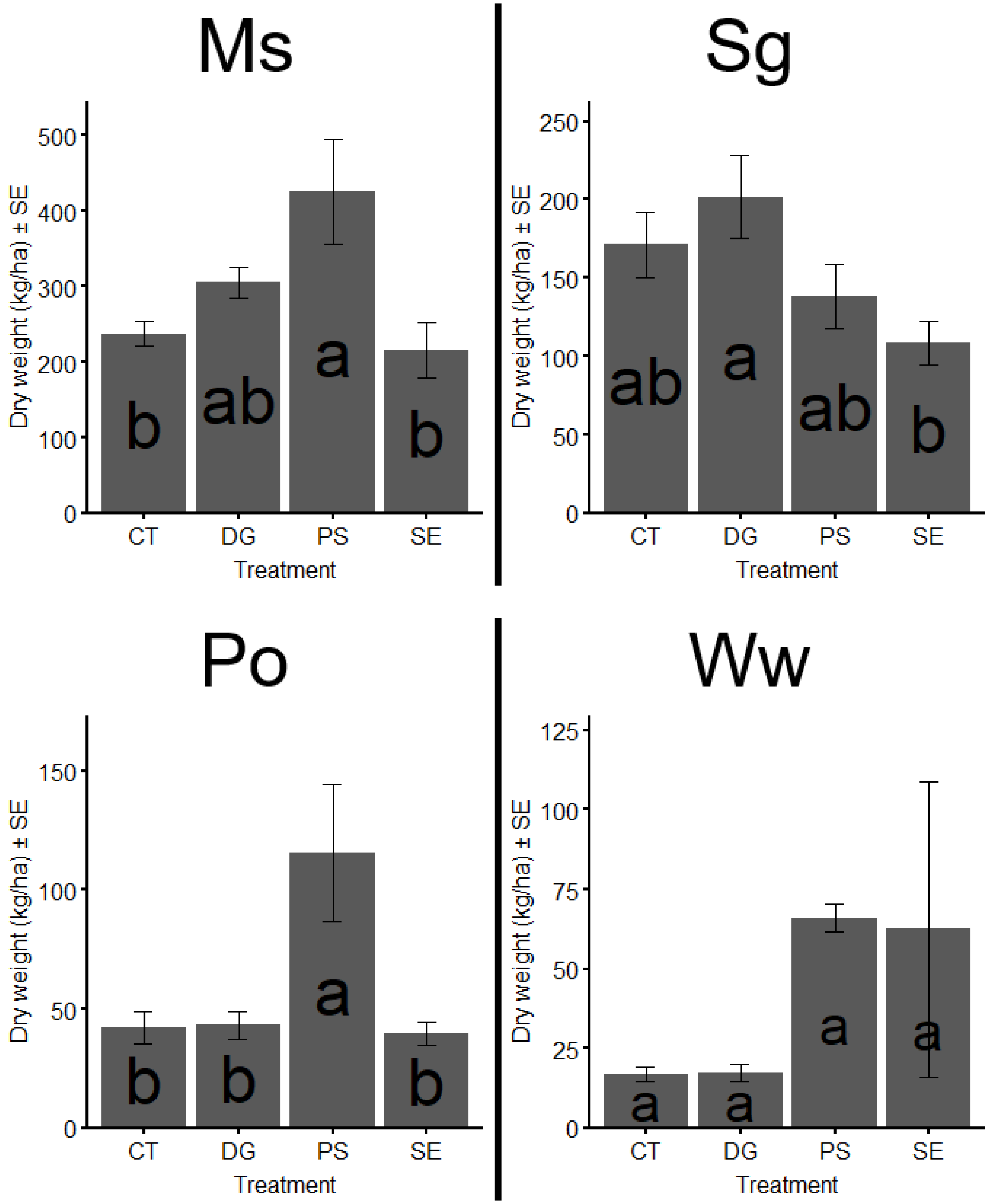


Figure 4.1.1 Aboveground biomass yield (dry weight per hectare) of four biomass crops (Miscanthus (Ms), switchgrass (Sg), poplar (Po), or willow (Ww)) grown under different soil amendment treatments (no additives control (CT), liquid *A. nodosum* extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) from a site in East Gore, Hants County

NS. Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

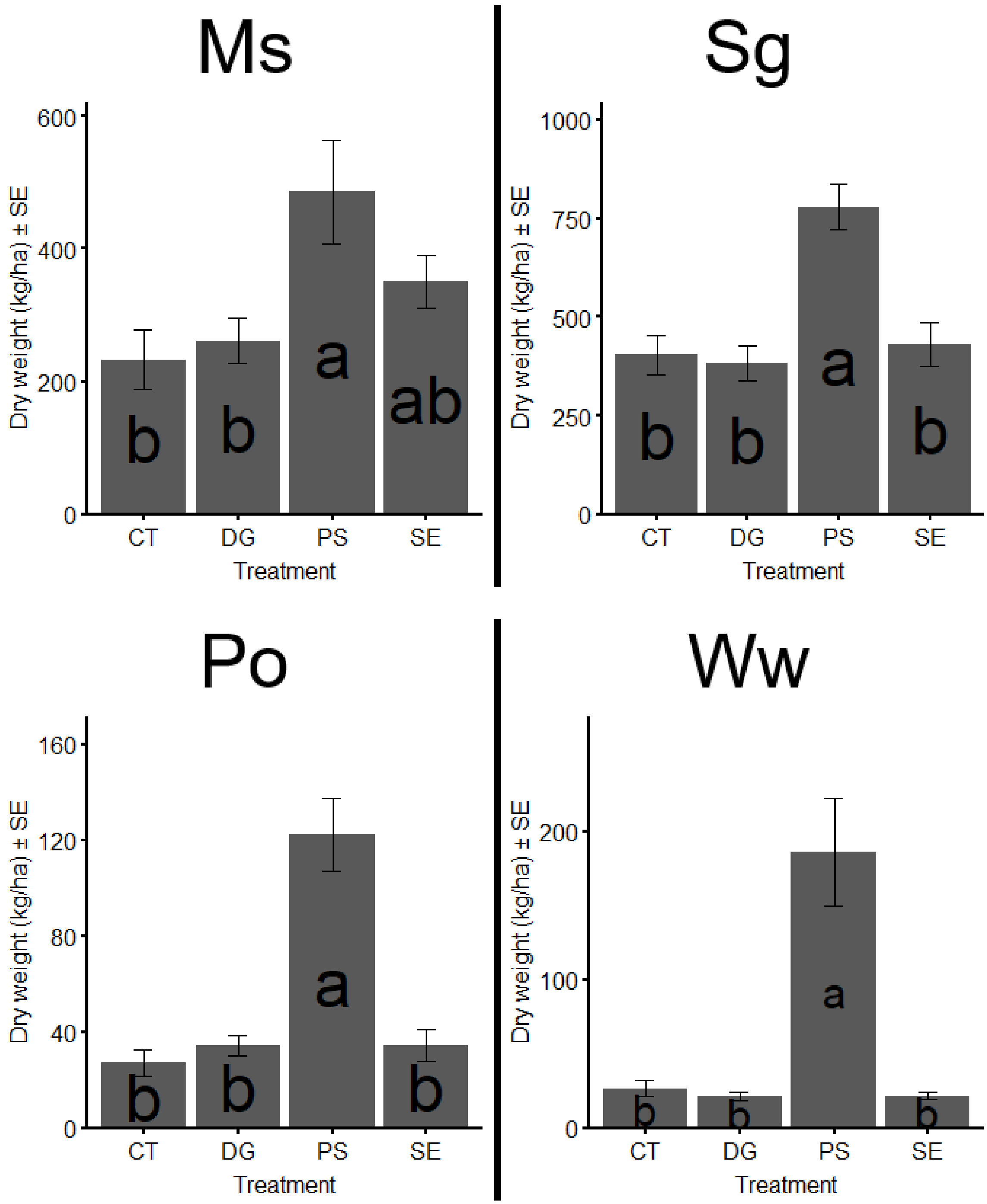


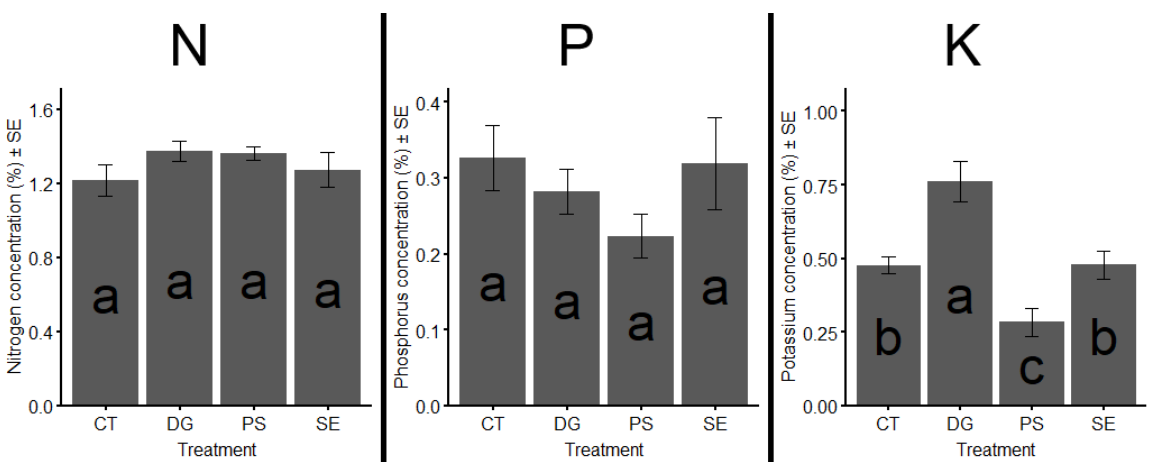
Figure 4.1.2 Aboveground biomass yield (dry weight per hectare) of four biomass crops (Miscanthus (Ms), switchgrass (Sg), poplar (Po), or willow (Ww)) grown under different

soil amendment treatments (no additives control (CT), liquid *A. nodosum* extract (SE), anaerobic digestate (DG), paper mill sludge (PS)) from a site in Skye Glen, Cape Breton NS. Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

One-way analyses of variance for treatment effects on year one yield was calculated using analysis of variance through a normal or gamma model. Statistical evaluations showed that crops grown in subplots treated with paper mill sludge had significantly higher yields compared to the control (p-values < 0.05), excluding switchgrass and willow in East Gore (fig. 4.1.1). In most cases, crops treated with anaerobic digestate and seaweed extract did not have a significantly higher yield compared to the control by year one harvest. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.2 Miscanthus tissue nutrient concentrations (2019)

Chemical analyses of aggregate Miscanthus dry matter samples were done by the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS using aboveground tissue samples collected in November of 2019.



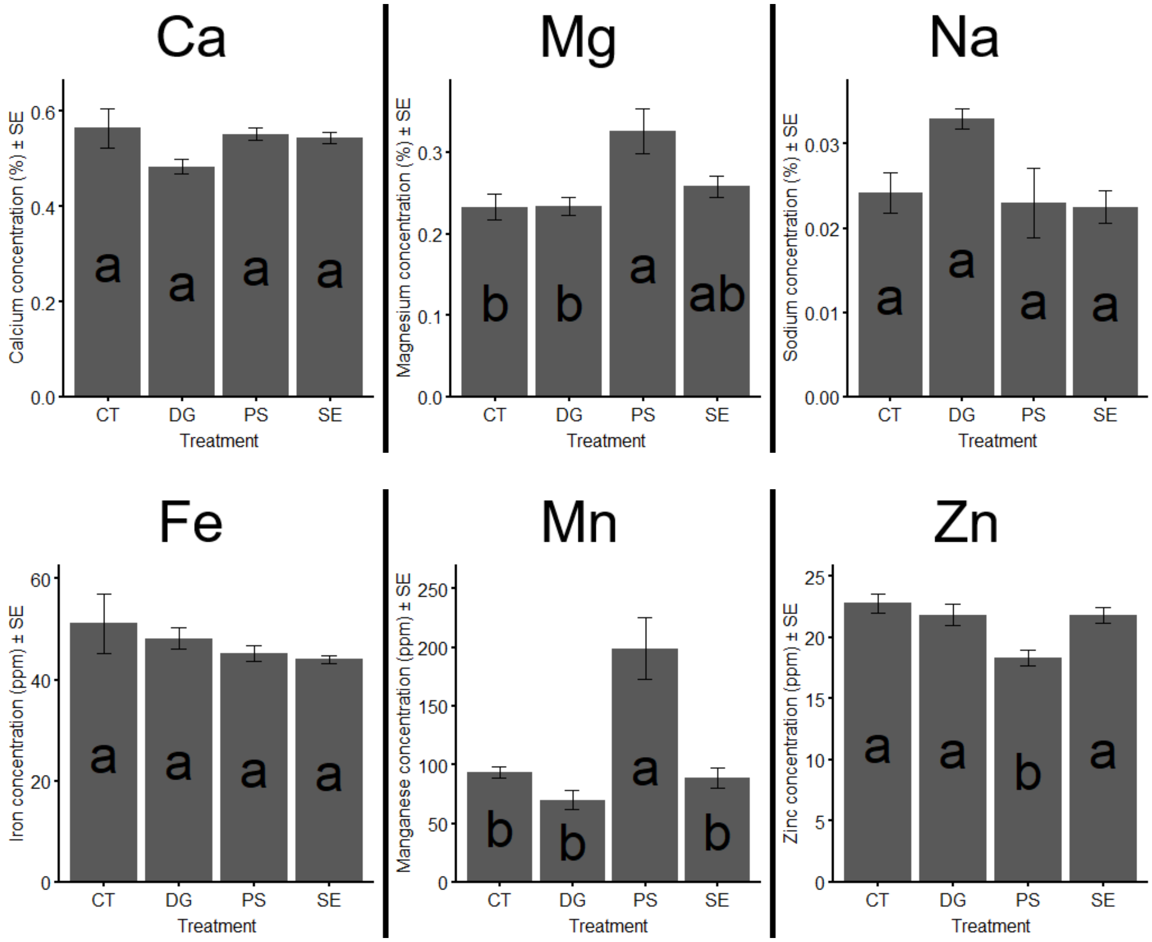


Figure 4.2.1 Effect of soil amendments on the nutrient concentrations (percent or ppm) of Miscanthus biomass from the East Gore site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

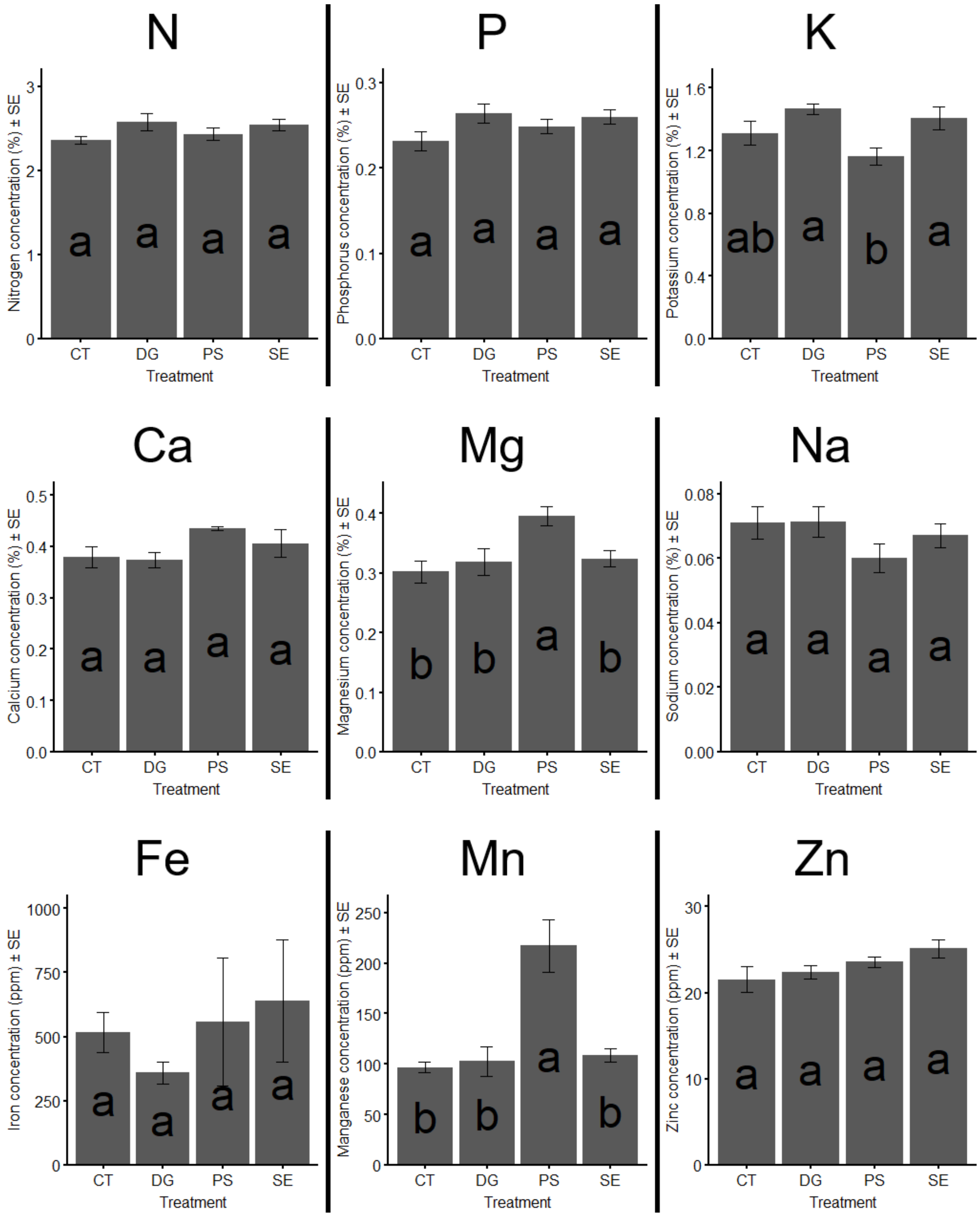


Figure 4.2.2 Effect of soil amendments on the nutrient concentrations (percent or ppm) of Miscanthus biomass from the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG).

Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

Analysis of variance found significant differences in the group means of potassium (p-value = 0.0002), magnesium (p = 0.0096), manganese (p = 4e-5), and zinc (p = 0.0060) concentrations for East Gore data. Subsequent post-hoc tests showed that the average magnesium and manganese concentration of the paper mill sludge group was higher than the control, with this pattern being reversed for potassium and zinc quantity. The average potassium concentration of the digestate group was also greater than that the control's. Following significant ANOVA results for magnesium (p = 0.0136) and manganese (p = 0.0002) nutrient concentrations for Skye Glen data, post-hoc testing showed the paper mill sludge treatment group as having an average measure above that of the control group. Complete one-way analyses of variance, post-hoc tests, and mean nutrient concentration tables can be found in the appendix.

4.3 Miscanthus nutrient yield (2019)

Miscanthus samples taken from 2019's fall harvest were chemically analyzed by the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS. These results were then converted into a yield measurement (kilogram per hectare) using dry weight and survival data. As data collection occurred shortly after planting, 100% survival was assumed.

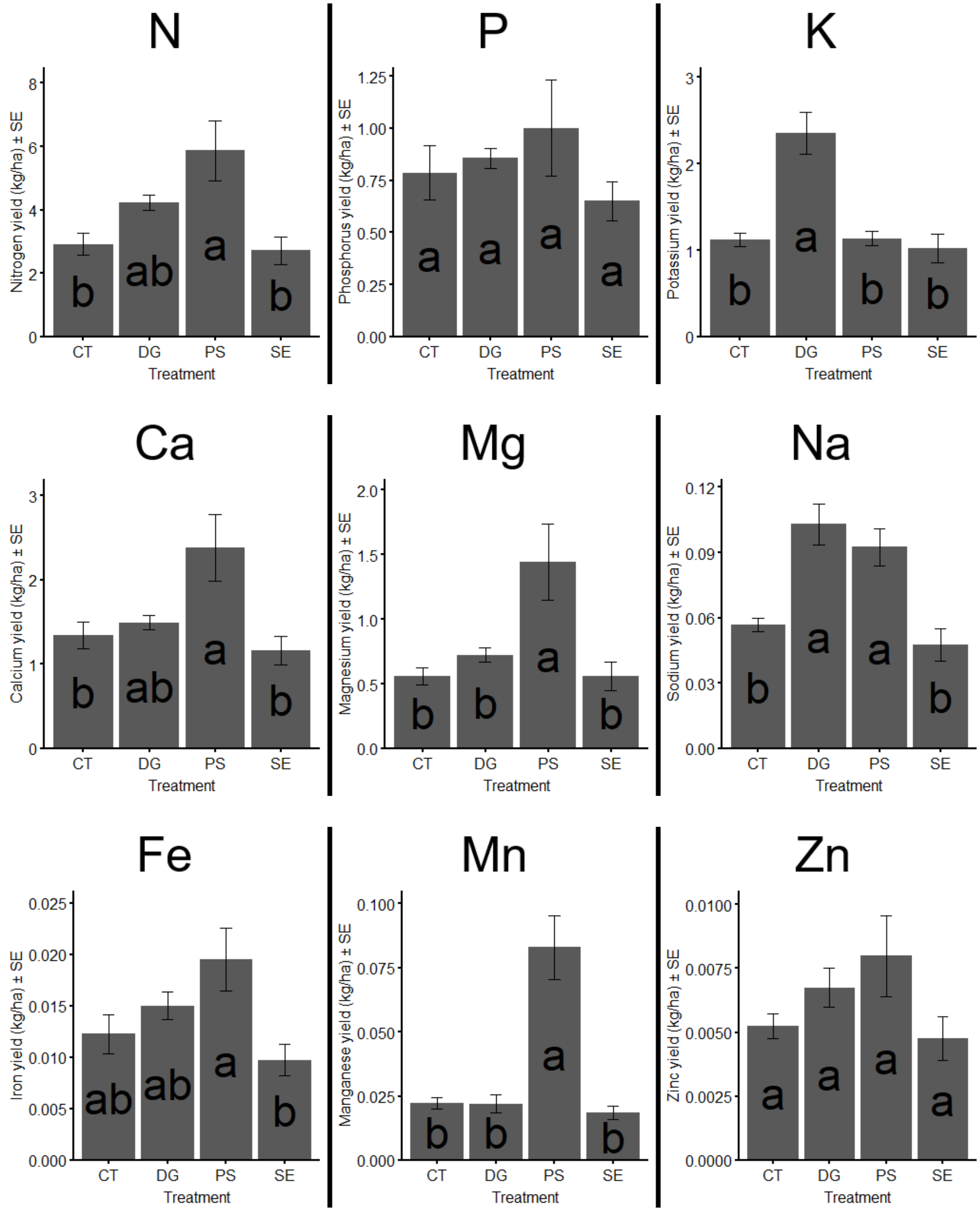


Figure 4.3.1 Effect of soil amendments on the nutrient yield of Miscanthus plant tissue (kg/ha) from the East Gore site. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge

(PS). Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

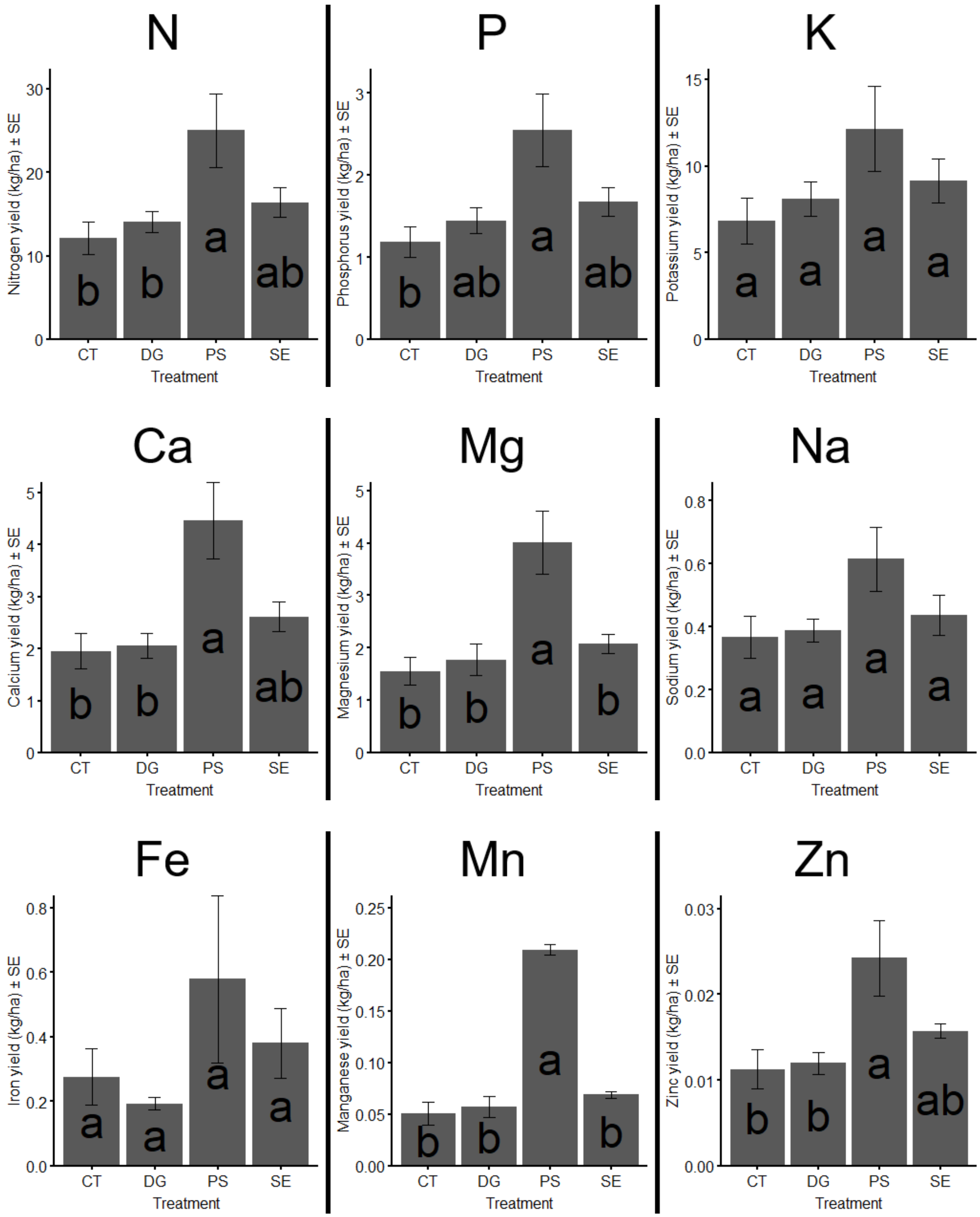


Figure 4.3.2 Effect of soil amendments on the nutrient yield of Miscanthus plant tissue (kg/ha) from the Skye Glen site. Amendments included a no additives control (CT),

anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

One-way analyses of variance for Miscanthus nutrient yield were calculated for several macro- and micronutrients. For both sites, the majority of analyses showed that the nutrient yield of Miscanthus in subplots treated with paper mill sludge was significantly higher than those in control subplots (p-values < 0.05). Miscanthus treated with anaerobic digestate in East Gore had significantly higher sodium and potassium yields compared to control plants (fig. 4.3.1). *Ascophyllum nodosum* extract did not have a significant effect on nutrient yield for any Miscanthus grown in East Gore. Phosphorus and zinc yields did not differ significantly for any soil amendment at East Gore. Miscanthus treated with digestate or seaweed extract in Skye Glen did not accumulate significantly more nutrients than untreated Miscanthus. In Skye Glen, sodium and iron yield did not vary considerably between subplots treated with different soil amendments (fig. 4.3.2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.4 Woody crop planting survival (2019)

Survival rates were obtained by taking the number of living poplar or willow in a subplot and dividing that value by 65 (the number of cuttings planted per subplot). In terms of average survival rates in East Gore, poplar and willow treated with digestate was lowest (poplar: 58/65 plants, 89% survival; willow: 55/65 plants, 85% survival), while the highest counts were from subplots treated with paper mill sludge/seaweed extract for poplar (61/65 plants, 94% survival) or paper mill sludge for willow (62/65 plants, 95% survival). In Skye Glen, the lowest survival rates were from poplar in control subplots (46/65 plants, 71%

survival) and willow in digestate/seaweed extract subplots (54/65 plants, 83% survival). The control subplot had the highest average survival rate for willow (58/65 plants, 89% survival), with paper mill sludge having the highest value for poplar (54/65 plants, 83% survival). Analysis of variance showed that all p-values were greater than the alpha (see appendix), meaning the null hypothesis (group means are equal) was not rejected. In other words, there were no significant differences in survival rates between treatment groups at both sites.

August plant growth

To assess plant performance midway through the growing season, several crop growth parameters were measured at the Skye Glen and East Gore sites mid-August 2020. These parameters included survival, leaf area, and plant height, and were statistically evaluated using analysis of variance through a normal or gamma model in the R programming language. The results of these analyses can be seen below.

4.5 Survival rate, 2020

A cumulative measure of survival (encompassing both planting and overwintering survival rate) was calculated by taking the number of living plants per Miscanthus, poplar and willow subplot (counted during August data collection) and dividing their respective sums by the total number of crops planted per subplot (65 for poplar and willow, or 90 for Miscanthus).

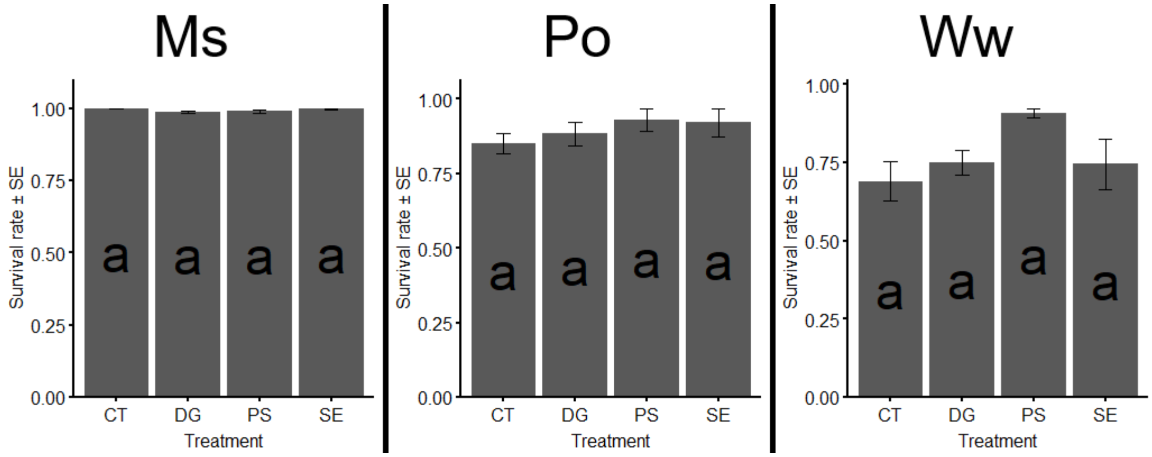


Figure 4.5.1 Effect of soil amendments on the survival rate of Miscanthus (Ms), poplar (Po), and willow (Ww) from the East Gore site. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

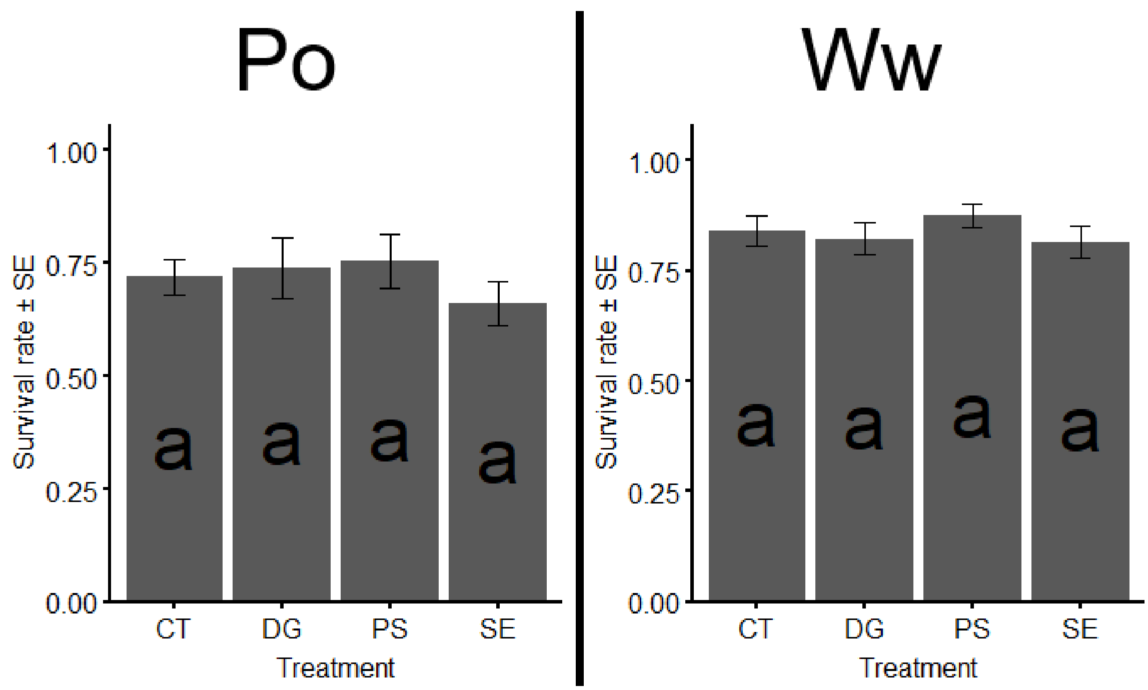


Figure 4.5.2 Effect of soil amendments on the survival rate of poplar (Po), and willow (Ww) from the Skye Glen site. Amendments included a no additives control (CT),

anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

The treatment group with the highest mean survival value was paper mill sludge, while the lowest mean value was typically associated with crops in the control group for East Gore (fig. 4.5.1) and the seaweed extract group for Skye Glen (fig. 4.5.2). Barring Miscanthus, the single highest mean value was from poplar in East Gore treated with paper mill sludge (0.93), while the lowest was from poplar in Skye Glen treated with seaweed extract (0.66). Data analysis showed that there was no statistically significant difference in survival rates between treatment groups for each crop (p-values ≥ 0.05). Complete one-way analyses of variance for these data can be seen in the appendix.

4.6 Poplar leaf count (August 2020)

The total number of leaves on select poplar trees (10 subsamples per subplot) was measured during August data collection.

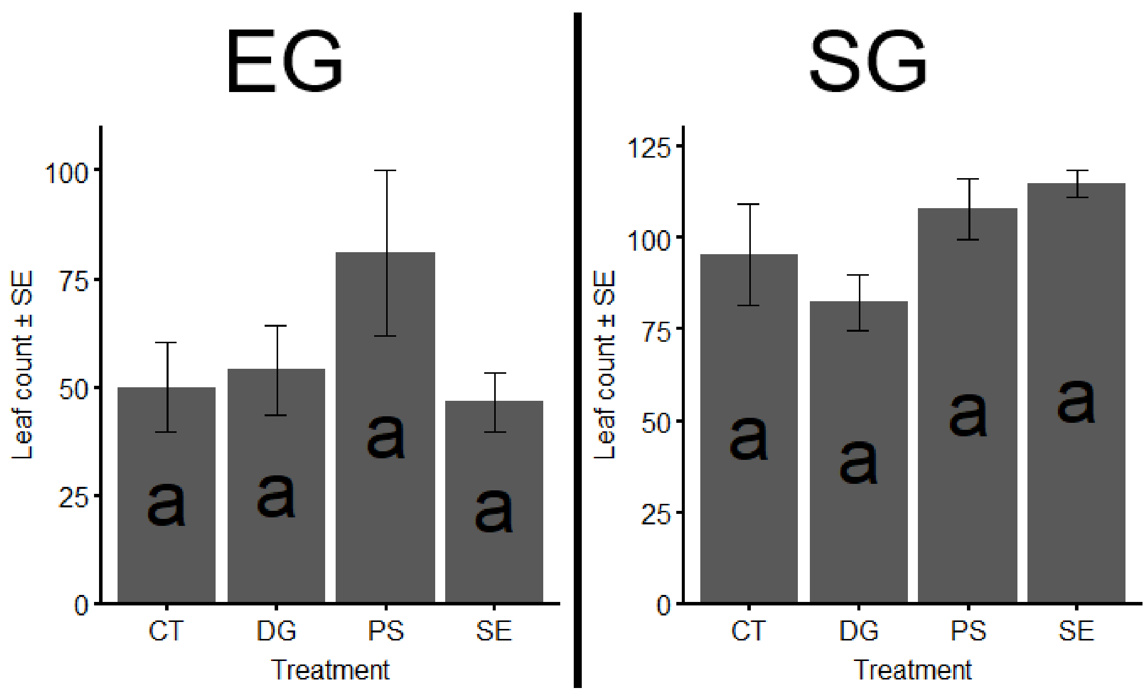


Figure 4.6.1 Effect of soil amendments on the leaf count of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

The treatment groups with the lowest mean leaf count values were seaweed extract and anaerobic digestate for the East Gore (fig. 4.6.1) and Skye Glen (fig. 4.6.2) sites, respectively – statistically, they were not significantly different than the control (p-values > 0.05). Conversely, the highest mean values occurred with the paper mill sludge and seaweed extract groups (again, respectively). Despite the paper mill sludge group's mean count value being 1.6-fold larger than the control, it was not a statistically significant difference ($p = 0.225$), likely due to its high variance (as visualized in the appendix). Skye Glen data were similarly nonsignificant ($p = 0.108$). Complete one-way analyses of variance for these data can be seen in the appendix.

4.7 Poplar leaf area (August 2020)

The area of each individual leaf on select poplar trees (10 subsamples per subplot) was measured using a portable leaf area meter during August data collection.

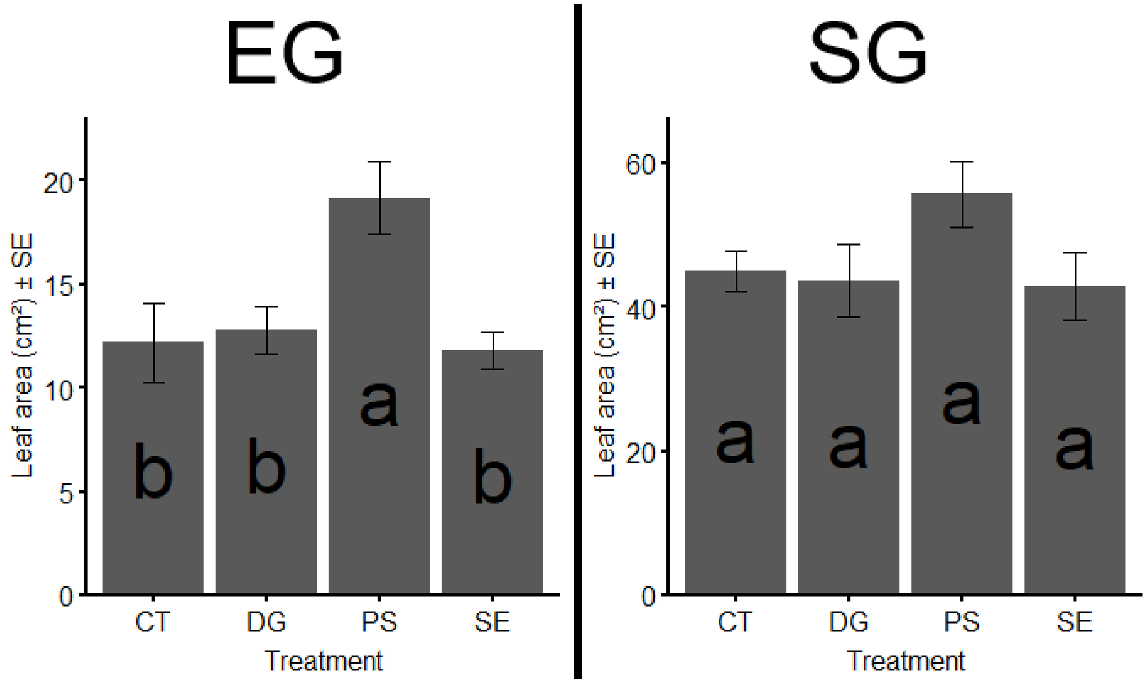


Figure 4.7.1 Effect of soil amendments on the leaf area (cm^2) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

Both sites show similar patterns, with the lowest mean leaf area value belonging to the seaweed extract treatment group (EG: 11.8 cm^2, SG: 42.9 cm^2), and the highest to the paper mill sludge group (EG: 11.8 cm^2, SG: 42.9 cm^2). Mean values between the control and treatment groups were not significantly different from each other in Skye Glen ($p = 0.187$). In the East Gore site, analysis of variance showed the paper mill sludge group as having a significantly higher mean area value than the other groups (p-values < 0.05). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.8 Poplar stem count (August 2020)

The total number of stems on select poplar trees (10 subsamples per subplot) was measured during August data collection.

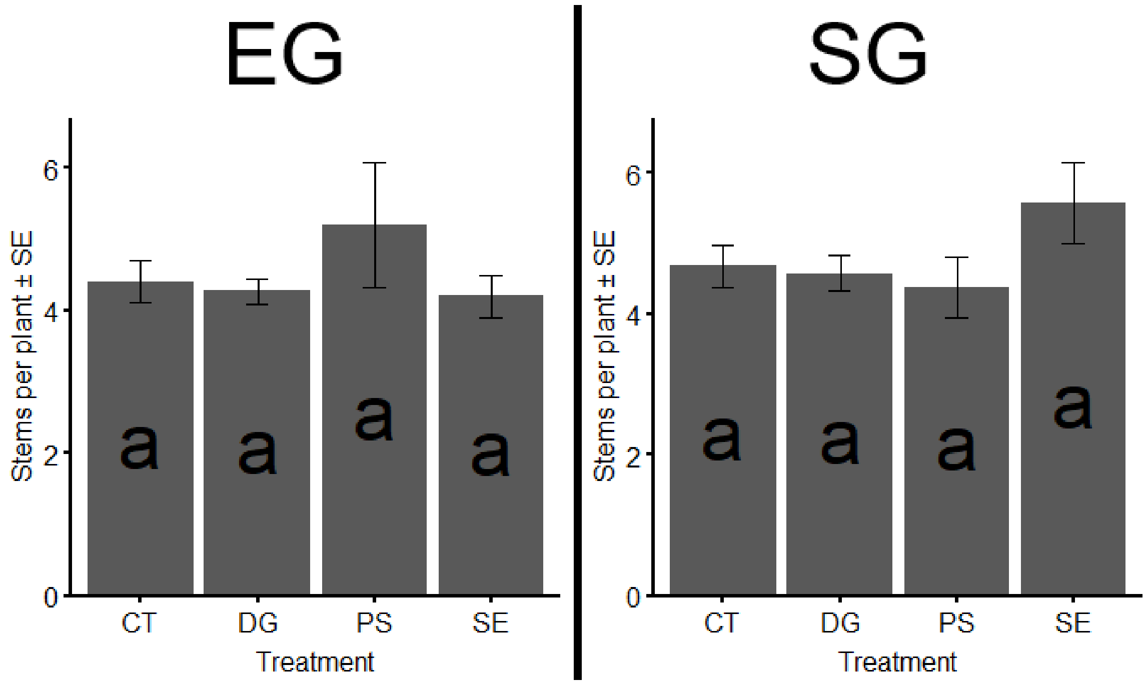


Figure 4.8.1 Effect of soil amendments on the stem count of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

The highest mean stem count value for poplar at the East Gore site (fig. 4.8.1) was from paper mill sludge treatment subplots (5.2), with the lowest mean value being from seaweed extract treatment subplots (4.2). The opposite was seen in the Skye Glen data (fig. 4.8.2), where the paper mill sludge group had the lowest mean values (4.4) and seaweed extract the highest (5.6). Analysis of variance found treatment group mean values had no statistically significant difference from that of the control's (p-values ≥ 0.05). Complete one-way analyses of variance for these data can be seen in the appendix.

4.9 Poplar average stem length (August 2020)

The length of each stem on select poplar trees (10 subsamples per subplot) was measured during August data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

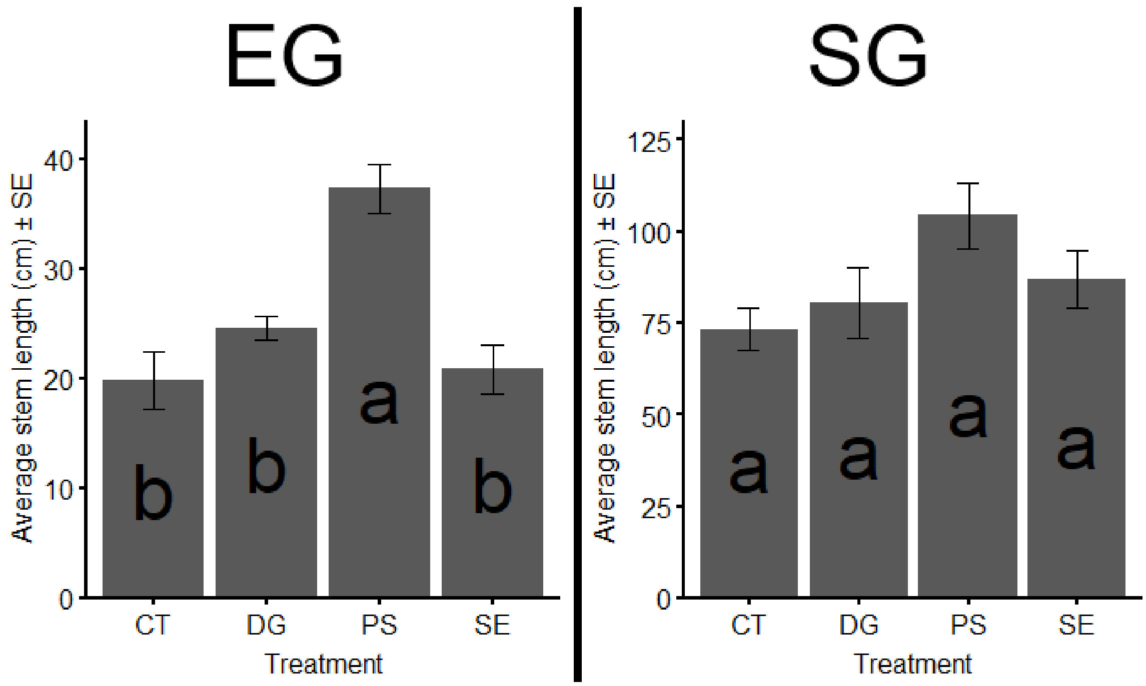


Figure 4.9.1 Effect of soil amendments on the average stem length (cm) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

Assessing length per stem rather than a combined measurement reveals different patterns. The lowest and highest mean length values were associated with the control (EG:

19.8 cm, SG: 73.3 cm) and paper mill sludge (EG: 37.3 cm, SG: 104.2 cm) treatment groups, respectively, for both sites. While analysis of variance did not find significance with Skye Glen data, it was determined that the mean value of the paper mill sludge treatment group was significantly different than the other groups for East Gore data (p-values < 0.05). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.10 Poplar total stem length (August 2020)

The length of each stem on select poplar trees (10 subsamples per subplot) was measured during August data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

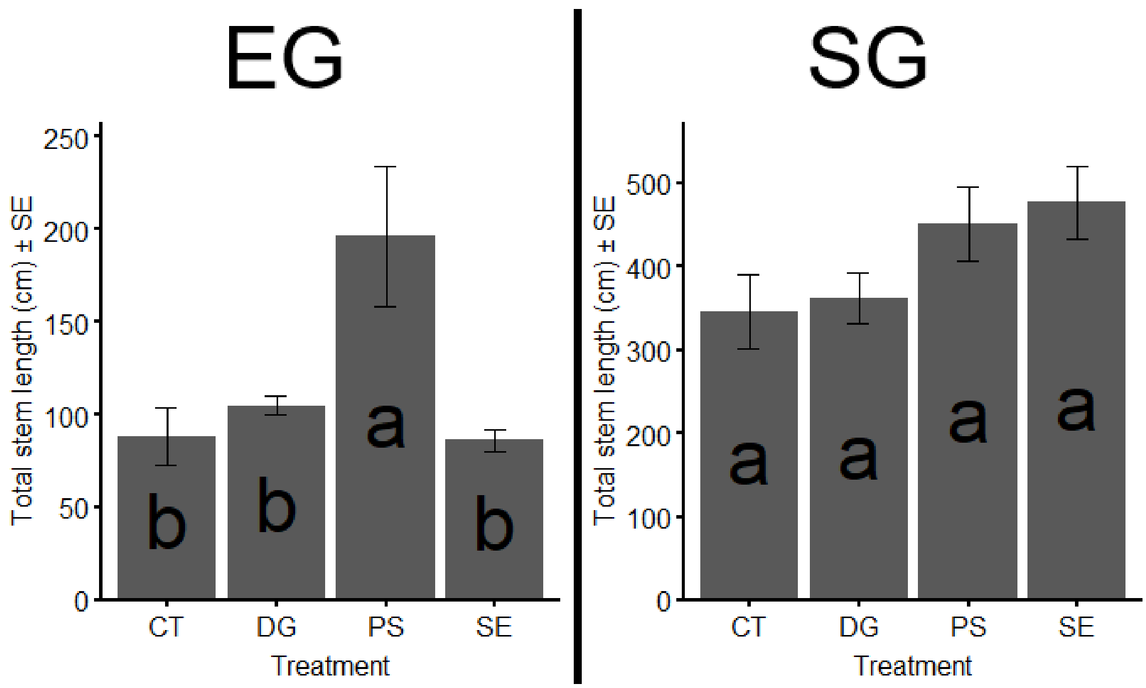


Figure 4.10.1 Effect of soil amendments on the total stem length (cm) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill

sludge (PS). 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.

In terms of characterizing these data, the highest mean length value was seen in the paper mill sludge (196.1 cm) and seaweed extract treatment groups (476.9 cm) for the East Gore (fig. 4.10.1) and Skye Glen (fig. 4.10.2) data, respectively. The lowest mean values were from East Gore's seaweed extract treatment group (86.1 cm; though the control treatment was similar at 87.9 cm) and Skye Glen's control group (346.2 cm). Analysis of variance found a significant difference between treatment group mean values for East Gore's data (p = 0.002), but not for Skye Glen's data (p = 0.114). Specifically, the paper mill sludge treatment group had a significantly higher total stem length compared to the other groups. For instance, there was a 2.2-fold difference between the paper mill sludge treatment group and the control. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.11 Willow leaf count (per tallest stem; August 2020)

The number of leaves on the longest stem of select willow trees (10 subsamples per subplot) were measured during August data collection.

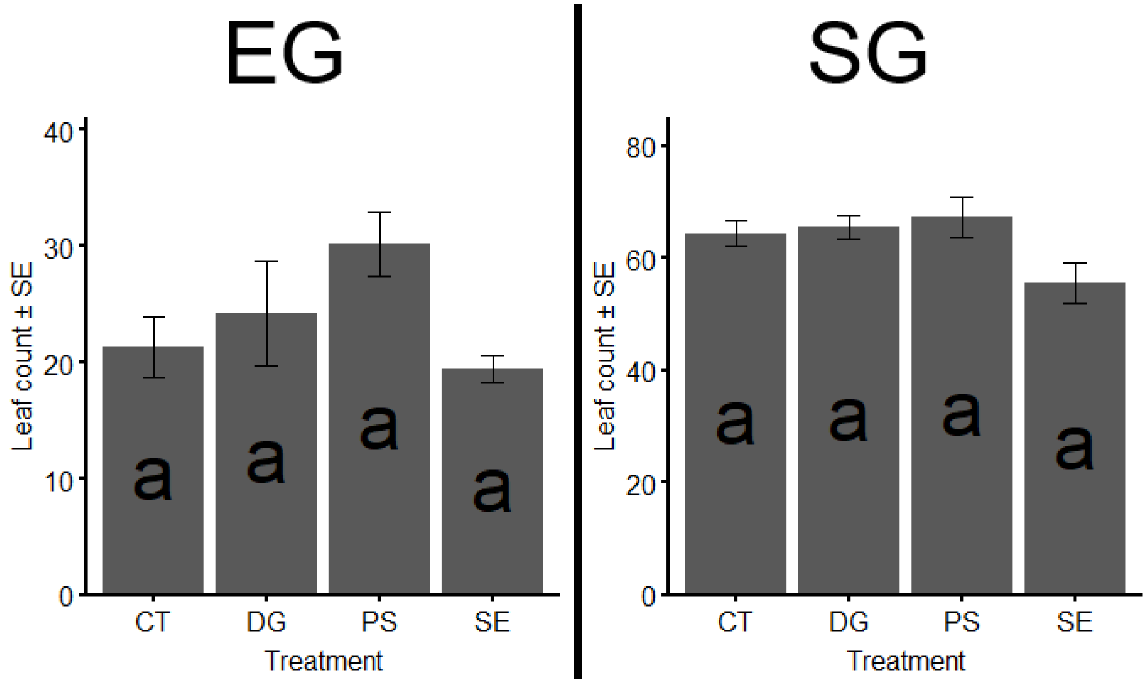


Figure 4.11.1 Effect of soil amendments on the leaf count of the tallest willow stems from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

The groups with the highest (paper mill sludge; EG: 30.2, SG: 67.4) and lowest (seaweed extract; EG: 19.5, SG: 55.5) mean leaf count values were the same for both sites. Treatment group mean values from either site were statistically determined to have no significant differences (EG: $p = 0.112$; fig. 4.11.1, SG: $p = 0.066$; fig. 4.11.2) through one-way analyses of variance, which can be seen fully in the appendix.

4.12 Willow leaf area (per tallest stem; August 2020)

Ten leaves from the middle of the longest stem on select willow trees (10 subsamples per subplot) were destructively sampled during August data collection.

Leaves were later measured in lab using a portable leaf area meter. Leaves were not sampled in the East Gore site to avoid impacting performance.

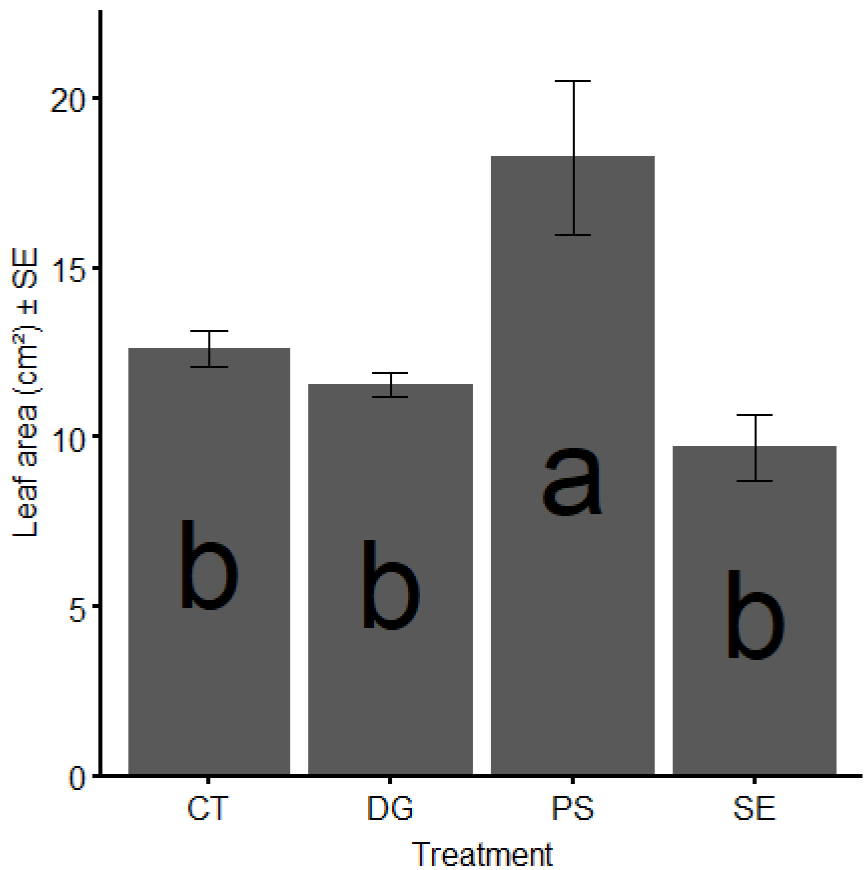


Figure 4.12.1 Effect of soil amendments on the leaf area (cm^2) of willow from the Skye Glen site. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

The highest mean value for leaf area was from the paper mill sludge treatment group (18.3 cm^2), which was 1.5-fold larger than the control group (12.6 cm^2). Analysis of variance found this difference to be statistically significant (p-value = 0.0012). Inversely, the seaweed extract treatment group mean value was the lowest at 9.7 cm^2. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.13 Willow stem count (August 2020)

The total number of stems on select willow trees (10 subsamples per subplot) was measured during August data collection.

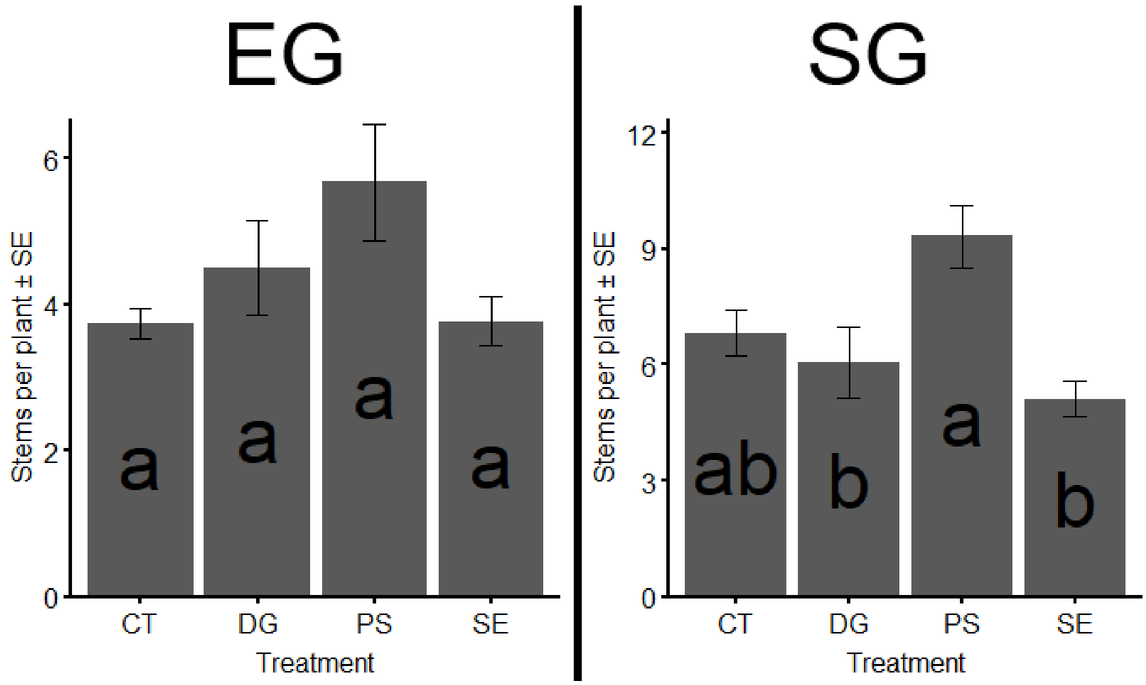


Figure 4.13.1 Effect of soil amendments on the stem count of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

The highest and lowest mean stem count values for the East Gore site were 5.7 and 3.8 for the paper mill sludge and the control/seaweed extract treatment groups, respectively. Skye Glen followed the same pattern; however the control group mean value (6.8) was larger than the seaweed extract's (5.1). In terms of significance, the Skye Glen treatment groups were statistically different from each other (p-value = 0.0080; fig. 4.13.2), while East Gore's were not (p-value = 0.0932; fig. 4.13.1). Specifically, Skye Glen's paper mill sludge treatment group was significantly different than the digestate and seaweed extract groups, but not the control group. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.14 Willow average stem length (August 2020)

The length of each stem on select willow trees (10 subsamples per subplot) was measured during August data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

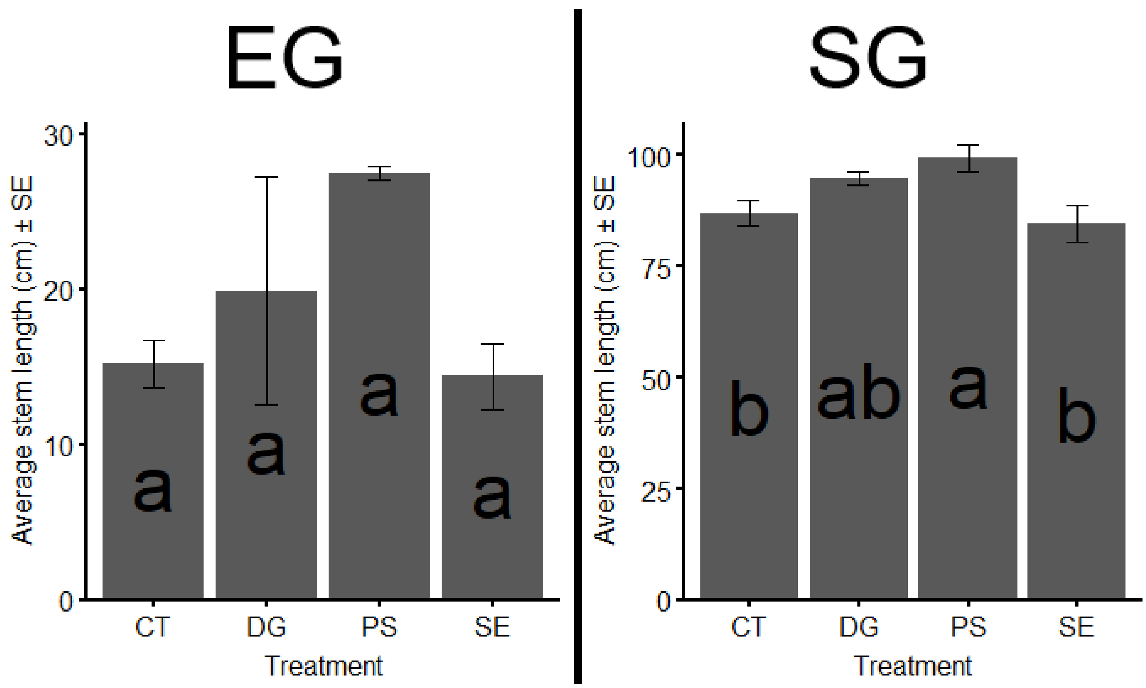


Figure 4.14.1 Effect of soil amendments on the average stem length (cm) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill

sludge (PS). 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.

The highest and lowest mean length value occurred with the same groups as total length, being the paper mill sludge (EG: 27.5 cm, SG: 99.3 cm) and seaweed extract treatments (EG: 14.4 cm, SG: 84.5 cm), respectively. On a per stem basis, differences in mean values between the control and paper mill sludge groups (EG: 1.8-fold, SG: 1.1-fold) were less pronounced. Analysis of variance found a significant difference in mean length values between treatment groups for the Skye Glen data (p = 0.019; fig. 4.14.2), but not the East Gore data (p = 0.124; fig. 4.14.1). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.15 Willow total stem length (August 2020)

The length of each stem on select willow trees (10 subsamples per subplot) was measured during August data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

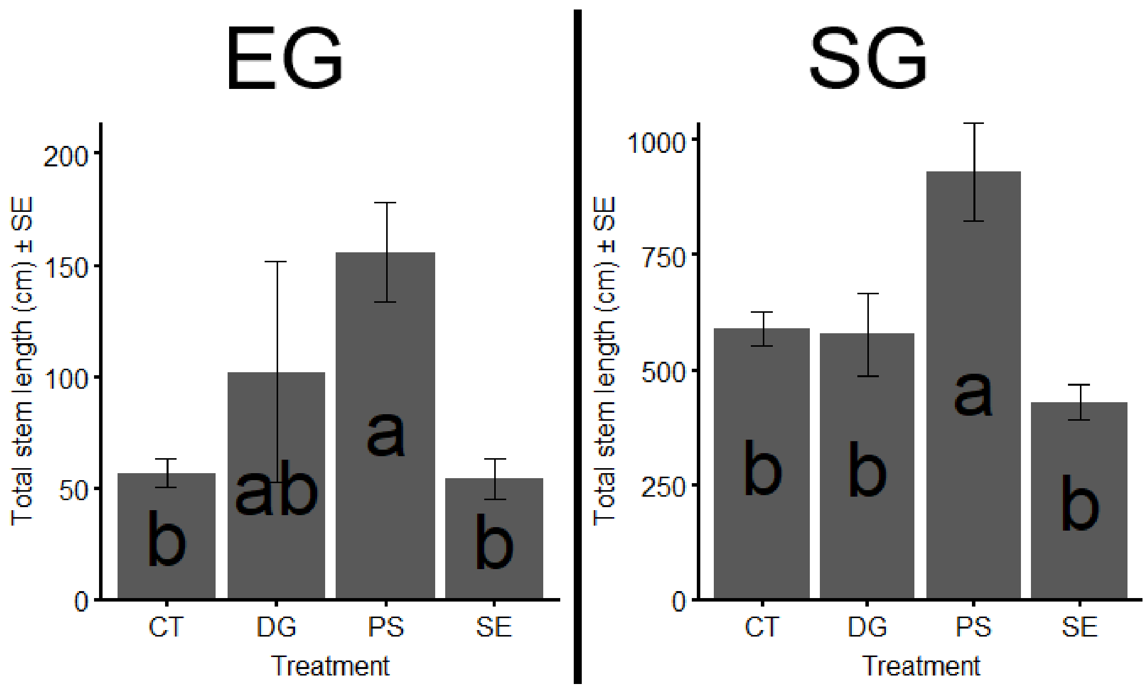


Figure 4.15.1 Effect of soil amendments on the total stem length (cm) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

At both sites, the seaweed extract treatment groups were lowest in terms of total stem length mean values (EG: 54.6 cm, SG: 430.5 cm), while the paper mill sludge treatment groups were highest (EG: 156.0 cm, SG: 931.2 cm). The mean value of the paper mill sludge group was significantly larger than the control (EG: 2.7-fold difference, SG: 1.6-fold difference), as shown by statistical analysis (EG: $p = 0.05$; fig. 4.15.1; SG: $p = 0.00333$; fig. 4.15.2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.16 Miscanthus tiller count (August 2020)

The total number of tillers from select Miscanthus plants were counted during August data collection.

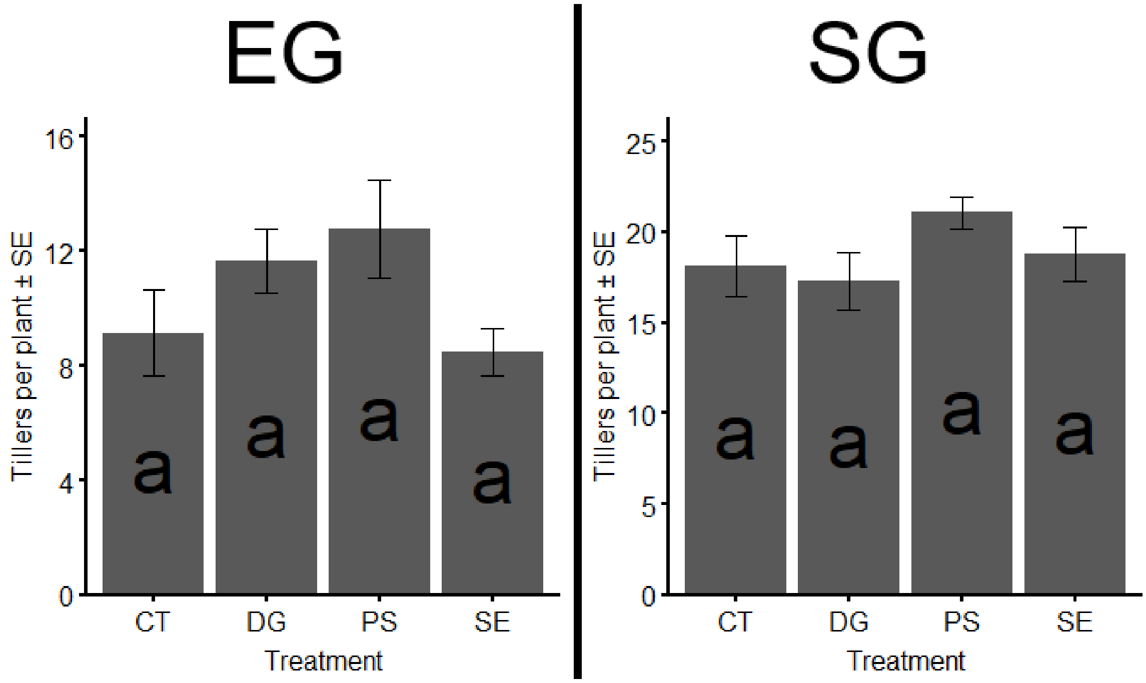


Figure 4.16.1 Effect of soil amendments on the tiller count of Miscanthus from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

According to analyses of variance, there was no statistically significant difference between the number of Miscanthus tillers per treatment group for both the East Gore (p = 0.126) and Skye Glen (p = 0.329) sites. For mean count values, the paper mill sludge group was highest (EG: 12.8, SG: 21.1), while the seaweed extract and anaerobic digestate groups were lowest (East Gore (8.5) and Skye Glen (17.3), respectively). Complete one-way analyses of variance of these data can be seen in the appendix.

4.17 Miscanthus leaf length (per tallest tiller; August 2020)

The longest tiller of select Miscanthus plants (10 subsamples per subplot) was destructively sampled during August data collection. Leaves from these stems were later measured using a portable leaf area meter. Stems were not destructively measured in the East Gore site to avoid impacting performance.

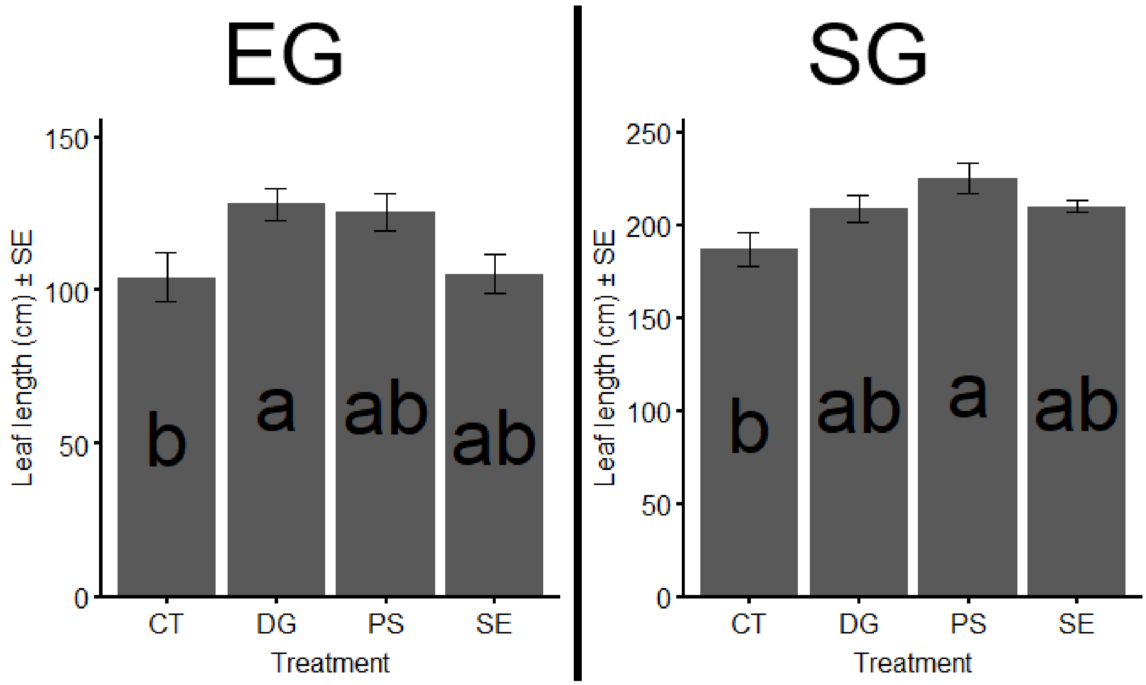


Figure 4.17.1 Effect of soil amendments on the leaf length (per tallest tiller; cm) of Miscanthus from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within 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.

In terms of mean length values, the anaerobic digestate (EG: 128.1 cm) and paper mill sludge groups (SG: 225.7 cm) were highest, while the control values were the lowest for both sites (EG: 104.3 cm, SG: 187.4 cm). For both sites, analysis of variance found significance between treatment groups (EG: $p = 0.0376$, fig. 4.17.1; SG: $p = 0.0234$, fig. 4.17.2). Tukey's post-hoc test for East Gore data revealed that the digestate group mean value was different than the control's (p-value = 0.0450), with the same being true for Skye

Glen's paper mill sludge group (p-value = 0.0013). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.18 Miscanthus leaf area (per tallest tiller; August 2020)

Leaves from the longest tiller of select Miscanthus plants (10 subsamples per subplot) were measured using a portable leaf area meter during August data collection. Average area per leaf was then obtained by taking the combined area of each leaf blade (per tallest tiller) and dividing it by the total leaf count of the tiller it originated from.

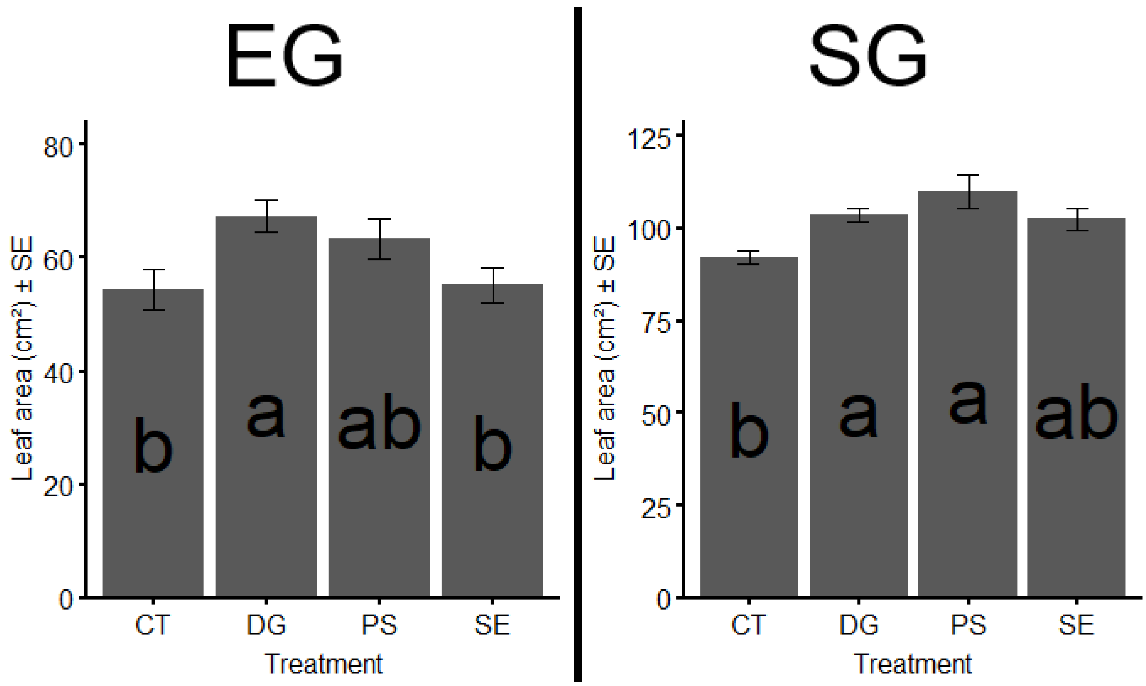


Figure 4.18.1 Effect of soil amendments on the leaf area of Miscanthus (per tallest tiller) from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract (SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

The lowest mean leaf area value for both sites was the control group (EG: 54.5 cm^2, SG: 92.3 cm^2), while the highest were the digestate and paper mill sludge groups for East

Gore (67.4 cm^2; fig. 4.18.1) and Skye Glen data (109.4 cm^2; fig. 4.18.2), respectively. Analyses of variance for both sites had p-values less than the alpha (0.05; EG p-value = 0.0461; SG p-value = 0.0166), with Tukey's post-hoc test showing the digestate and paper mill sludge group as significantly different than the control group for the East Gore (p = 0.0295) and Skye Glen data ($p < 0.001$), respectively. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.19 Miscanthus total leaf area (per tallest tiller; August 2020)

Leaves from the longest tiller of select Miscanthus plants (10 subsamples per subplot) were measured using a portable leaf area meter during August data collection. Total leaf area was then obtained by combining the area of all leaves from each respective tiller.

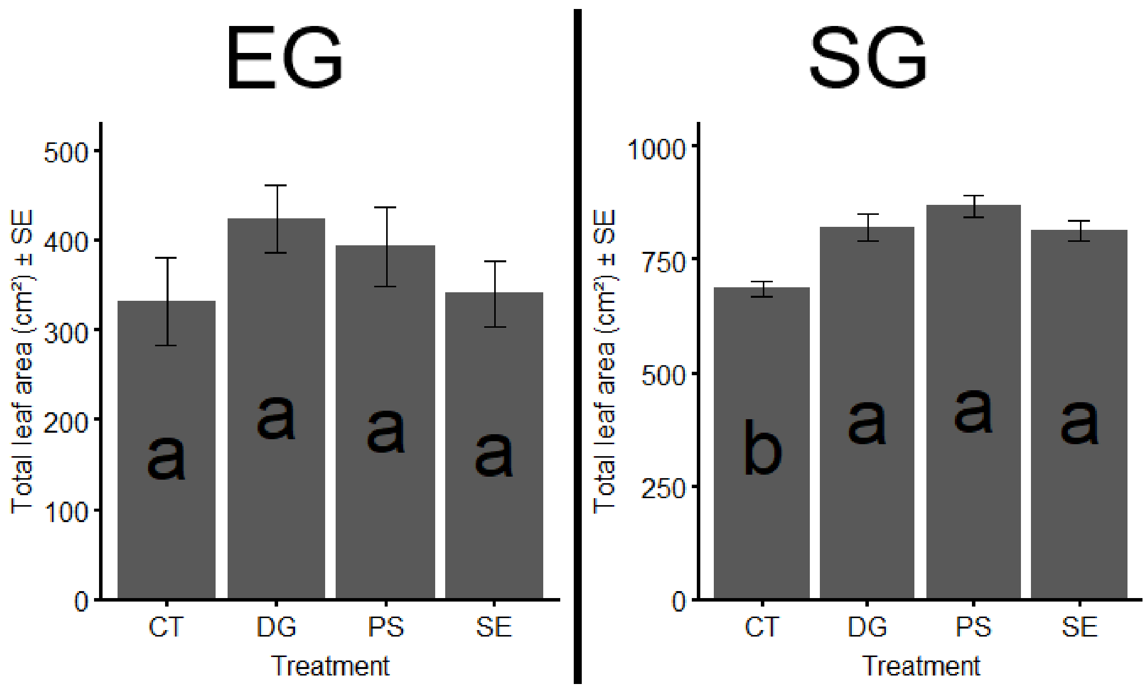


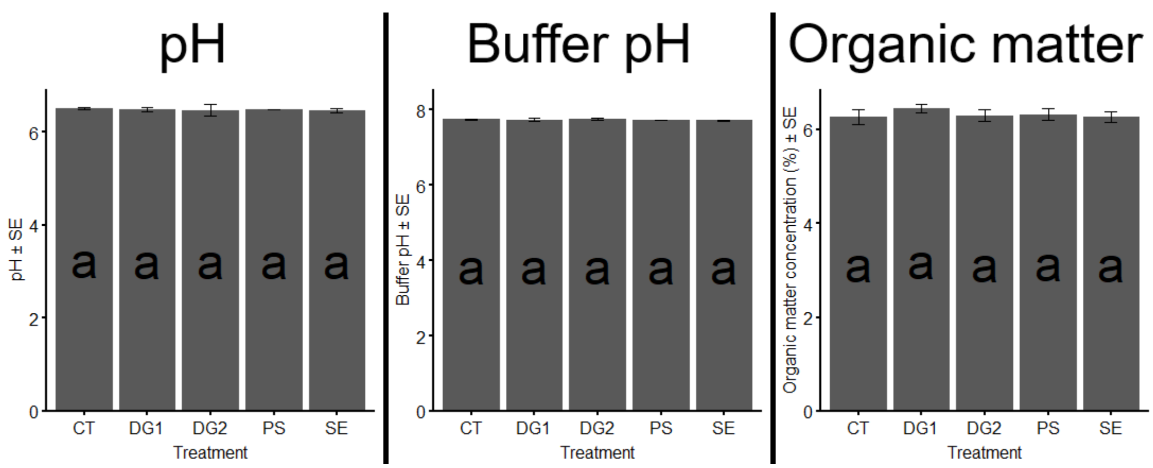
Figure 4.19.1 Effect of soil amendments on the total leaf area (cm; per tallest tiller) of Miscanthus from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), liquid *Ascophyllum nodosum* extract

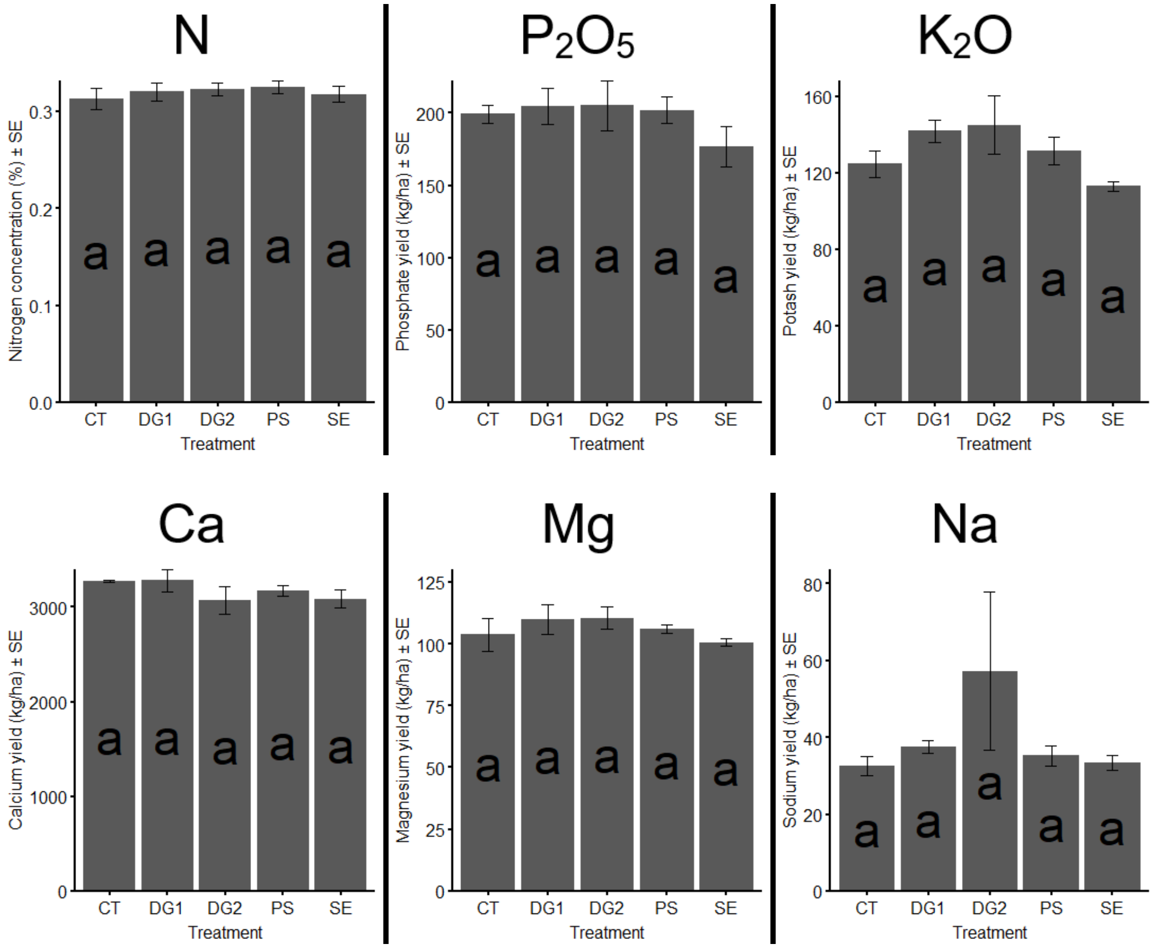
(SE), and paper mill sludge (PS). Within each site, treatments labelled with the same letter were not significantly different from each other (n = 4; $\alpha = 0.05$). Error bars represent standard error.

The highest and lowest mean area values were respectively defined by the digestate (424.3 cm^2) and control groups (332.3 cm^2) for East Gore (fig. 4.19.1), and the paper mill sludge (868.9 cm^2) and control groups (686.6 cm^2) for Skye Glen (fig. 4.19.2). Following a significant treatment effect (p-value = 0.0013), Tukey's post-hoc revealed all treatment group means in Skye Glen to be statistically greater than the control's ($p < 0.05$). There was no significance found in the East Gore data (ANOVA p = 0.399). The highest value from the Skye Glen site (868.9 cm^2) was 1.3-fold larger than that of the control (686.6 cm^2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.20 Soil compositional analysis (August 2020)

Soil cores were obtained from each site during August data collection. These samples were later sent to the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS for the compositional analysis of nutrients and heavy metals.




N
Nitrogen concentration (%) ± SE
0.0
0.1
0.2
0.3
a a a a a
CT DG1 DG2 PS SE
Treatment
P_2O_5
Phosphate yield (kg/ha) ± SE
0
50
100
150
200
a a a a a
CT DG1 DG2 PS SE
Treatment
K_2O
Potash yield (kg/ha) ± SE
0
40
80
120
160
a a a a a
CT DG1 DG2 PS SE
Treatment
Ca
Calcium yield (kg/ha) ± SE
0
1000
2000
3000
a a a a a
CT DG1 DG2 PS SE
Treatment
Mg
Magnesium yield (kg/ha) ± SE
0
25
50
75
100
125
a a a a a
CT DG1 DG2 PS SE
Treatment
Na
Sodium yield (kg/ha) ± SE
0
20
40
60
80
a a a a a
CT DG1 DG2 PS SE
Treatment

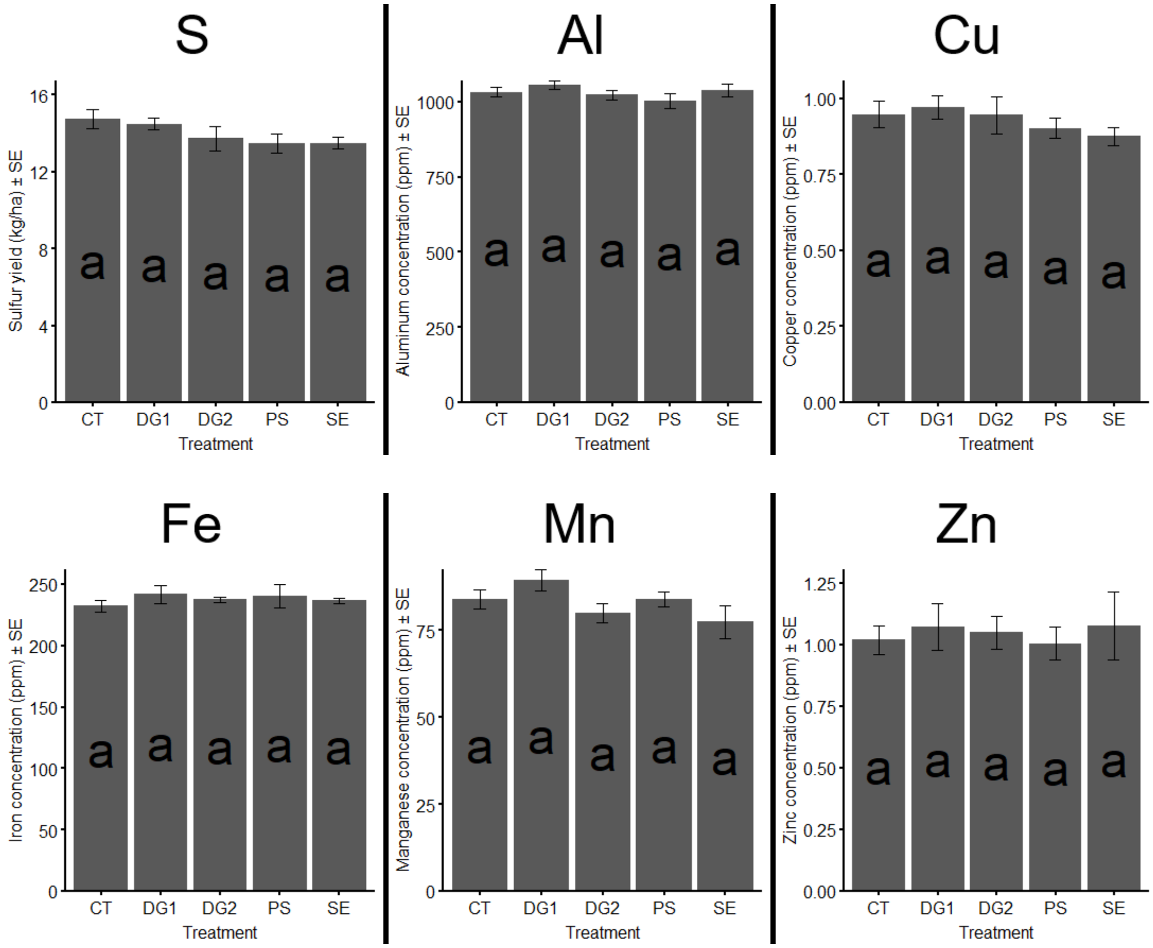
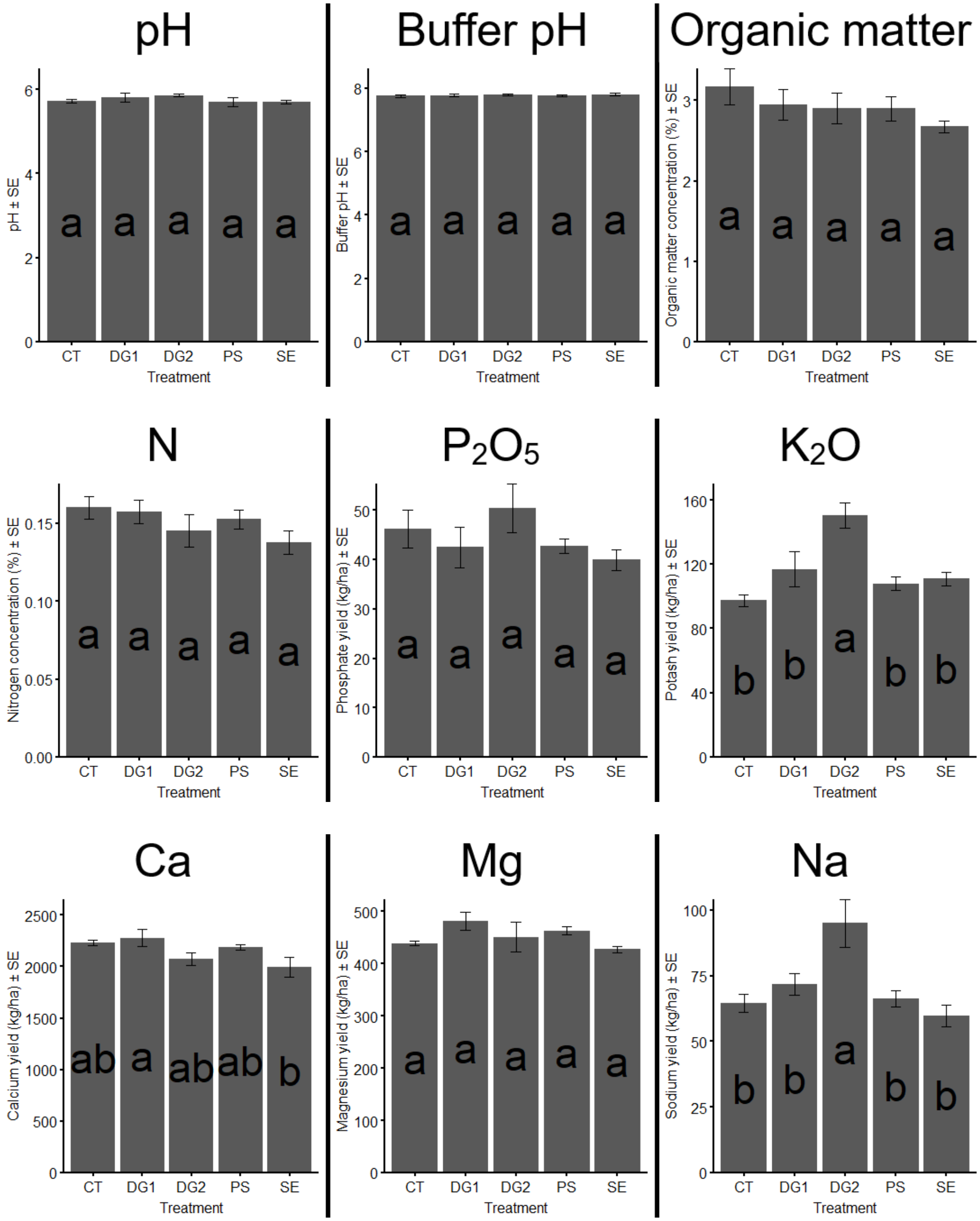


Figure 4.20.1 Effect of amendments on soil composition (pH, nutrient yield (kg/ha) and concentration (ppm)) from the East Gore site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.


pH
pH ± SE
a a a a a
Buffer pH
Buffer pH ± SE
a a a a a
Organic matter
Organic matter concentration (%) ± SE
a a a a a
N
Nitrogen concentration (%) ± SE
a a a a a
P2O5
Phosphate yield (kg/ha) ± SE
a a a a a
K2O
Potash yield (kg/ha) ± SE
b b a b b
Ca
Calcium yield (kg/ha) ± SE
ab a ab ab b
Mg
Magnesium yield (kg/ha) ± SE
a a a a a
Na
Sodium yield (kg/ha) ± SE
b b a b b
CT DG1 DG2 PS SE
Treatment

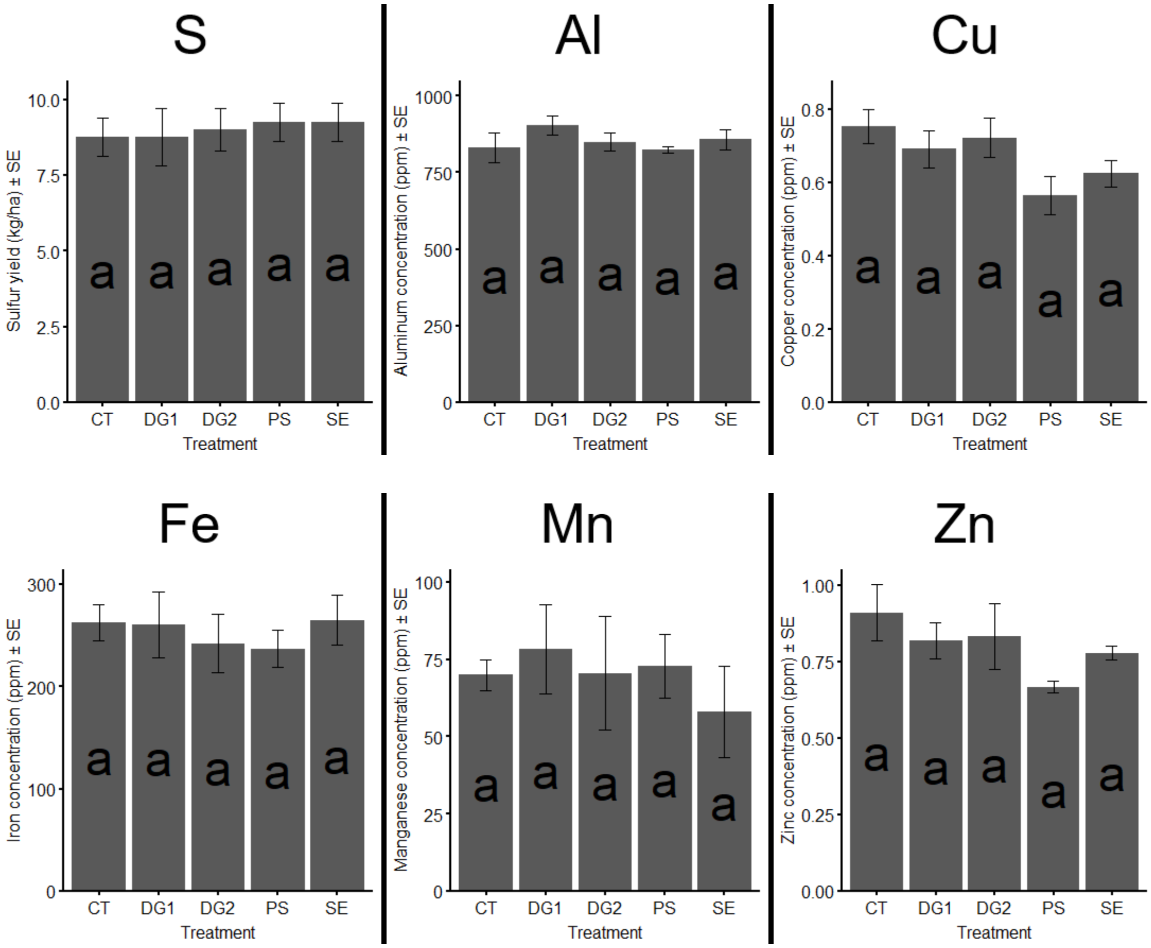


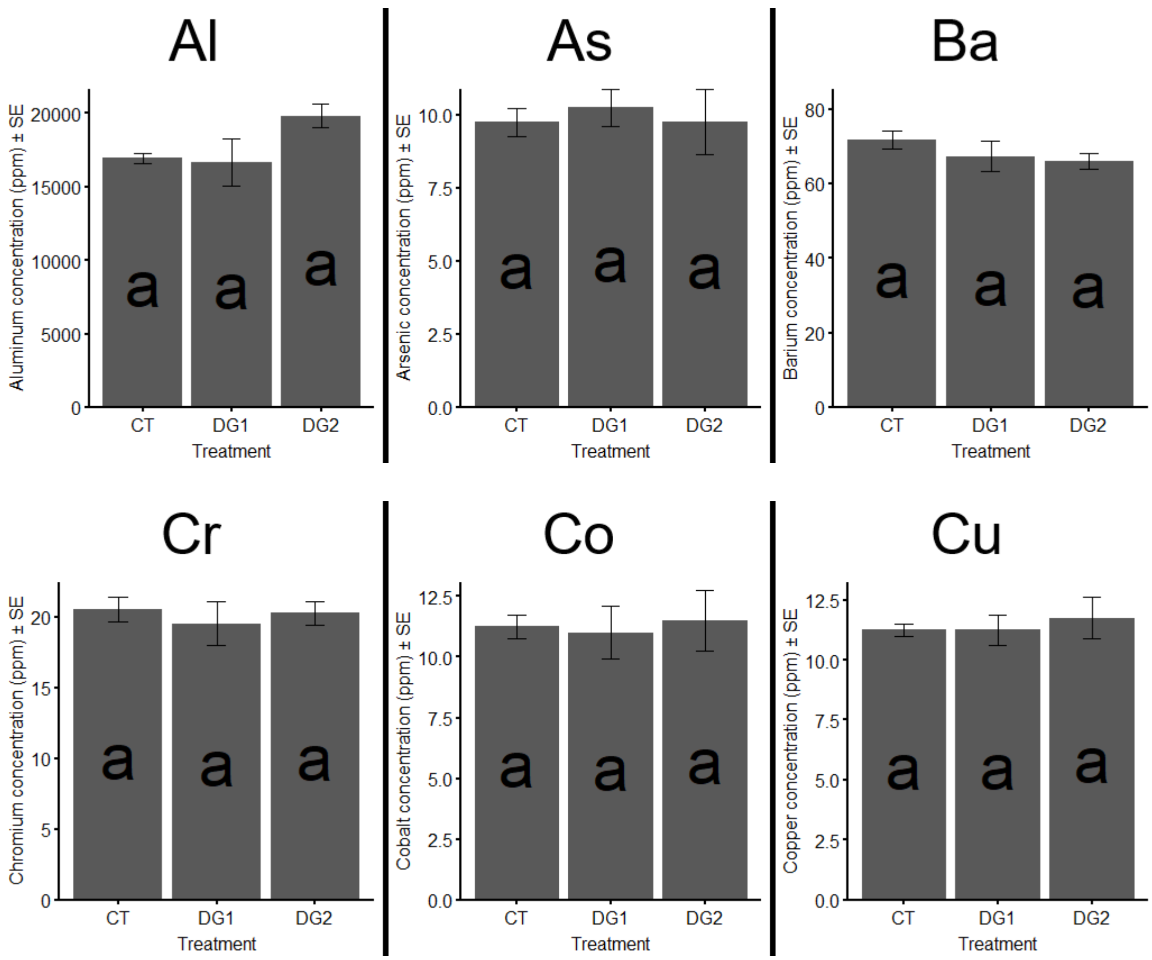
Figure 4.20.2 Effect of amendments on soil composition (pH, nutrient yield (kg/ha) and concentration (ppm)) from the Skye Glen site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other ($n = 4$; $\alpha = 0.05$). Error bars represent standard error.

Analysis of variance found no significance for the nutrient analysis of East Gore's soil samples (p-values ≥ 0.05). This was in contrast to the Skye Glen data, where the dual application digestate group had a statistically significant yield of potash ($p = 0.0008$) and sodium ($p = 0.0016$) compared to the control (as determined by post-hoc tests; p-values <

0.001). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.21 Soil heavy metal concentrations (August 2020)

Soil cores were obtained from each site during August data collection. These samples were later sent to the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS for the compositional analysis of nutrients and heavy metals.



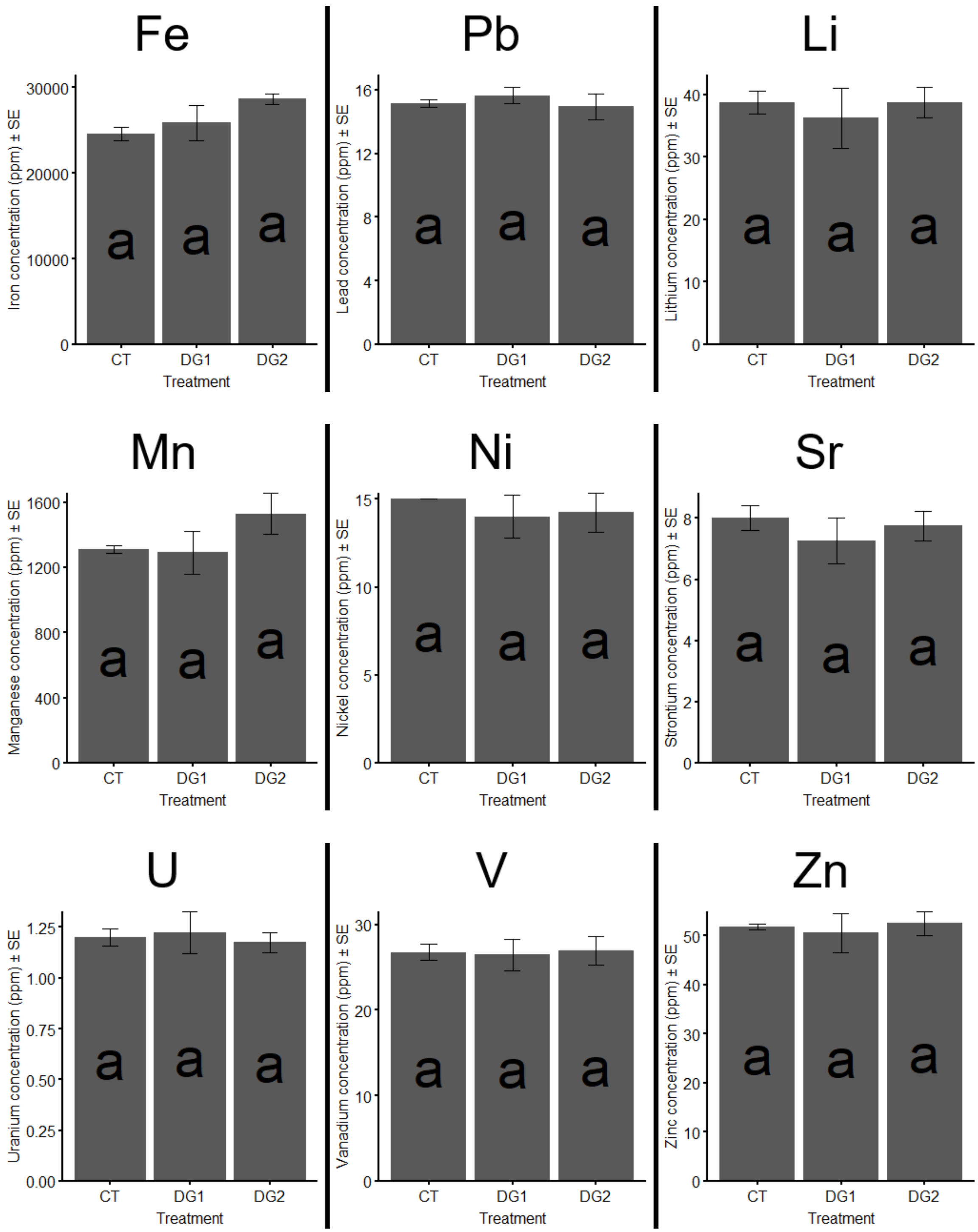
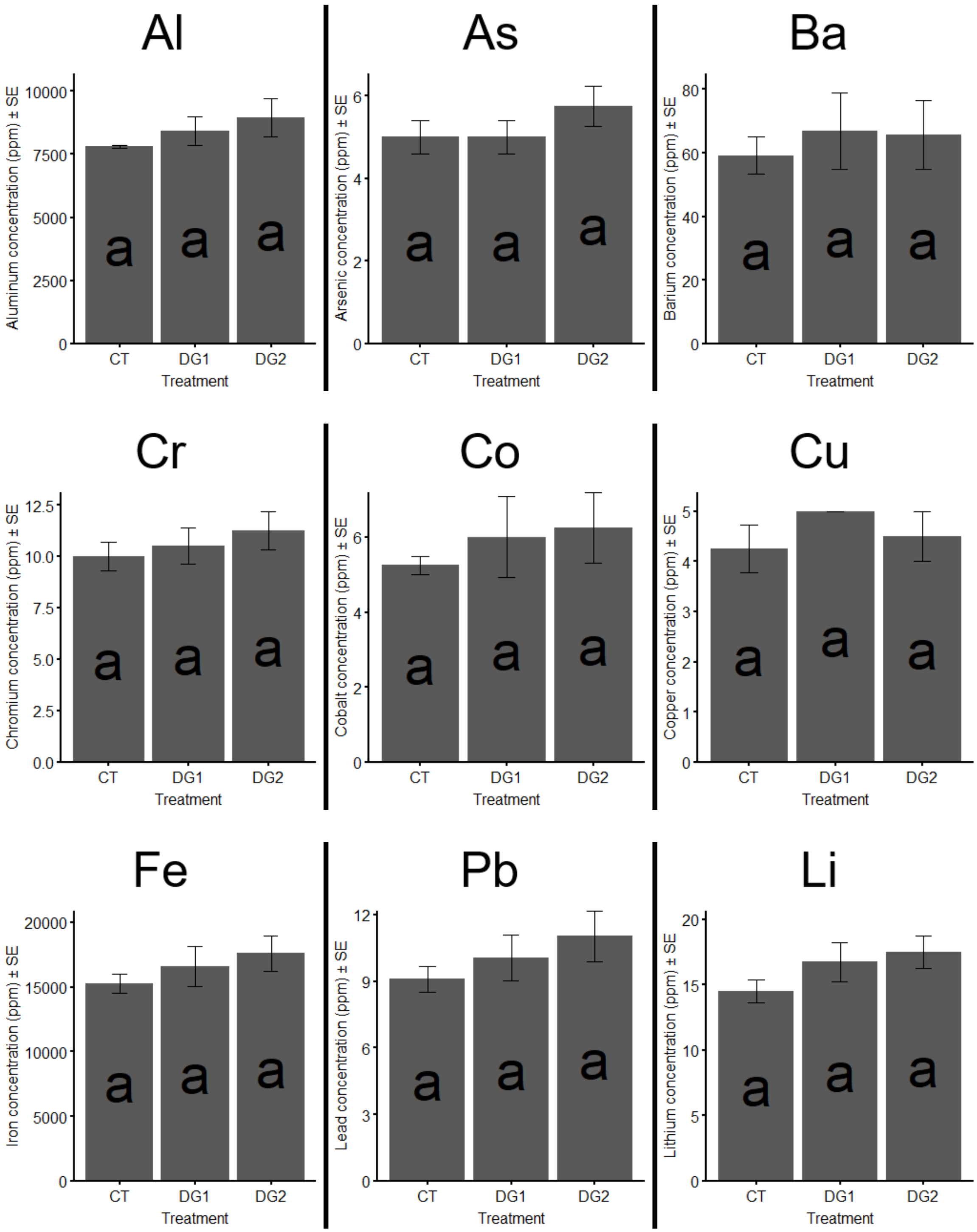


Figure 4.21.1 Effect of amendments on soil heavy metal concentration (ppm) from the East Gore site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2).

Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.



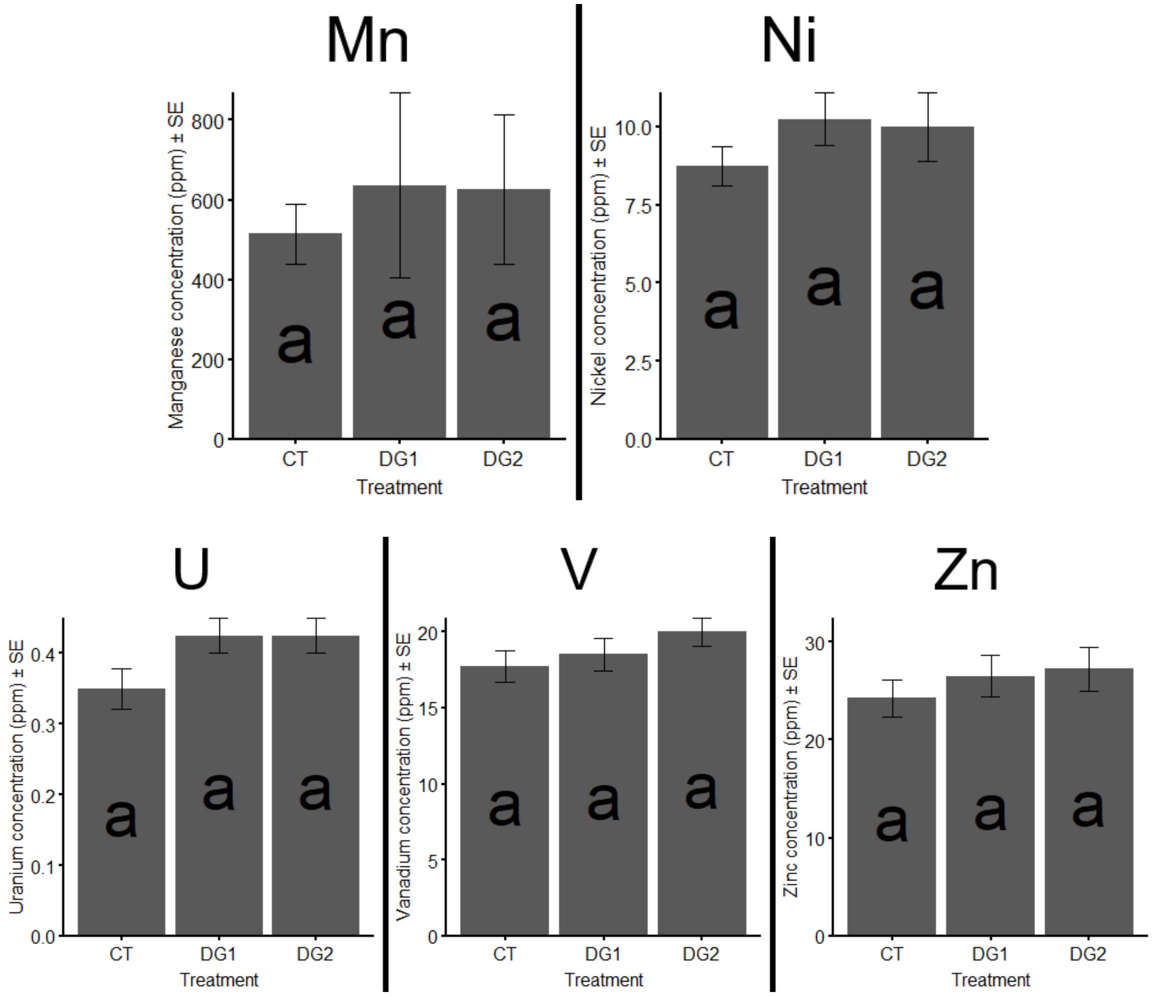


Figure 4.21.2 Effect of amendments on soil heavy metal concentration (ppm) from the Skye Glen site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

There were no statistically significant differences between treatment group mean values for heavy metal data (p-values > 0.05) as determined by analysis of variance. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

End of season plant growth

Aspects of plant growth were again collected in fall 2020 to determine the progress of the biomass crops after one growing season. The biomass of annual grass crops was obtained using destructive methods, while non-destructive measurements (stem length, diameter) were done as biomass indicators for the woody perennial crops.

4.22 Switchgrass yield (fall 2020)

The fresh weight of aboveground biomass within eight randomly distributed plastic discs was obtained during end of season data collection. After drying, subsample weights were converted into dry weight per hectare measurements, as seen below. As survival rate could not be determined, 100% survival was assumed.

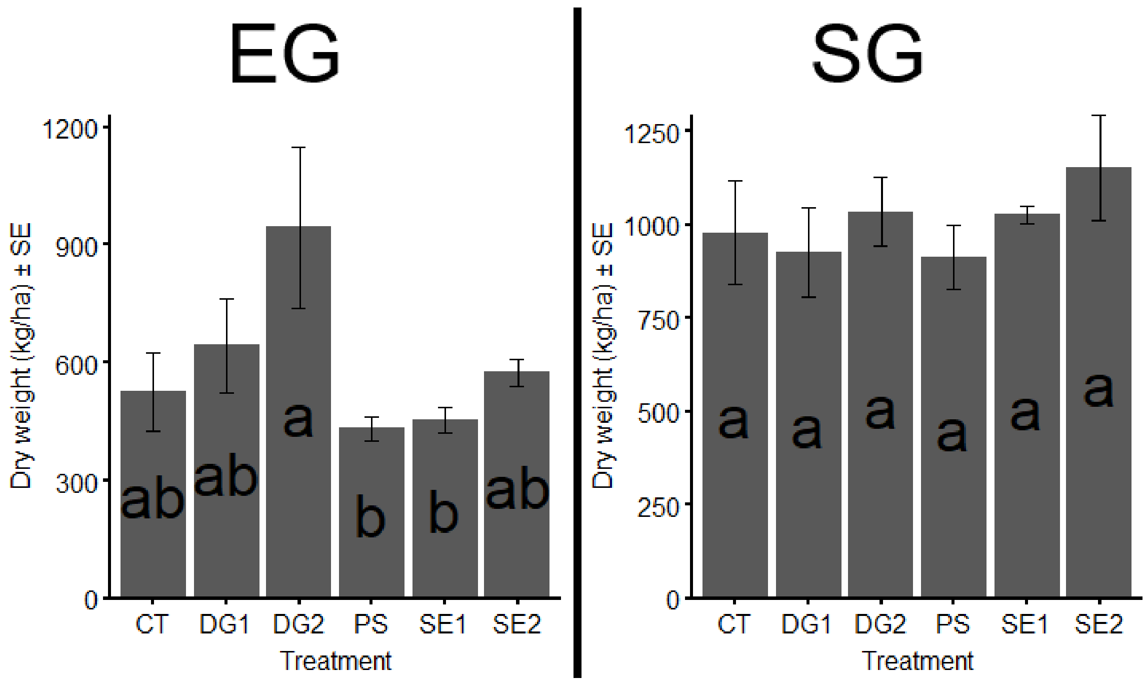


Figure 4.22.1 Effect of soil amendments on the dry weight (kg) per hectare of switchgrass from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The highest mean yield value for the East Gore site occurred with the dual application of anaerobic digestate (946 kg/ha; 4.20.1), with the dual application of seaweed extract having the highest mean value for Skye Glen (1154 kg/ha; fig.4.22.2). The paper mill sludge treatment group had the lowest mean value for both sites (EG: 433 kg/ha, SG: 913 kg/ha). Analysis of variance found none of the treatment group means to have a statistically significant difference from the control value (EG p-value = 0.013; SG p-value = 0.65). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.23 Switchgrass moisture content (fall 2020)

The fresh weight of aboveground biomass within eight randomly distributed plastic discs was obtained during end of season data collection. After drying, percent moisture content was calculated using the formula (FW – DW) ÷ DW × 100.

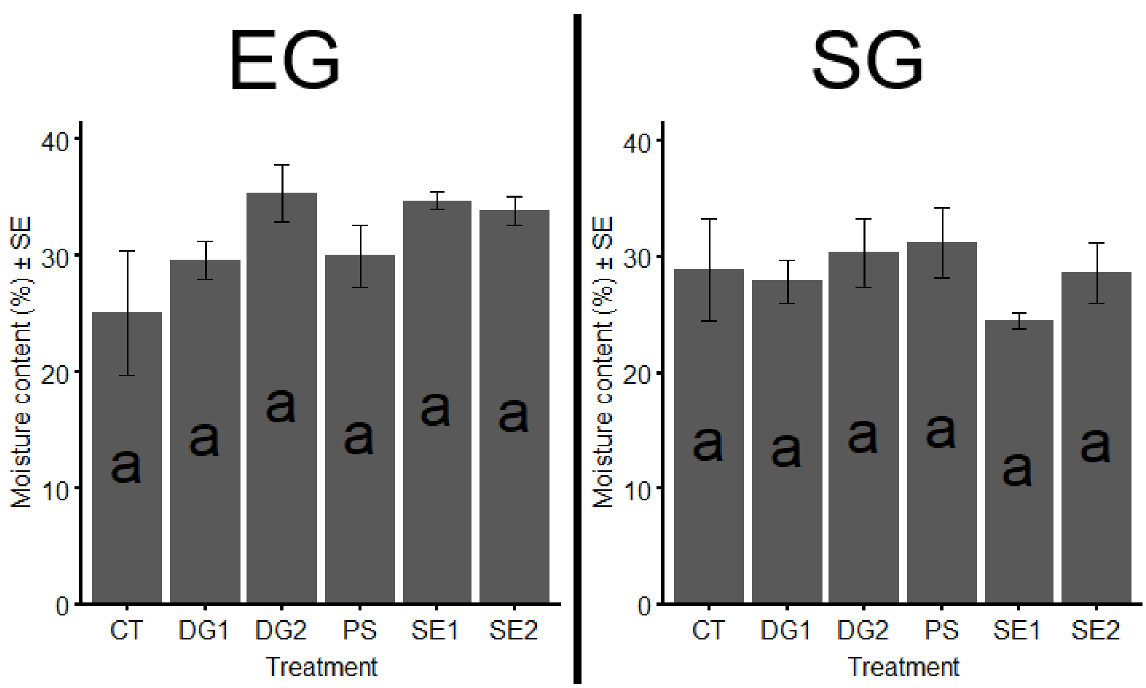


Figure 4.23.1 Effect of soil amendments on the moisture content (%) of switchgrass from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other (n = 4; α = 0.05). Error bars represent standard error.

A significant effect was not found for the one-way analysis of treatment effect on switchgrass moisture content (EG p-value = 0.218; SG p-value = 0.6431). The highest mean moisture value occurred with the DG2 (35.3) and paper mill sludge (31.2) treatment groups for East Gore (fig.4.23.1) and Skye Glen (fig.4.23.2) data, respectively. Complete one-way analyses of variance for these data can be seen in the appendix.

4.24 Miscanthus yield (fall 2020)

The fresh weight of select Miscanthus plants (10 subsamples per subplot) was obtained during end of season data collection. After drying, subsample weights were converted into dry weight per hectare measurements, as seen below.

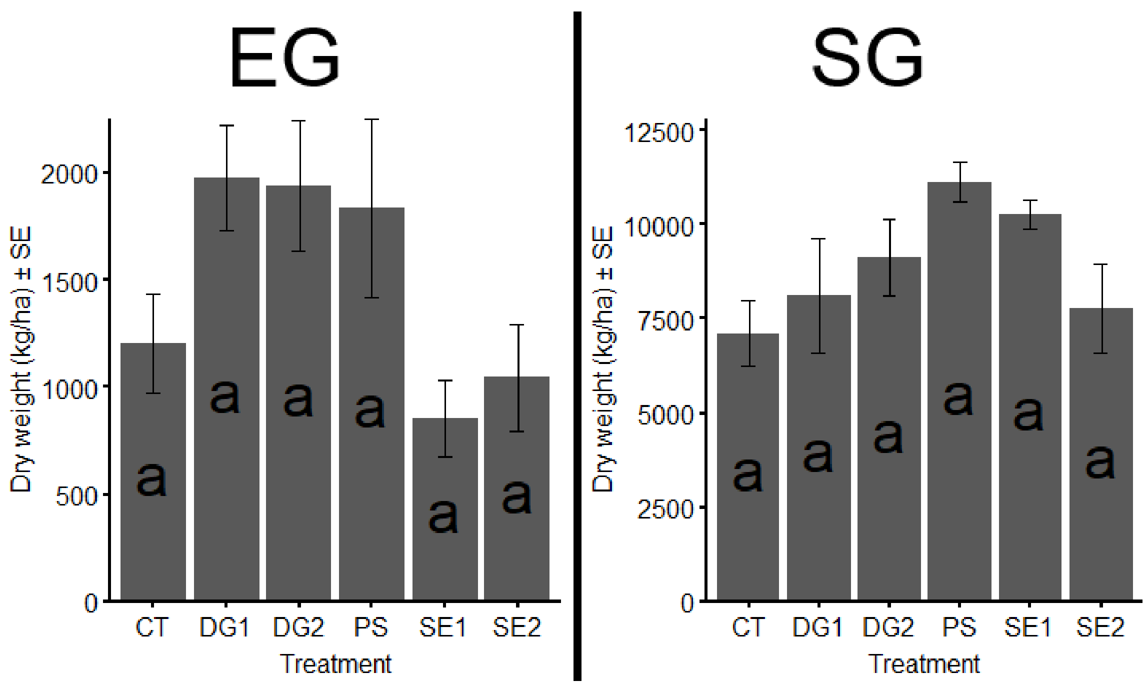


Figure 4.24.1 Effect of soil amendments on the dry weight (kg) per hectare of Miscanthus from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The highest mean yield value occurred with the single application digestate group for East Gore (1978 kg/ha), and paper mill sludge group for Skye Glen (11132 kg/ha). The lowest mean values occurred with the single application of seaweed extract and the control group for East Gore (854 kg/ha) and Skye Glen (7115 kg/ha), respectively. Statistical analyses found no significance with these data (EG p-value: 0.032, fig.4.24.1; SG p-value: 0.073, fig.4.24.2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.25 Miscanthus moisture content (fall 2020)

The fresh weight of select Miscanthus plants (10 subsamples per subplot) was obtained during end of season data collection. After drying, percent moisture content was calculated using the formula $(FW - DW) \div DW \times 100$.

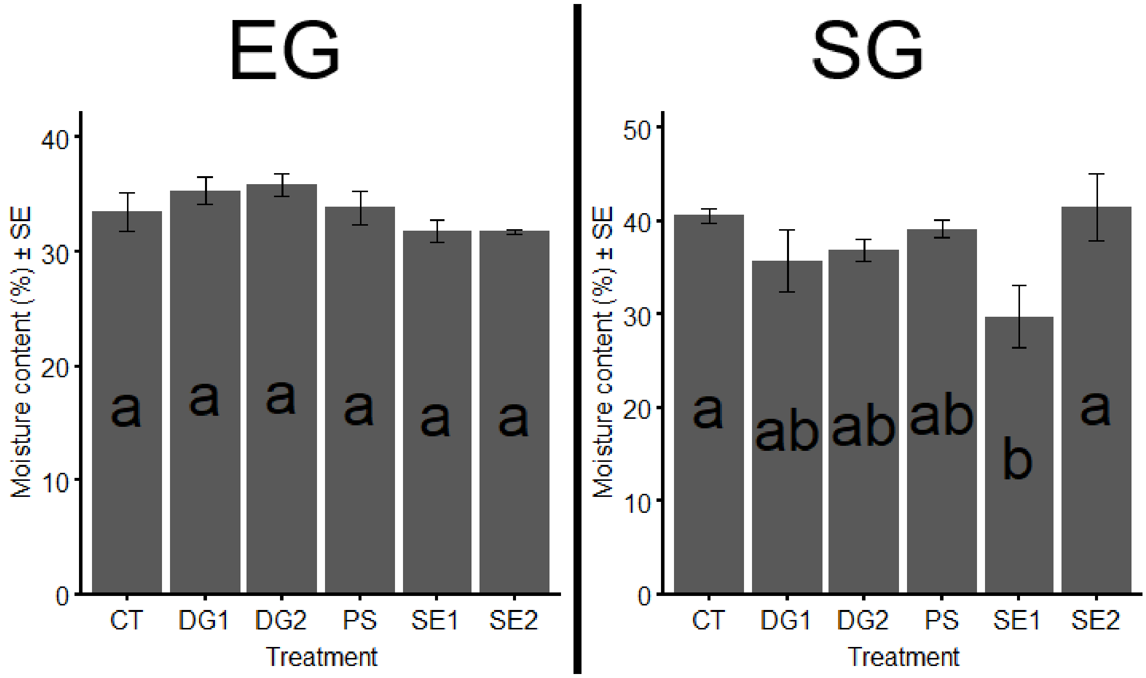
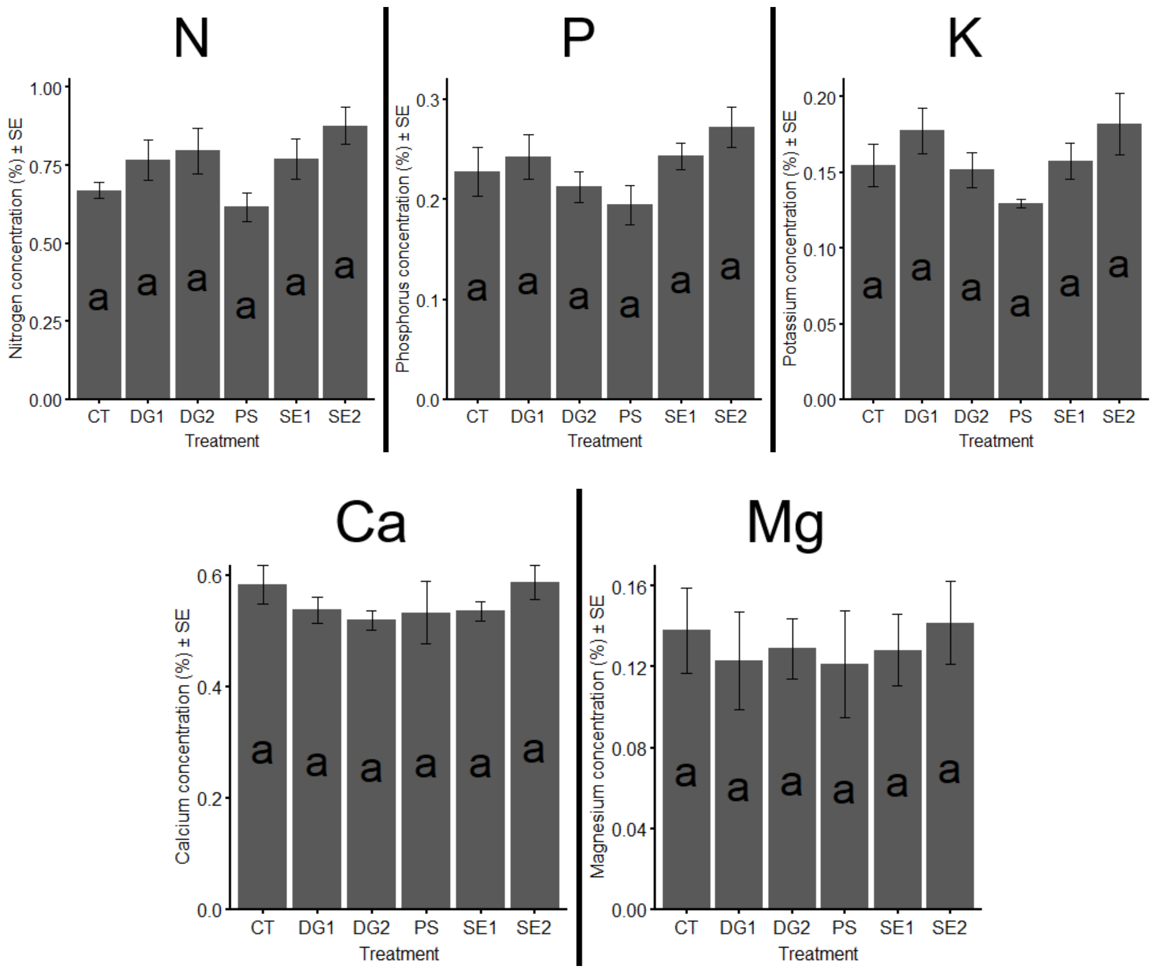


Figure 4.25.1 Effect of soil amendments on the moisture content (%) of Miscanthus from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

Following a significant treatment effect for Skye Glen's Miscanthus moisture data (p-value = 0.0452, fig.4.25.2), Tukey's post-hoc test found treatment group SE1 as having a mean value that was significantly different than that of the control group (p = 0.0293). Inversely, analysis of East Gore moisture content data did not result in significance (p = 0.1116, fig.4.25.1). East Gore's DG2 (35.9) and Skye Glen's SE2 (41.5) treatment groups had the greatest mean moisture values. Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.26 Miscanthus tissue nutrient concentrations (fall 2020)

Chemical analyses of aggregate samples of Miscanthus dry matter were done by the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS using plant samples collected in November of 2020.



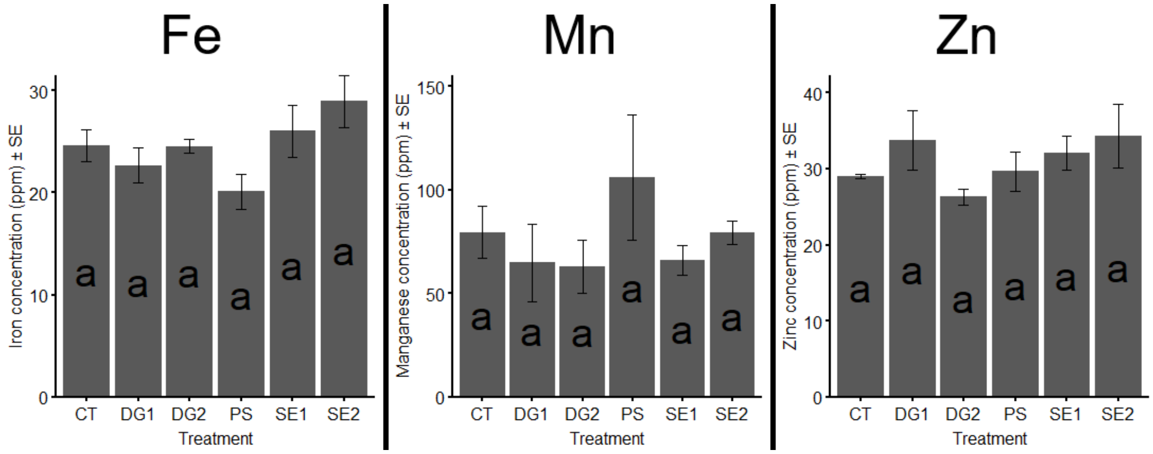
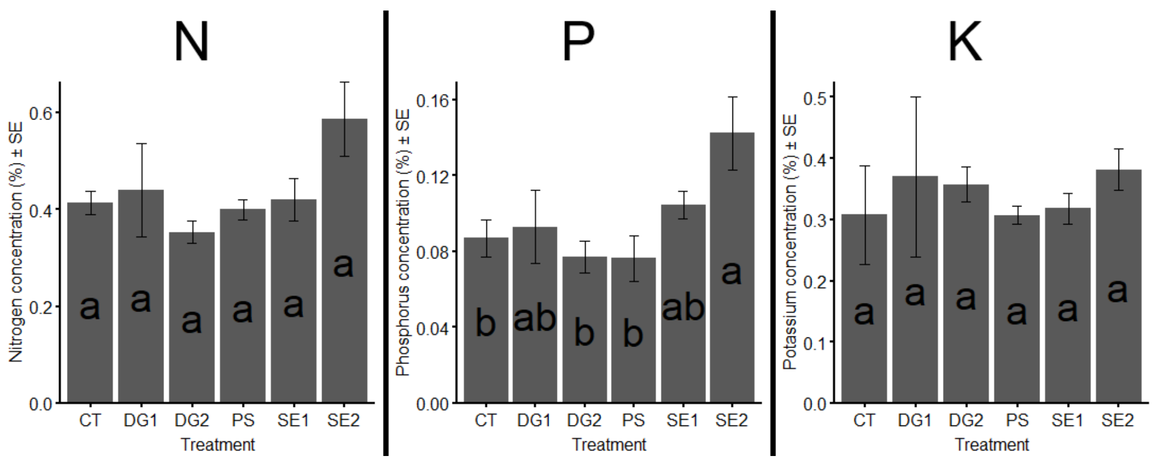


Figure 4.26.1 Effect of soil amendments on nutrient concentrations (percent or parts per million) of Miscanthus shoot tissue from the East Gore site. Treatments included a no-additives control (CT), paper mill sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Treatments labelled with the same letter were not significantly different from each other (n = 3; α = 0.05). Error bars represent standard error.



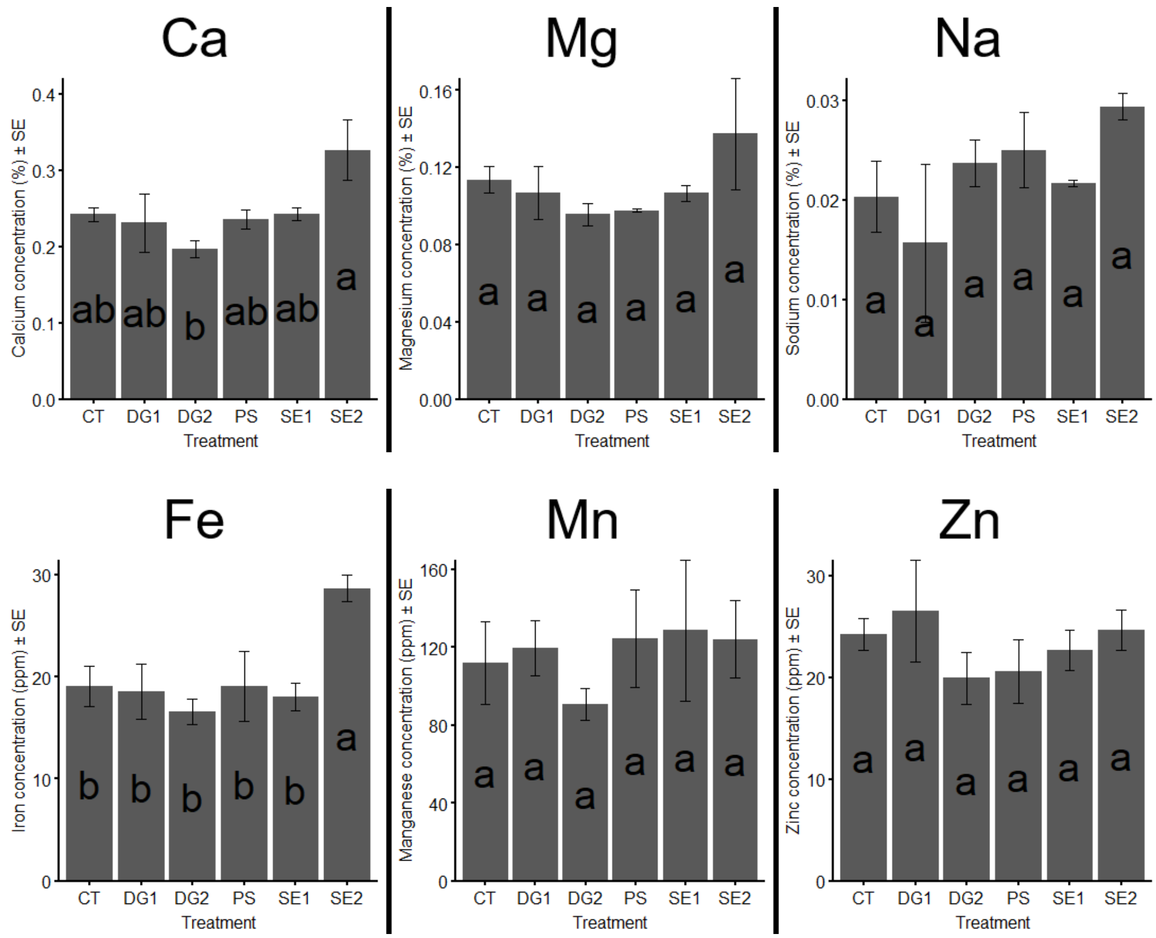


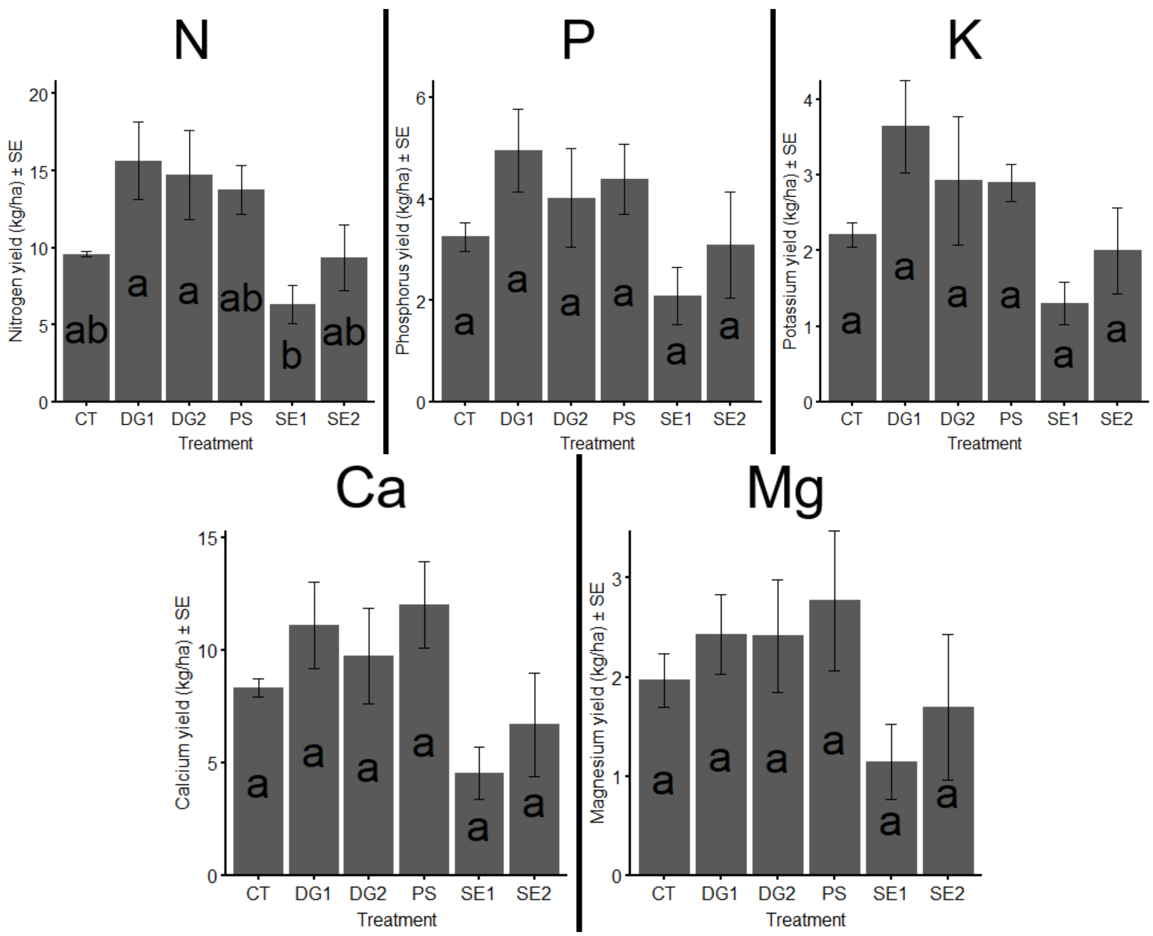
Figure 4.26.2 Effect of soil amendments on nutrient concentrations (percent or parts per million) of Miscanthus shoot tissue from the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Treatments labelled with the same letter were not significantly different from each other ($n = 3$; $\alpha = 0.05$). Error bars represent standard error.

As shown by analysis of variance, treatment group mean values that were significantly different from the control included phosphorus (p-value = 0.0397) and iron (p = 0.0227) for Skye Glen data. Specifically, the dual application seaweed extract group was shown (via post-hoc tests) to have a higher mean value when compared to the control.

Conversely, none of East Gore's nutrient concentration data had significance ($p \geq 0.05$). Complete one-way analyses of variance, post-hoc tests, and mean nutrient quantity tables can be found in the appendix.

4.27 Miscanthus nutrient yield (fall 2020)

Miscanthus samples taken from 2020's fall harvest were chemically analyzed by the Nova Scotia Department of Agriculture Analytical Laboratory in Truro, NS. These results were then converted into a kilogram per hectare measurement using dry weight and survival data.



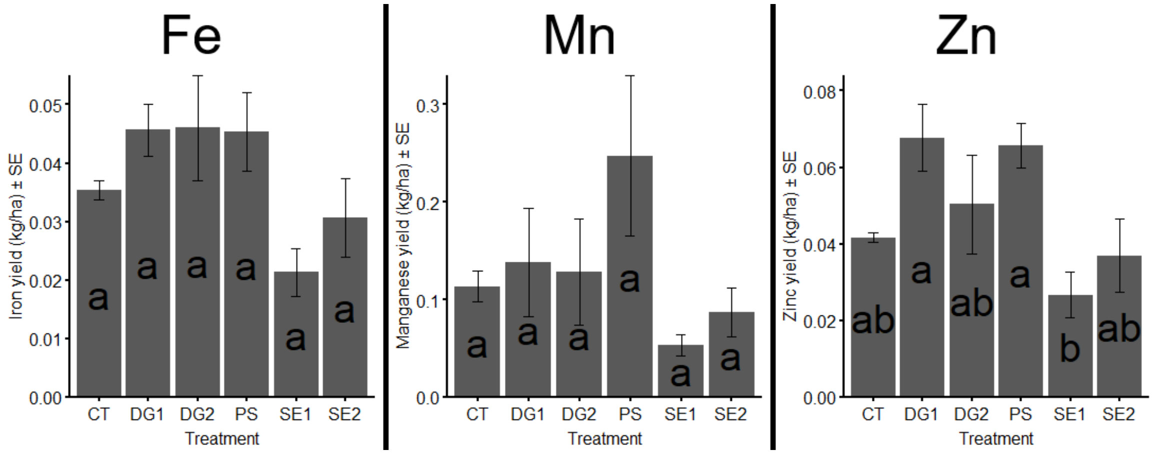
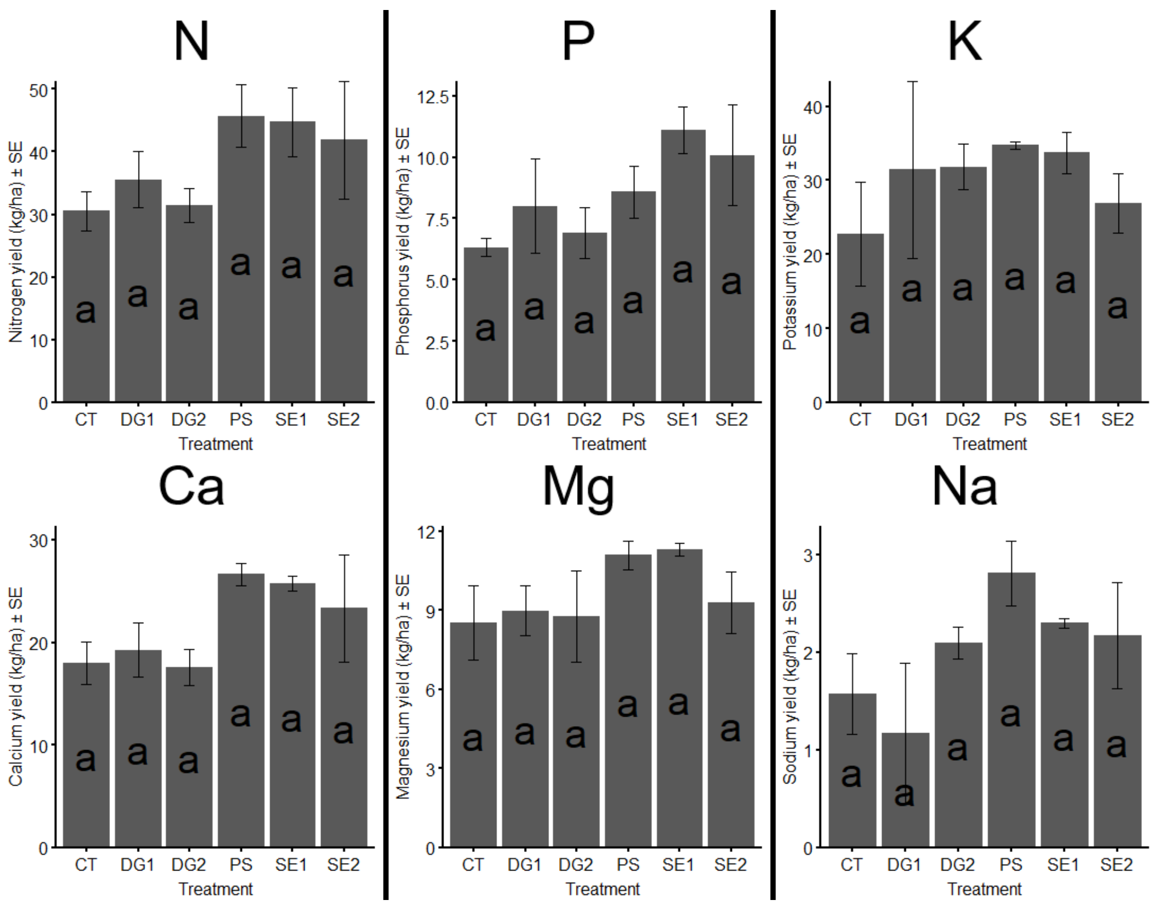


Figure 4.27.1 Effect of soil amendments on the nutrient yield of Miscanthus shoot tissue (kg/ha) from the East Gore site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other (n = 3; α = 0.05). Error bars represent standard error.



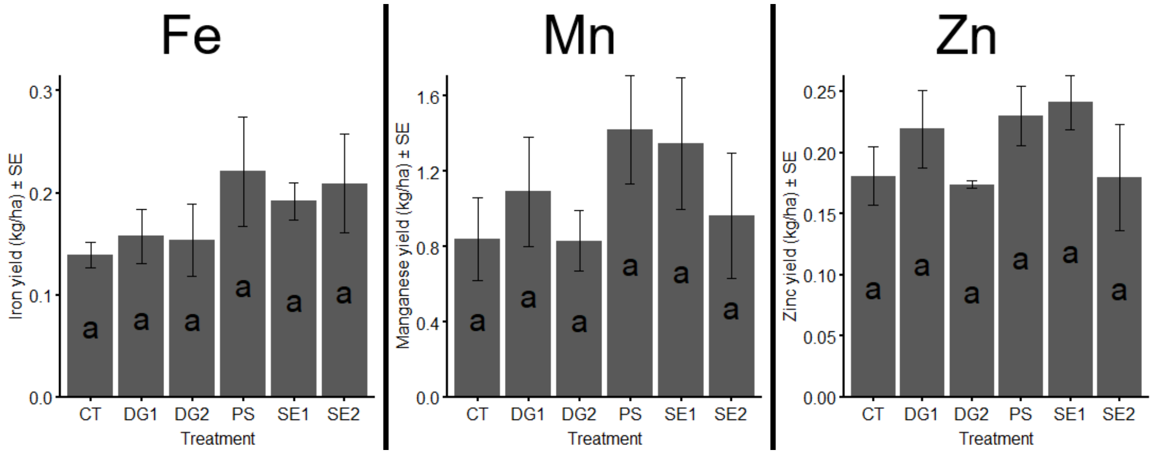


Figure 4.27.2 Effect of soil amendments on the nutrient yield of Miscanthus shoot tissue (kg/ha) from the Skye Glen site. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Treatments labelled with the same letter were not significantly different from each other (n = 3; α = 0.05). Error bars represent standard error.

One-way ANOVA of treatment group mean values resulted in significance for East Gore's nitrogen ($p = 0.0347$) and zinc yields ($p = 0.0247$). However, subsequent post-hoc testing did not reveal any treatment groups with a mean yield value that was significantly different than the control group. The remaining Miscanthus nutrients did not differ in yield significantly between treatment groups at either site (ANOVA p-value > 0.05). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.28 Poplar average stem length (fall 2020)

The length of all secondary and tertiary stems (or up to 8 in Skye Glen) on select poplar trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

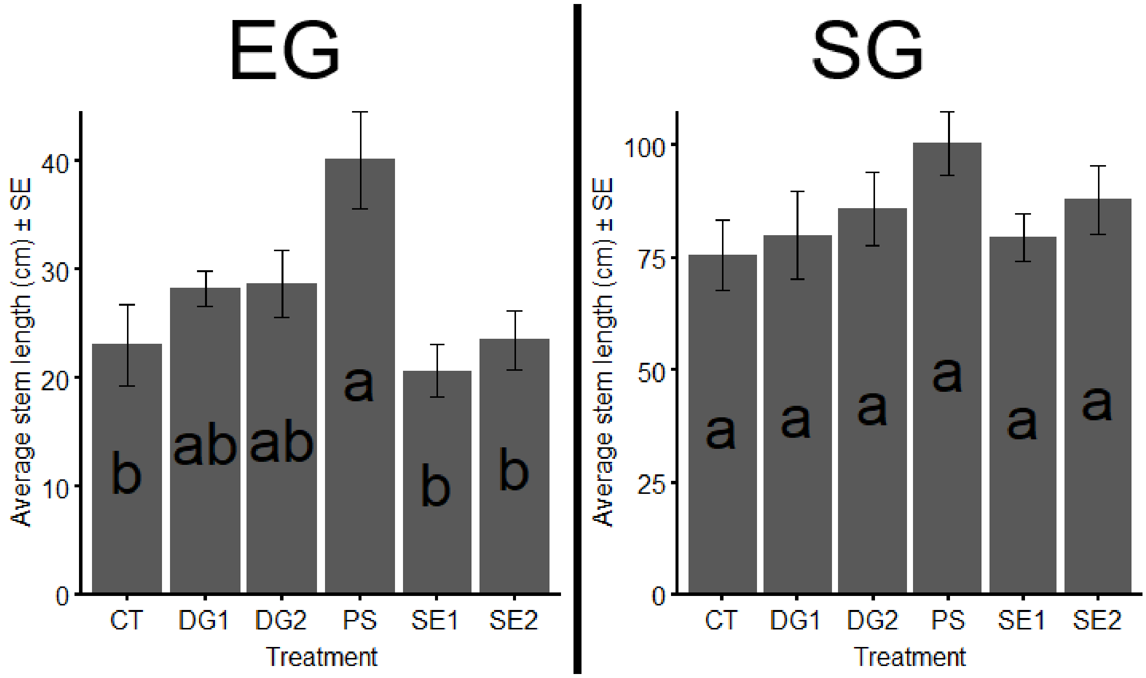


Figure 4.28.1 Effect of soil amendments on the average stem length (cm) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The treatment group with the greatest mean length value was that of paper mill sludge (EG: 40 cm, SG: 101 cm). There was a statistically significant difference between the paper mill sludge treatment group and the control for East Gore data ($p = 0.005$, fig.4.28.1), with no significance found for Skye Glen data ($p = 0.309$, fig.4.28.2). Complete one-way analyses of variance for these data can be seen in the appendix.

4.29 Poplar total stem length (fall 2020)

The length of all secondary and tertiary stems (or up to 8 in Skye Glen) on select poplar trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

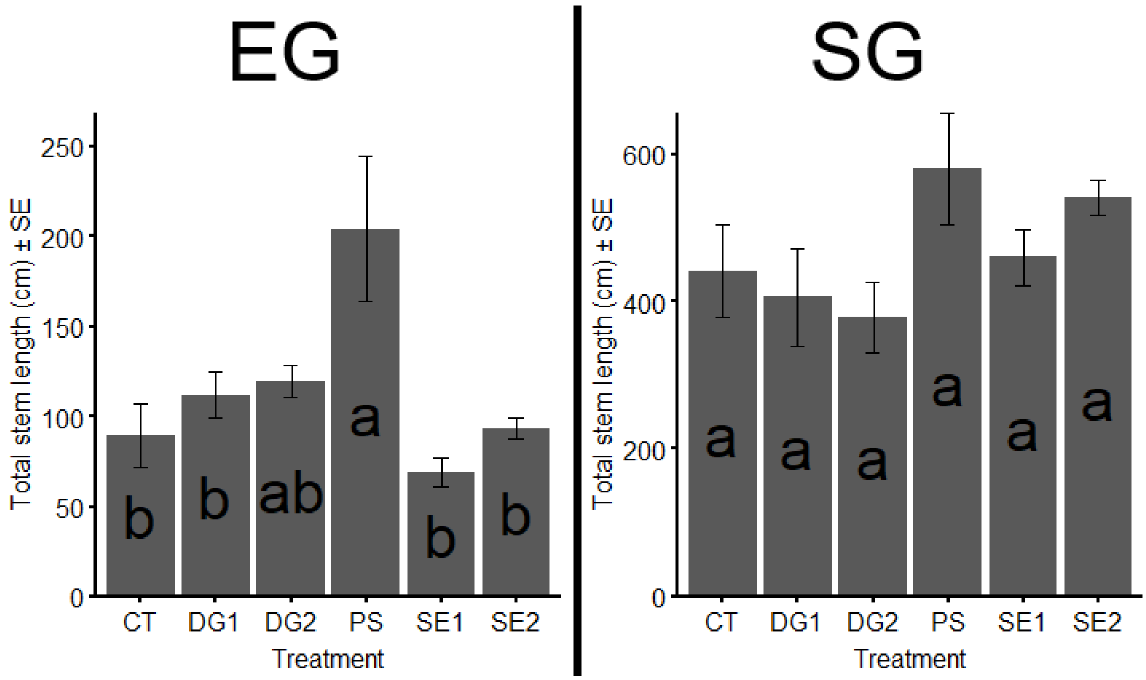


Figure 4.29.1 Effect of soil amendments on the total stem length (cm) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The highest mean stem value occurred with the paper mill sludge treatment group for both sites (EG: 204 cm, fig.4.29.1; SG: 579 cm, fig.4.29.2), the lowest value being the single-application seaweed extract for East Gore (69 cm) and dual application digestate for Skye Glen (379 cm). Tukey's test showed a significant difference between the control and paper mill sludge group means for East Gore data (p <0.001). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.30 Poplar stem diameter (fall 2020)

The diameter of secondary and tertiary stems on select poplar trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, average stem diameter was obtained by taking the combined diameter of all stems on one tree and dividing it by the number of stems measured on that same tree.

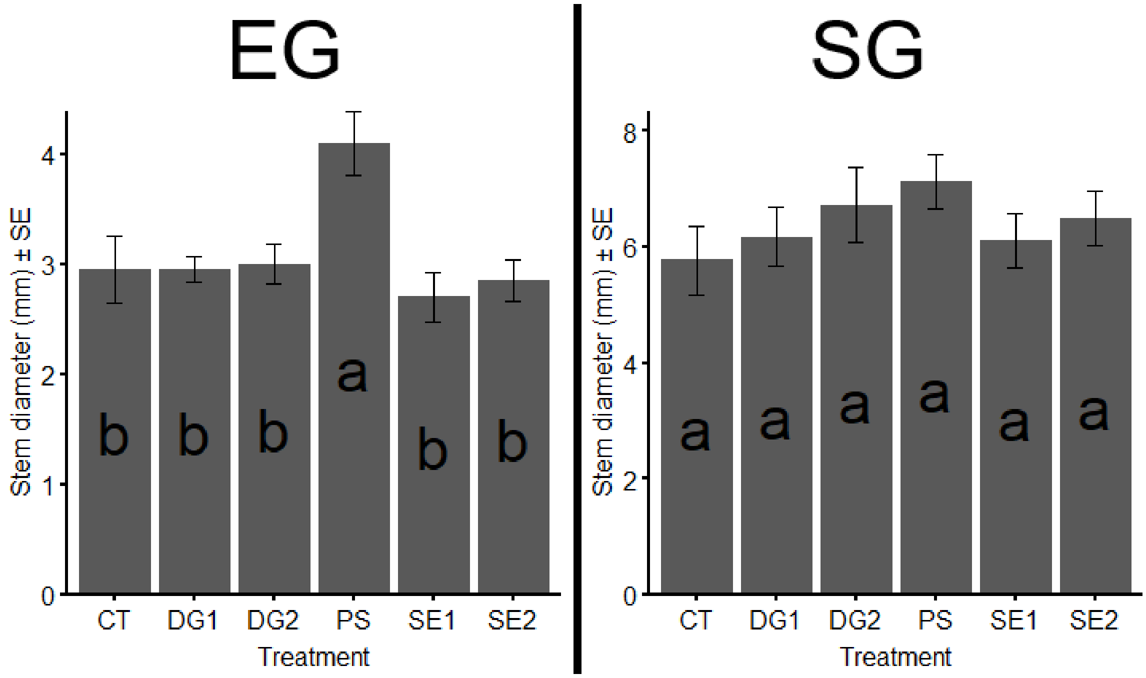


Figure 4.30.1 Effect of soil amendments on the stem diameter (mm) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Within 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.

The highest mean diameter value was the paper mill sludge treatment group for both sites (EG: 4.10 mm; SG: 7.13 mm), with the lowest value being the single application seaweed extract treatment group for East Gore (2.70 mm, fig.4.30.1) and the control for

Skye Glen (5.78 mm, fig.4.30.2). Statistical analyses found a significant difference ($p = 0.0046$) when comparing the mean value of the paper mill sludge group to the control group in East Gore. Complete one-way analyses of variance for these data can be seen in the appendix.

4.31 Poplar stem volume estimate (fall 2020)

The length and diameter of secondary/tertiary stems on select poplar trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, a conservative estimate of stem volume was obtained using the formula $(\pi r^2)/2 \times l$ (where "r" is the radius at the base of the stem, and "l" is stem length).

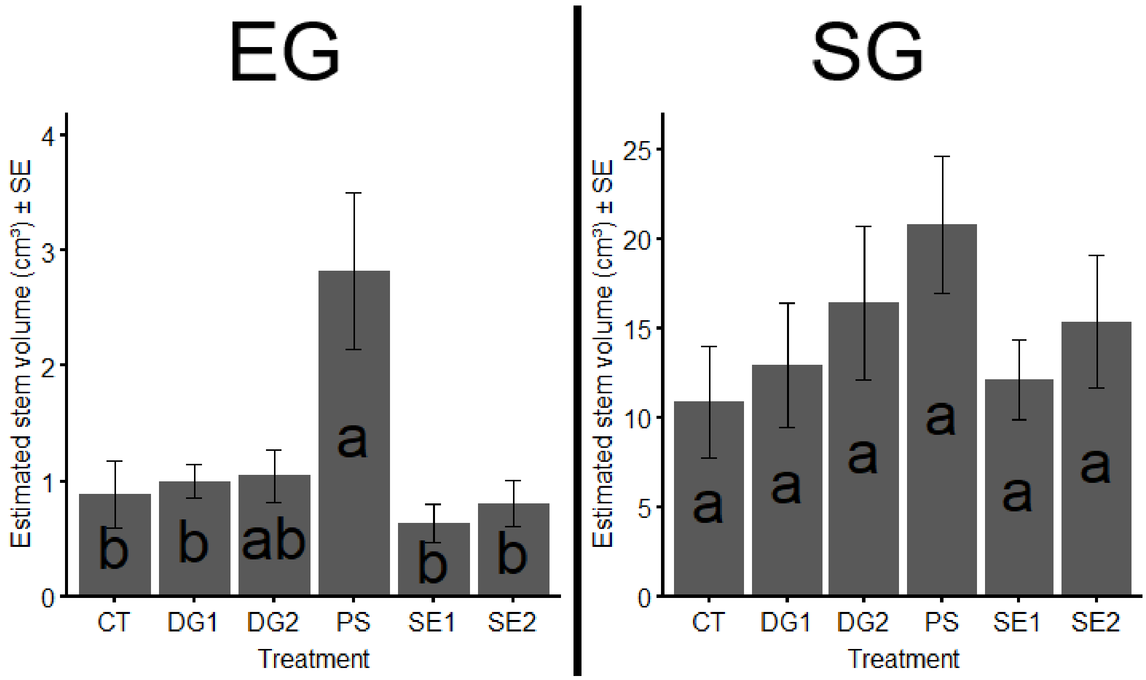


Figure 4.31.1 Effect of soil amendments on the estimated stem volume (cm^3) of poplar from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The treatment group with the highest mean volume estimate value was paper mill sludge for both East Gore (2.8 cm^3) and Skye Glen (20.7 cm^3). The control group had the lowest mean value for Skye Glen data (10.9 cm^3), while single application seaweed extract had the lowest mean value for East Gore data (0.6 cm^3). Tukey's post-hoc test found significant differences in the estimated volume value between the paper mill sludge and control group for East Gore data ($p = 0.0040$, fig.4.31.1), but found no significance for Skye Glen data ($p = 0.4171$, fig.4.31.2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.32 Willow average stem length (fall 2020)

The length of secondary and tertiary stems on select willow trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

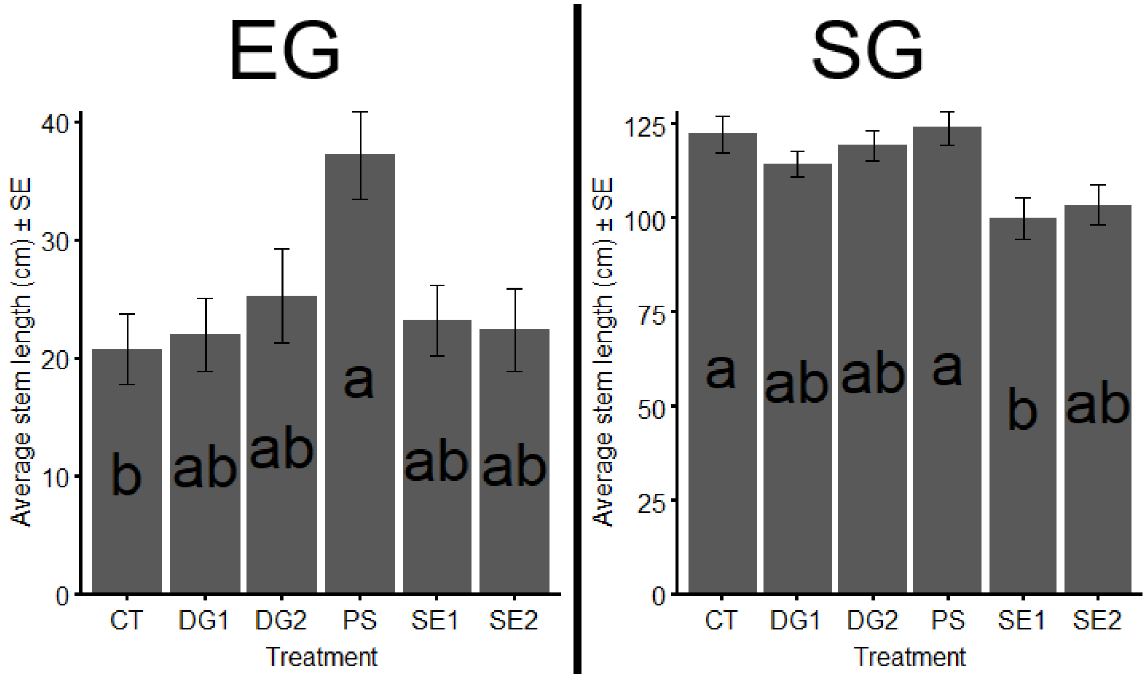


Figure 4.32.1 Effect of soil amendments on the average stem length (cm) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The treatment group with the highest mean stem length value from the Skye Glen data (fig.4.32.2) was paper mill sludge (124 cm), though this was marginally higher than the control (123 cm). However, its lowest mean value (100 cm; single-app seaweed extract) was significantly lower than the control, as confirmed by analysis of variance ($p = 0.007$). The East Gore results (fig.4.32.1) showed the paper mill sludge group (37 cm) as having a statistically significant (ANOVA $p = 0.0294$) difference in mean length value compared to the lowest group, the control (21 cm). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.33 Willow total stem length (fall 2020)

The length of secondary and tertiary stems on select willow trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

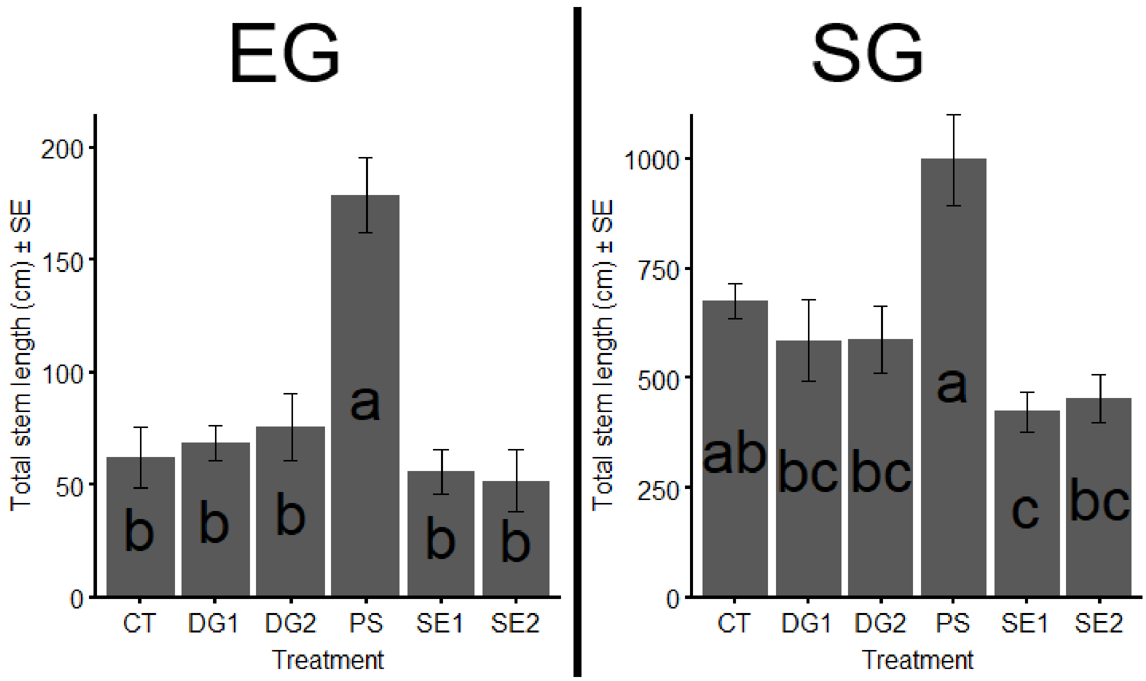


Figure 4.33.1 Effect of soil amendments on the total stem length (cm) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

The paper mill sludge group had the highest mean length value for both sites (EG: 179 cm; SG: 998 cm), with the seaweed extract group having the lowest (EG: ~53.9 cm; SG: ~439.7 cm). Statistically, the paper mill sludge group was significantly different from the control group in East Gore (Tukey $p < 0.001$, fig.4.33.1), but not Skye Glen (Tukey p

= 0.168, fig.4.33.2). The mean value of the single application seaweed extract group was significantly lower than that of the control's in Skye Glen (Tukey p = 0.0498). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.34 Willow stem diameter (fall 2020)

The diameter of secondary and tertiary stems on select willow trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, average stem diameter was obtained by taking the combined diameter of all stems on one tree and dividing it by the number of stems measured on that same tree.

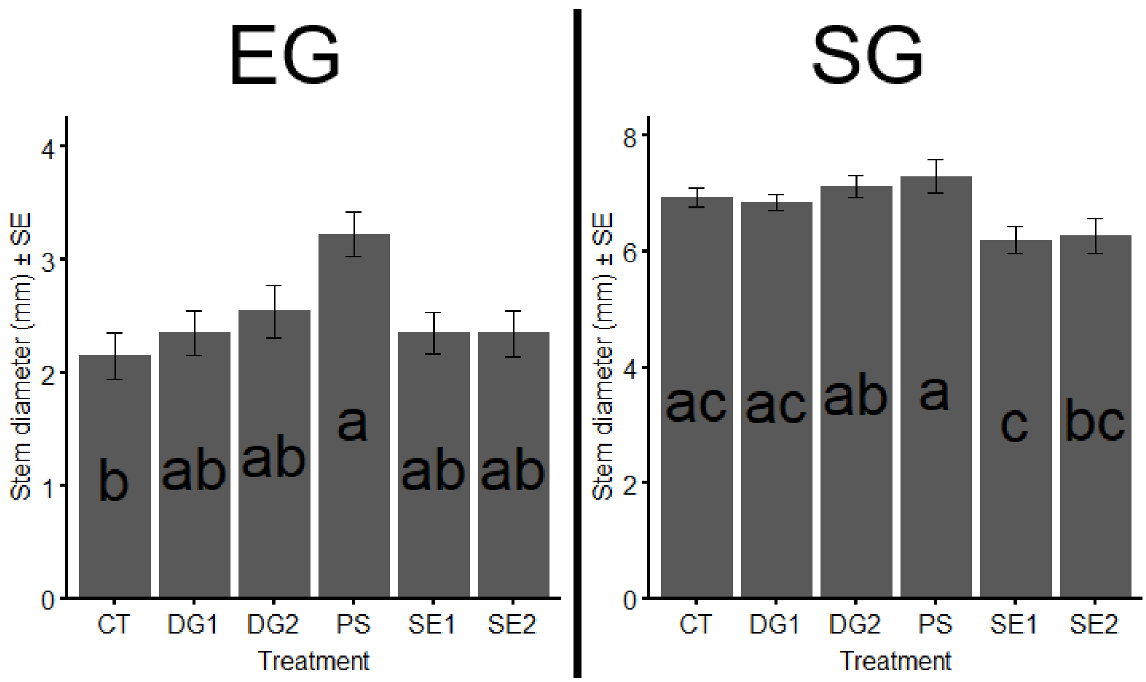


Figure 4.34.1 Effect of soil amendments on the stem diameter (mm) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Within 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.

The treatment groups with the highest and lowest mean diameter values were similar to the stem length data for both sites. The highest mean value was the paper mill sludge group for East Gore (3.2 mm) and Skye Glen (7.3 mm), with the lowest mean value belonging to the control (EG; 2.2 mm) or seaweed extract treatments (SG; ~6.2 mm). East Gore's paper mill sludge was the only group to be statistically significant from the control (EG p-value: 0.023, fig.4.34.2; SG p-value: 0.013, fig.4.34.2). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.35 Willow stem volume estimate (fall 2020)

The length and diameter of secondary/tertiary stems on select willow trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, a conservative estimate of stem volume was obtained using the formula $(\pi r^2)/2 \times l$.

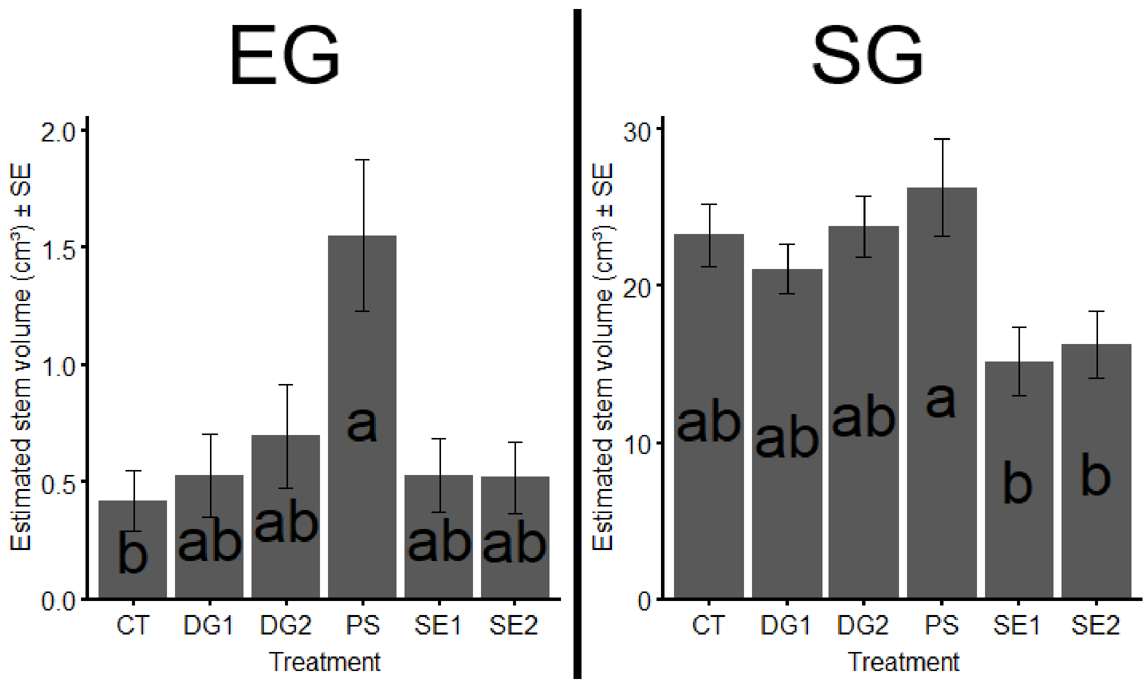


Figure 4.35.1 Effect of soil amendments on the estimated stem volume (cm^3) of willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate

(DG1/2) and liquid *A. nodosum* extract (SE1/2). 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.

East Gore's highest mean volume value was that of the paper mill sludge group (1.6 cm^3), with the lowest being the control group (0.4 cm^3). The highest mean value in Skye Glen was for the paper mill sludge treatment group (26.3 cm^3), with the single application seaweed extract group being the lowest (15.2 cm^3). ANOVA found the mean volume estimate of the paper mill sludge group as significantly different than the control for East Gore data (p-value = 0.0394, fig.4.35.1), but not Skye Glen data (p-values > 0.05; no significant difference between the control and treatment group means). Complete one-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

Comparison of poplar and willow growth

In order to ascertain interaction effects between crop type and soil amendments on comparable plant growth parameters, two-way analyses of variance were assessed for poplar and willow. Significant interaction effects allow for the direct comparison of treatment effects between different biomass crops via post-hoc pairwise analysis.

4.36 Survival rate, woody crops (2019)

In November of 2019, the number of surviving poplar and willow trees in each subplot was recorded at both sites.

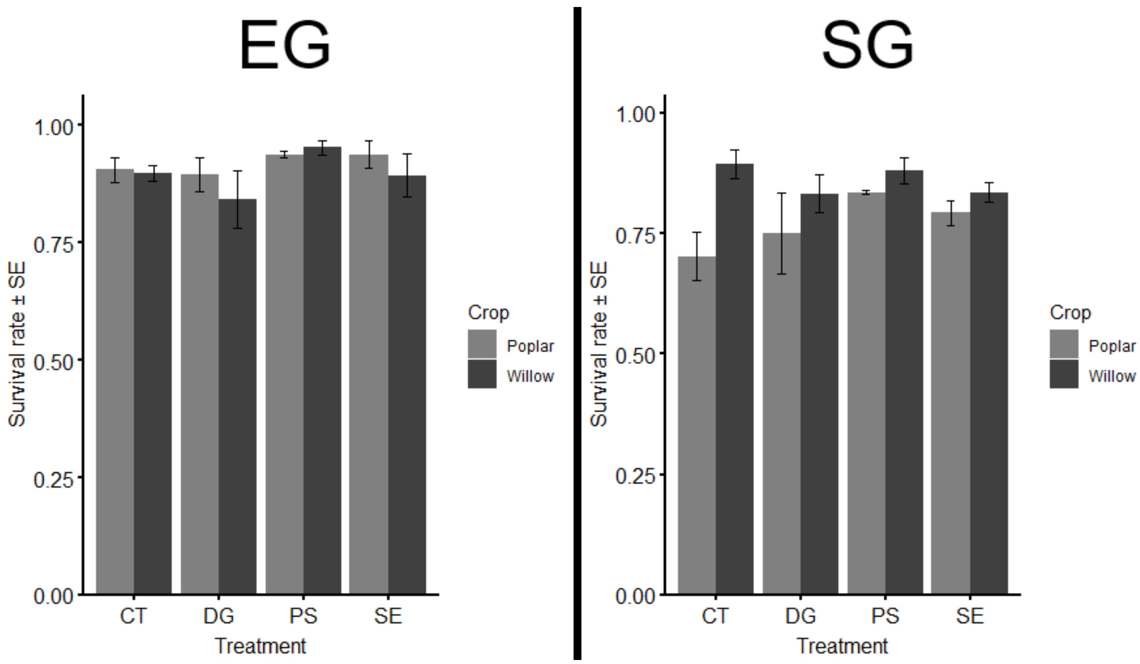


Figure 4.36.1 Effect of crop type and soil amendment on the survival rate of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 36.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on survival rate.

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	0.77	0.86	11.69	0.0055

Based on p-values obtained through analysis of variance, an interaction effect between crop/treatment type and distinct group means between soil amendments was not present ($p > 0.05$) for the East Gore (fig.4.36.1) and Skye Glen (fig.4.36.2) data. Similar results were found for crop type in East Gore, but not Skye Glen ($p = 0.0055$). This means that the survival rates between poplar and willow were unequal at that site (1.1-fold difference). Complete two-way analyses of variance for these data can be seen in the appendix.

4.37 Yield, woody crops (2019)

In November of 2019, coppiced stems of select poplar and willow trees were sampled at both sites. The resulting dry weights of these samples were converted into dry weight per hectare and evaluated using analysis of variance through a normal or gamma model, as seen below.

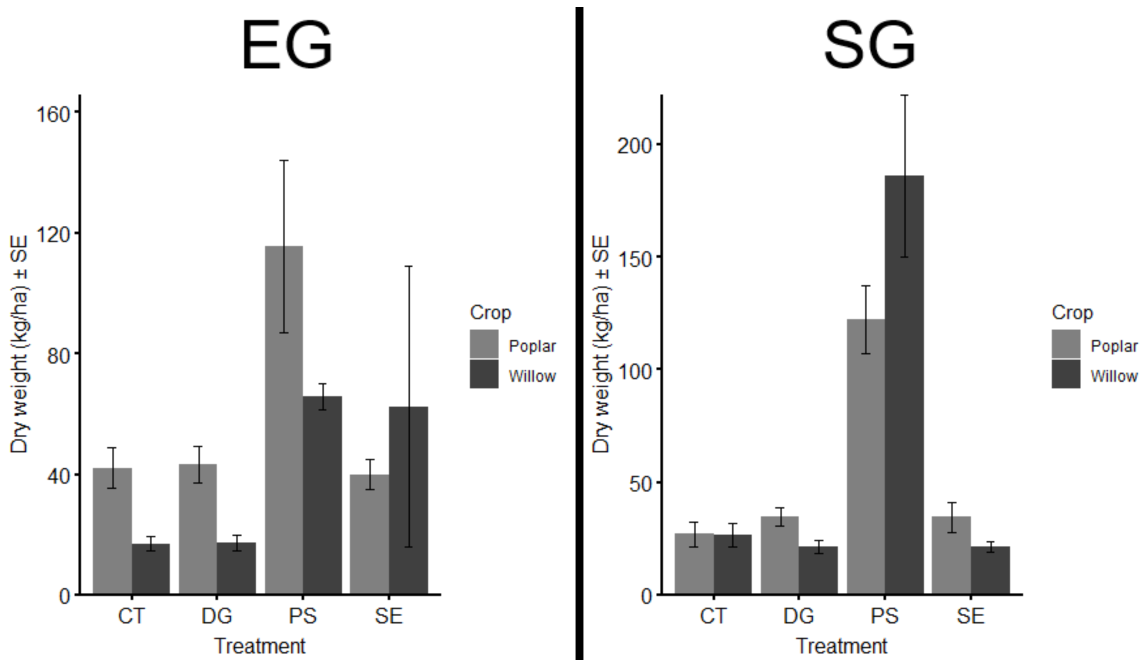


Figure 4.37.1 Effect of crop type and soil amendment on the dry weight (kg) per hectare of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 37.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on yield (kg/ha).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Control (1) vs. Paper mill sludge (2)	29.57	90.81	207.1	0.0230

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Control (1) vs. Paper mill sludge (2)	26.78	154.14	475.8	< 0.0000

Two-way analysis of variance found significant differences between treatment group mean values for both sites (EG p-value = 0.0152; SG p-value = 2e-9), with post-hoc tests distinguishing the paper mill sludge groups from the control (EG p-value = 0.0230, fig.4.37.1; SG p-value < 0.0000, fig.4.37.2). The interaction effect between crop and treatment type was also significant for the Skye Glen site (p = 0.0388), though pairwise post-hoc comparisons did not find significance (p > 0.05) between crops treated with identical soil amendments (e.g. poplar and willow treated with paper mill sludge). The mean yield values of poplar and willow across treatments were not significantly different in either site. Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.38 Survival rate 2020, woody crops

A cumulative measure of survival (encompassing both planting and overwintering survival rate) was calculated by taking the number of living plants per poplar and willow subplot (counted during August data collection) and dividing their respective sums by the total number of cuttings planted per subplot (65).

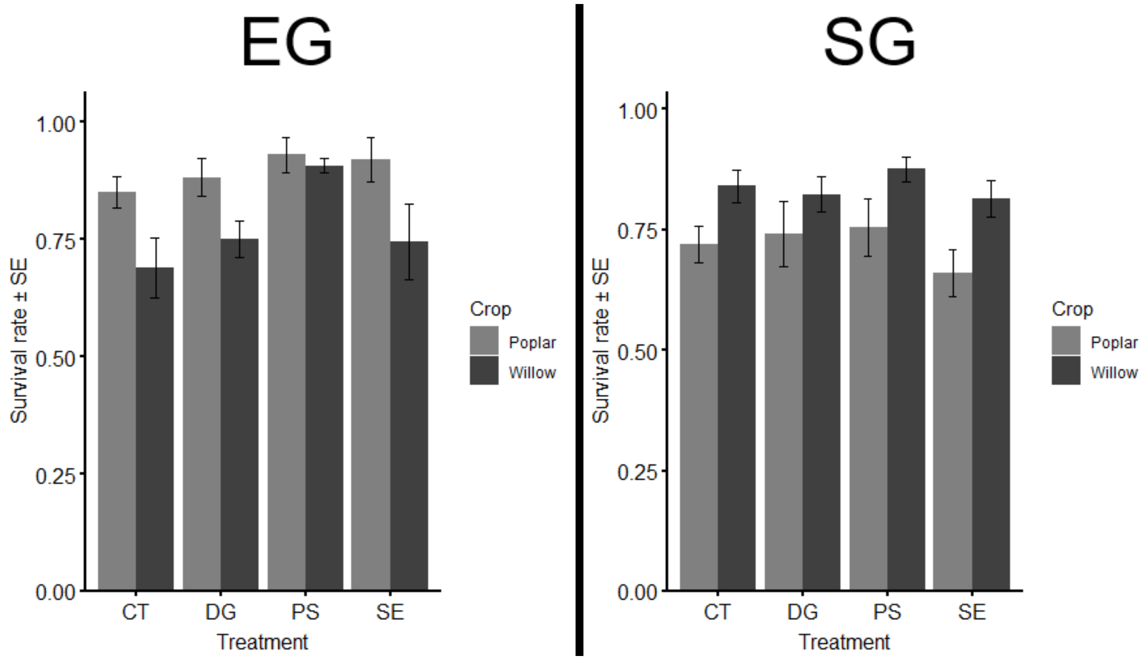


Figure 4.38.1 Effect of crop type and soil amendment on survival rate of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 38.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on survival rate.

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	0.90	0.77	16.88	0.0016
Control (1) vs. Paper mill sludge (2)	0.77	0.92	19.48	0.0256

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	0.72	0.84	16.67	0.0011

Significance was not found for the interaction between crop and treatment type for both sites (EG p-value: 0.4071, fig.4.38.1; SG p-value: 0.8922, fig.4.38.2). Inversely, the difference in overall mean survival values between poplar and willow was significant in

East Gore (0.0016) and Skye Glen (0.0011), having an overall difference of 1.2-fold between crops. As its p-value (0.0383) was low enough to reject the null hypothesis, the mean survival values associated with each treatment group were also different from each other for East Gore's data exclusively (Tukey's test: PS and CT group means unequal, p-value of 0.0256). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.39 Stem count, woody crops (August 2020)

The total number of stems on select willow and poplar trees was measured at both sites during August data collection.

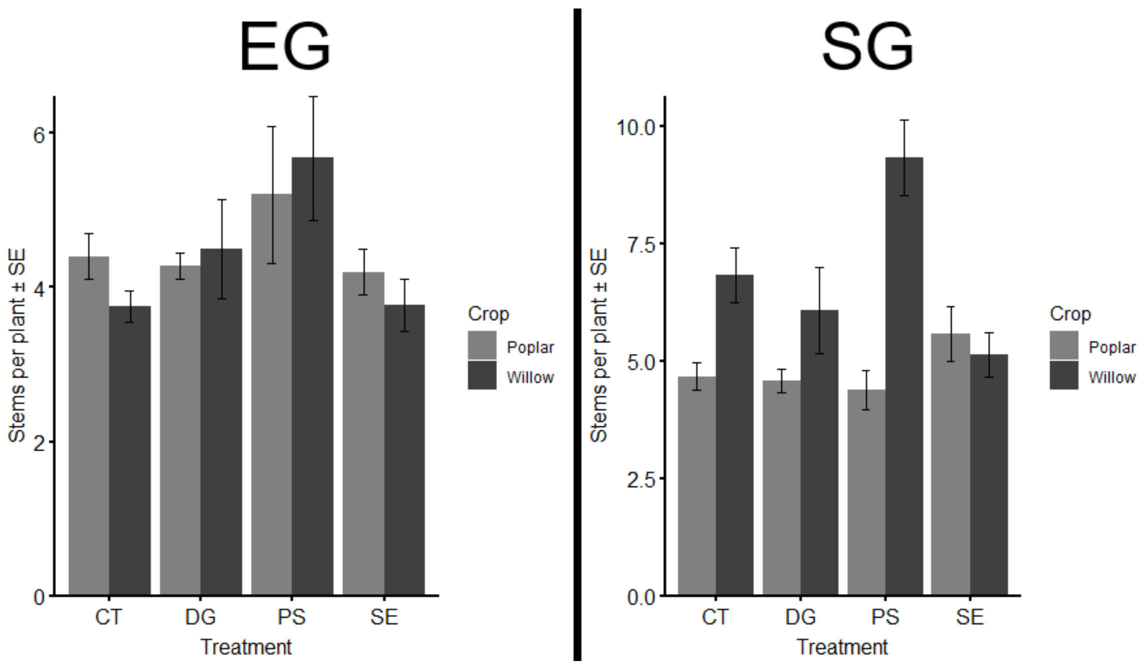


Figure 4.39.1 Effect of crop type and soil amendment on the stem count of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 39.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on stem count.

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	4.80	6.84	42.5	0.00005
Poplar/Paper mill sludge (1) vs. Willow/Paper mill sludge (2)	4.38	9.33	113.0	0.0001

Mean stem count values varied significantly between crop types at Skye Glen (p = 5e-5, table 39.1; 1.4-fold difference between willow/poplar). ANOVA also indicated differences between treatment groups for East Gore data (p = 0.0404, table 39.1), though Tukey's test found none. Additionally, it was determined that the effects of amendment type on stem count was dependent on crop type (and vice versa) through two-way analysis of variance (p = 0.0011) for Skye Glen data. Post-hoc pairwise comparisons saw the paper mill sludge treatment group of willow as being significantly different than that of poplar's (p = 0.0001). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.40 Average stem length, woody crops (August 2020)

The length of each stem on select poplar and willow trees was measured at both sites during August data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

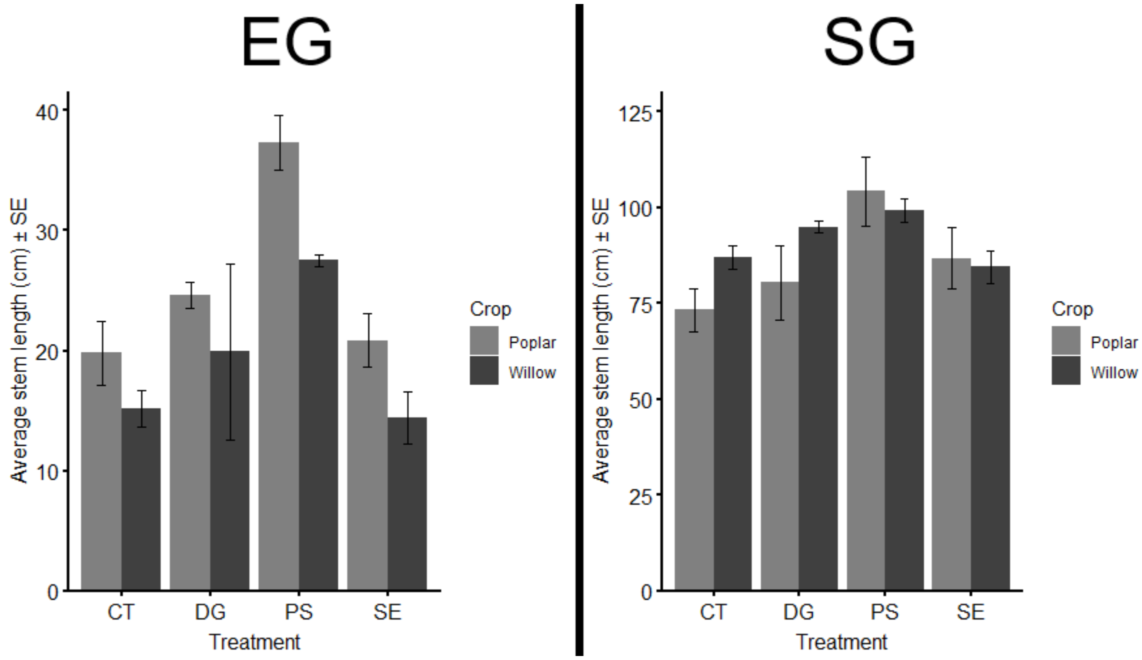


Figure 4.40.1 Effect of crop type and soil amendment on the stem length (cm) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 40.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on average stem length (cm).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	25.65	19.26	33.18	0.0085
Control (1) vs. Paper mill sludge (2)	17.51	32.40	85.04	0.0005

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Control (1) vs. Paper mill sludge (2)	80.18	101.71	26.85	0.0101

Based on the p-value of its associated analysis of variance ($p = 0.0085$), the mean stem length value of East Gore's poplar was statistically different compared to willow's – specifically, a 1.3-fold difference. Treatment group mean values were also different at both sites (EG p-value = 0.0002; SG p-value: 0.0139). Tukey's post-hoc test saw the mean values of the paper mill sludge group as being significantly distinct from the control groups for East Gore (p = 0.0005, fig.4.40.1) and Skye Glen (p = 0.0101, fig.4.40.2) data. No interaction effect was present for crop and treatment type. Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.41 Total stem length, woody crops (August 2020)

The length of each stem on select poplar and willow trees was measured at both sites during August data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

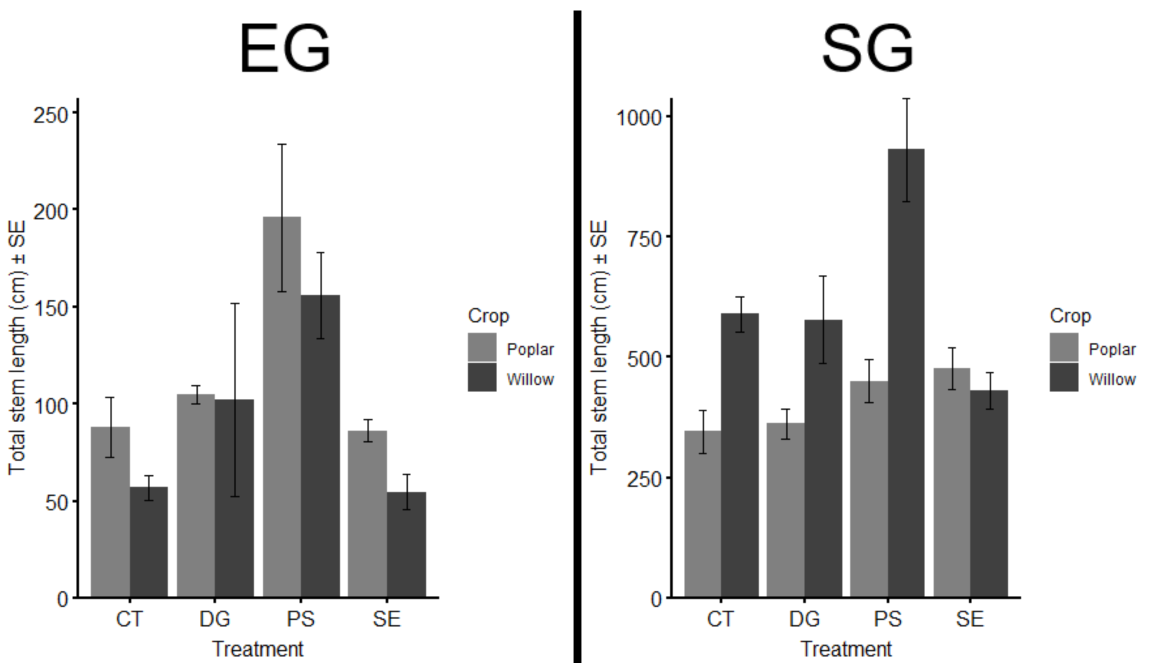


Figure 4.41.1 Effect of crop type and soil amendment on the total stem length (cm) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no additives control (CT), anaerobic digestate (DG), paper mill sludge (PS), and liquid *Ascophyllum nodosum* extract (SE). Error bars represent standard error.

Table 41.1 East Gore: significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on total stem length (cm).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Control (1) vs. Paper mill sludge (2)	72.44	176.03	143.0	0.0017

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	408.91	632.25	54.62	2e-6
Control (1) vs. Paper mill sludge (2)	467.76	690.96	47.72	0.0009
Poplar/Control (1) vs. Willow/Control (2)	346.20	589.325	70.23	0.0349
Poplar/Paper mill sludge (1) vs. Willow/Paper mill sludge (2)	450.75	931.175	106.6	2e-5

P-values from analyses of crop type (2e-6; 1.5-fold difference between willow/poplar on average), treatment group (0.0002), and the interaction between these independent variables (0.0003) was found to be less than the alpha (0.05) for Skye Glen data (fig.4.41.2). Thus, mean values between treatment groups and crop types (poplar, willow) were significantly different, and the effect of either independent variable tested (crop, treatment) was dependent on the other. Subsequent post-hoc comparisons revealed the mean length value associated with the control ($p = 0.0349$) and paper mill sludge treatment groups ($p = 2e-5$) as being significantly different between crop types. For East Gore data (fig.4.41.1), only treatment had significance ($p = 0.0007$), with the mean value of the paper mill sludge group being different than the control ($p = 0.0017$) like in Skye Glen ($p = 0.0009$). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.42 Average stem length, woody crops (fall 2020)

The length of secondary and tertiary stems on select poplar and willow trees was measured at both sites during end of season data collection. Using these data, average stem length was obtained by taking the combined length of all stems on one tree and dividing it by the number of stems measured on that same tree.

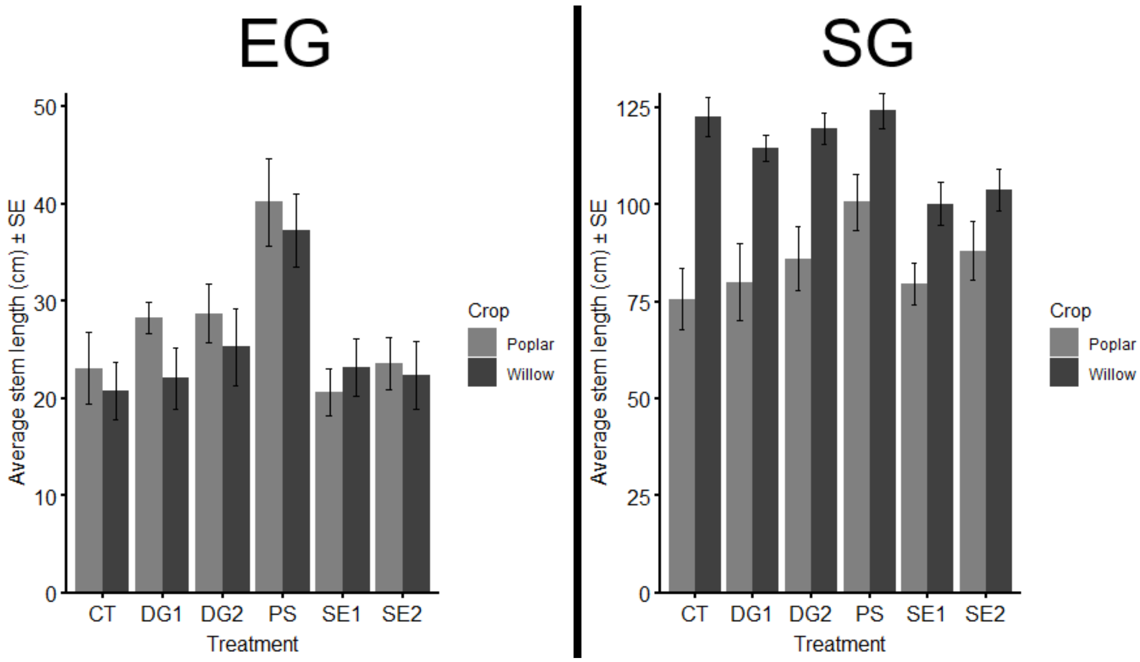


Figure 4.42.1 Effect of crop type and soil amendment on stem length (cm) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Error bars represent standard error.

Table 42.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on average stem length (cm).

East Gore				
Crop and/or treatment	Mean (1)	Mean (2)	% Difference	P-value

Control (1) vs. Paper mill sludge (2)	21.91	38.69	76.59	< 0.0000

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	84.97	114.05	34.22	1e-11
Poplar/Control (1) vs. Willow/Control (2)	75.63	122.50	61.97	9e-6
Poplar/Single app. digestate (1) vs. Willow/Single app. digestate (2)	80.0	114.48	43.10	0.0013
Poplar/Dual app. digestate (1) vs. Willow/Dual app. digestate (2)	85.98	119.50	38.99	0.0019

Significance was demonstrated through two-way analysis of crop/treatment interaction for the Skye Glen (p-value = 0.0423, fig.4.42.2), but not East Gore (p-value = 0.7678, fig.4.42.1) data. Tukey's test for Skye Glen data had the control (p = 9e-6) and both digestate treatment group mean values (DG1 p-value = 0.0013; DG2 p-value = 0.0019) as being unequal between crop types. P-values of treatment effect on stem length were below the alpha (0.05) for East Gore (p = 7e-6) and Skye Glen (p = 0.0027) data. Post-hoc testing resulted in no significance between the control and other treatment group mean values for Skye Glen (p > 0.05), as opposed to the paper mill sludge and control groups in East Gore (p < 0.0000).

The significance of Skye Glen's crop (p = 1e-11) parameter leads to rejection of the null hypothesis (i.e. group means are unequal). The difference in average stem length between willow and poplar in the Skye Glen site was 1.3-fold on average. Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.43 Total stem length, woody crops (fall 2020)

The length of secondary and tertiary stems on select poplar and willow trees was measured at both sites during end of season data collection. Using these data, total stem length was obtained by combining the length of all stems on each tree.

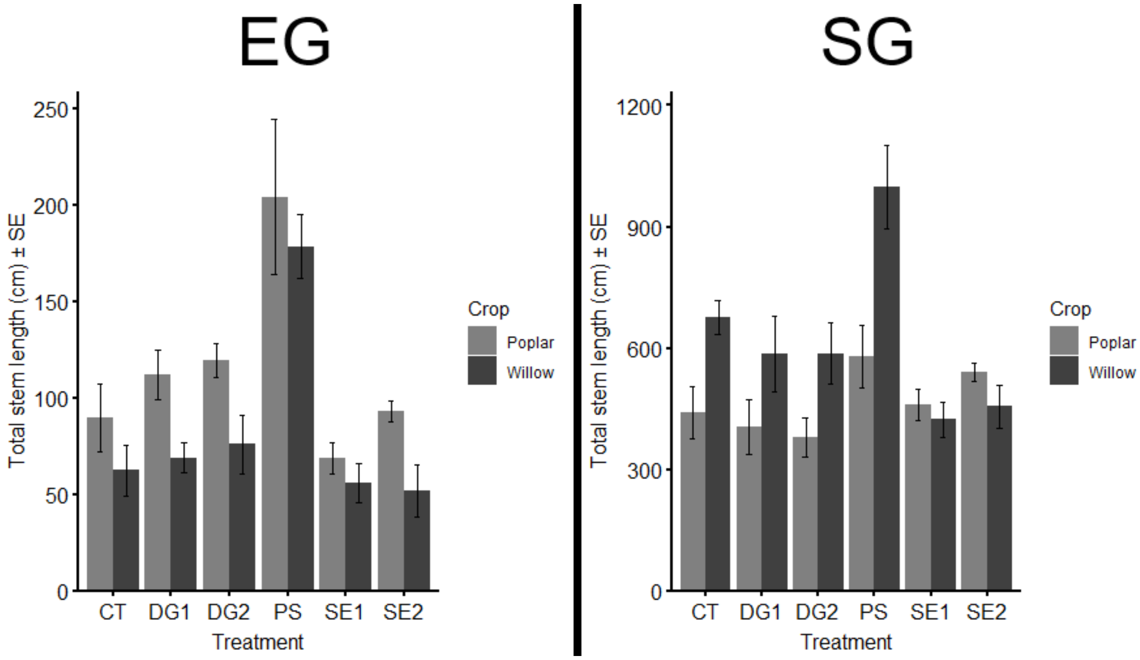


Figure 4.43.1 Effect of crop type and soil amendment on total stem length (cm) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Error bars represent standard error.

Table 43.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on total stem length (cm).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	114.56	82.33	39.15	0.0018
Control (1) vs. Paper mill sludge (2)	76.05	191.36	151.6	5e-7

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	467.67	621.25	32.84	3e-5
Control (1) vs. Paper mill sludge (2)	558.96	788.63	41.09	0.0026
Poplar/Paper mill sludge (1) vs. Willow/Paper mill sludge (2)	579.35	997.90	72.24	0.0003

At both sites, total stem length mean values associated with the "crop" and "treatment" independent variables were found to be unequal through analysis of variance. Thus, the p-values of these assessments (EG crop = 0.0018, EG treatment = 2e-8; SG crop = 3e-5, SG treatment = 5e-6) were below the alpha value of 0.05. The difference in mean total stem length values between woody crops was 1.4-fold and 1.3-fold for East Gore (fig.4.43.1) and Skye Glen (fig.4.43.2), respectively. Paper mill sludge was the only treatment group with a mean value that was significantly different than the control's for both East Gore (p-value = 5e-7) and Skye Glen (p-value = 0.0026) data.

P-values for the crop/treatment interaction effect (0.0007) were statistically significant for Skye Glen, but not East Gore data ($p > 0.05$). Subsequent post-hoc testing showed Skye Glen's paper mill sludge treatment mean value for poplar as distinct from willow's ($p = 0.0003$). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.44 Stem diameter, woody crops (fall 2020)

The diameter of secondary and tertiary stems on select poplar and willow trees was measured at both sites during end of season data collection. Using these data, average stem diameter was obtained by taking the combined diameter of all stems on one tree and dividing it by the number of stems measured on that same tree.

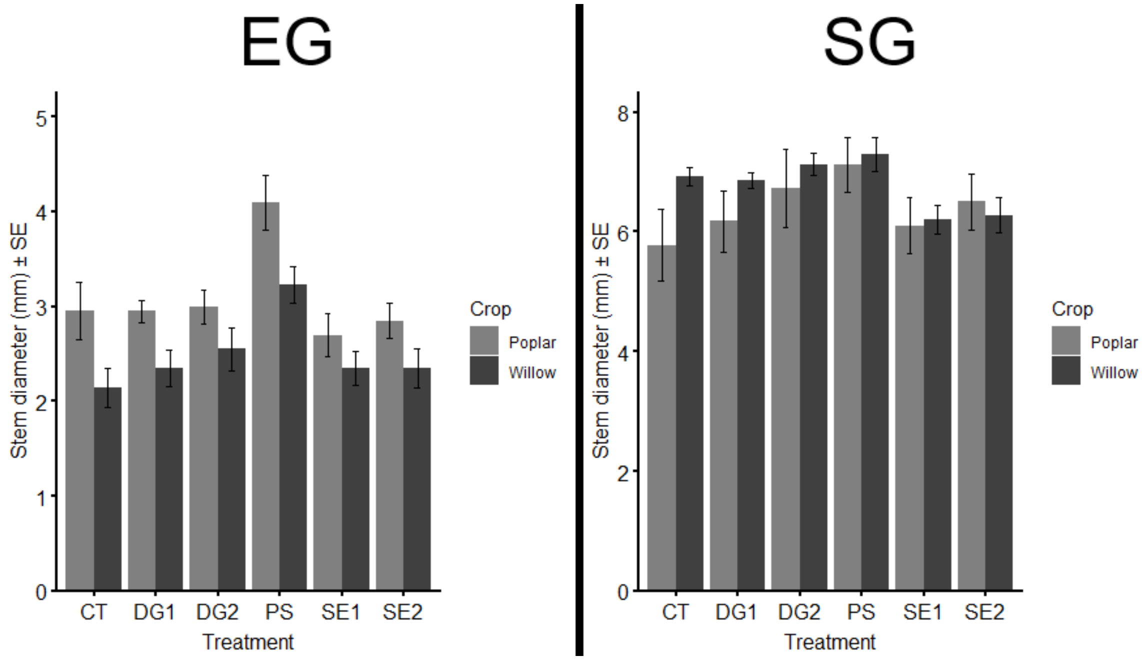


Figure 4.44.1 Effect of crop type and soil amendment on stem diameter (mm) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Error bars represent standard error.

Table 44.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on total stem diameter (mm).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	3.09	2.50	23.6	4e-6
Control (1) vs. Paper mill sludge (2)	2.55	3.66	43.53	< 0.0000

Notable p-values arose from East Gore's data for the crop (p = 4e-6, fig.4.44.1) and treatment group mean values (p = 3e-6, fig.4.44.2), indicating differing effects on stem diameter. Specifically, there was a 1.2-fold difference in mean diameter value between poplar and willow stems, and a significant difference between the paper mill sludge and control treatment group means ($p < 0.0000$). Significance was found for treatment ($p = 0.0344$) from Skye Glen's two-way ANOVA. Tukey's test showed no treatment group means from Skye Glen as being unequal from the control ($p > 0.05$). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.45 Estimated stem volume, woody crops (fall 2020)

The length and diameter of secondary/tertiary stems on select poplar and willow trees (10 subsamples per subplot) was measured during end of season data collection. Using these data, a conservative estimate of stem volume was obtained using the formula $(\pi r^2)/2 \times l$.

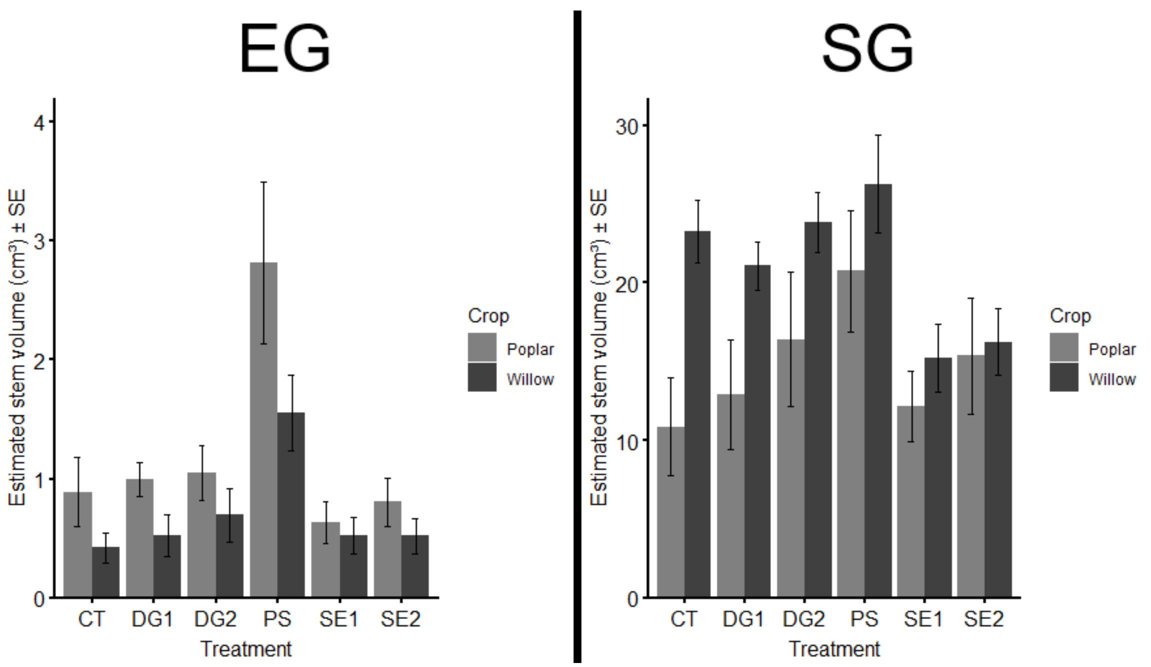


Figure 4.45.1 Effect of crop type and soil amendment on estimated stem volume (cm^3) of poplar and willow from the East Gore (EG) and Skye Glen (SG) sites. Amendments included a no-additives control (CT), paper mill sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). Error bars represent standard error.

Table 45.1 Significant differences between factors from a two-way ANOVA of crop (poplar and willow) and inoculation treatments (un-inoculated control, anerobic digestate, paper mill sludge, and seaweed extract) on estimated stem volume (cm^3).

East Gore				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	1.20	0.71	69.01	0.0044
Control (1) vs. Paper mill sludge (2)	0.66	2.19	231.8	5e-5

Skye Glen				
Crop and/or treatment	**Mean (1)**	**Mean (2)**	**% Difference**	**P-value**
Poplar (1) vs. Willow (2)	14.75	20.98	42.24	0.0007

The difference in group mean values between poplar and willow was statistically significant for both sites (EG p-value = 0.0044; SG p-value = 0.0007). Between willow and poplar mean values, there was a 1.7- and 1.4-fold difference in estimated stem volume for East Gore and Skye Glen results, respectively. Treatment group means were deemed distinct for East Gore (p = 7e-6, fig.4.45.1) and Skye Glen (p = 0.0293) data. While Tukey's test found a significant difference between the paper mill sludge and control group mean values in East Gore (p = 0.00005), Skye Glen's post-hoc had no significance relative to the control (p > 0.05). Additionally, significance was not found for the interaction of crop and treatment (EG p-value = 0.4072; SG p-value = 0.4471). Complete two-way analyses of variance and post-hoc tests for these data can be seen in the appendix.

4.46 Soil moisture and temperature data

To monitor soil conditions at a 15 cm depth, a HOBO® Micro Station installed with moisture and temperature sensors was set up at the periphery of each site, which collected data hourly. East Gore's soil moisture data has been omitted from August 29th, 2020 onwards due to sensor malfunction.

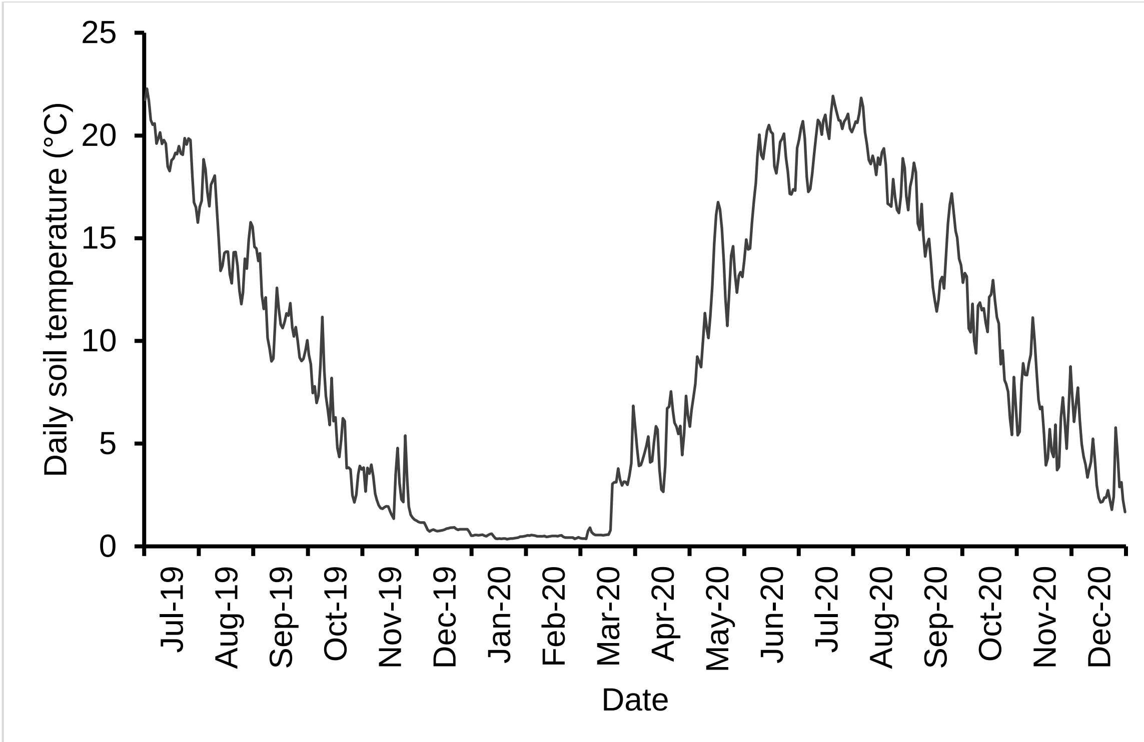


Figure 4.46.1 Daily temperature (°C) of soil at the East Gore site from July 30th, 2019 to December 31st, 2020.

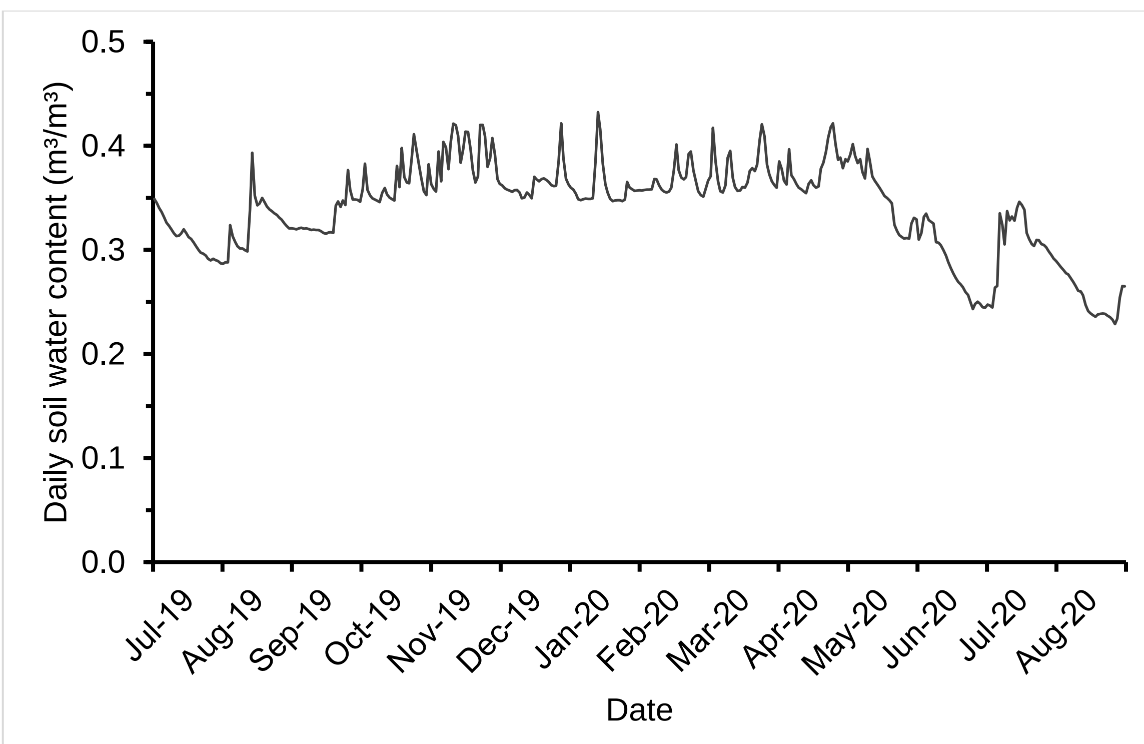


Figure 4.46.2 Daily water content (m^3/m^3) of soil at the East Gore site from July 30th, 2019 to August 29th, 2020.

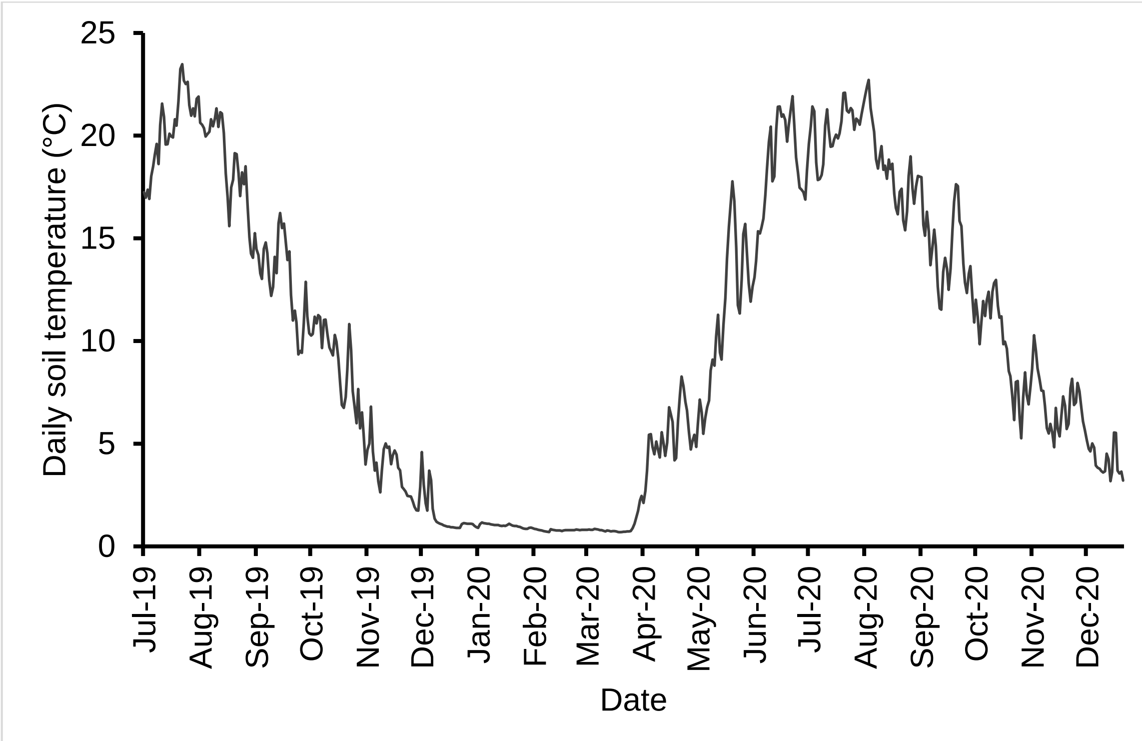


Figure 4.46.3 Daily temperature (°C) of soil at the Skye Glen site from July 19th, 2019 to December 31st, 2020.

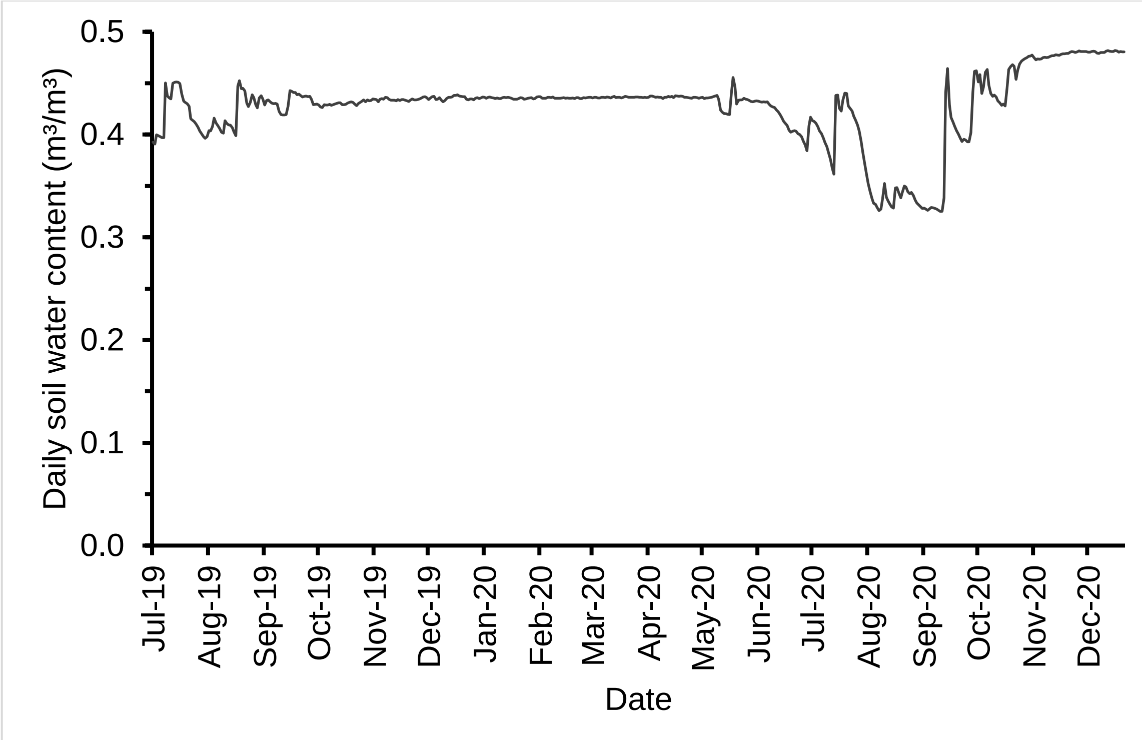


Figure 4.46.4 Daily water content (m^3/m^3) of soil at the Skye Glen site from July 19th, 2019 to December 31st, 2020.

The highest and lowest daily soil temperatures respectively occurred on July 31st, 2019 (22.376 °C) and February 7th, 2020 (0.346 °C) for the East Gore site, and on August 1st, 2019 (23.480 °C) and March 29th, 2020 (0.693 °C) for the Skye Glen site. The temperature data of both sites follow a clear pattern of fluctuation, wherein temperatures are warmest from the months of June to September, followed by a cooler period from the months of October to May. Daily soil moisture was highest on January 27th, 2020 for East Gore (0.4324 m^3/m^3) and December 26th, 2020 for Skye Glen (0.4818 m^3/m^3), and was lowest on August 25th, 2020 for East Gore (0.2287 m^3/m^3) and September 20th, 2020 for Skye Glen (0.3252 m^3/m^3). Skye Glen's soil moisture remained at a consistent 0.435 m^3/m^3 from October 2019 to May 2020, while East Gore's stayed in a range of roughly 0.35 to

0.40 m^3/m^3 until June 2020, where two notable troughs in soil moisture occur shortly thereafter.

5.0 DISCUSSION

The objective of this research was to see whether biomass crops could be established on Nova Scotian marginal land, and whether soil amendments could significantly impact crop establishment. To do this, two field sites were established within the Province, one in East Gore, Hants County and the other in Skye Glen, Inverness County. Sites were arranged according to a randomized block design, with four blocks per each of the tested biomass crops (poplar, willow, switchgrass, Miscanthus). To test soil amendments (anaerobic digestate (DG), paper mill sludge (PS), *Ascophyllum nodosum* extract (ANE), and a control without amendments), these blocks were divided into four. Crops were planted in the summer of 2019, with data collection starting in the fall of that same year. Growth parameters such as stem height and dry weight were recorded, and plants were scaled back (switchgrass/Miscanthus) or coppiced (poplar/willow). In the following year (2020), aspects of plant growth (leaf area, stem count, etc.) were again collected during the summer and fall seasons. Tissue nutrient analyses were also done in 2019 and 2020 on our chosen indicator species, Miscanthus, by the Nova Scotia Department of Agriculture's Analytical Laboratory in Truro, NS. An additional application of digestate and *A. nodosum* extract was also applied during summer 2020 via a split-plot design, adding to the total number of amendment groups. Data were analyzed using analysis of variance through a generalized linear model, using a normal or gamma model (depending on the distribution of data).

This discussion will first focus on the effects of the soil amendments on the tree and grass crops, followed by a broad performance comparison of these crops. Next, this section will discuss the most promising combinations of crop species/soil amendments, site-specific effects, and end with the wider context of this research.

5.1 Effects of paper mill sludge on poplar and willow

In August 2020, a significant difference between the control and paper mill sludge treatment groups was found for the total stem length of East Gore poplar (fig. 4.10.1) and willow, as well as Skye Glen willow (fig. 4.15.1). Similar results were also observed for poplar leaf area in East Gore (fig. 4.7.1) and willow leaf area in Skye Glen (fig. 4.12.1), as well as the average stem length of poplar and willow in East Gore and Skye Glen (respectively; fig 4.9.1, 4.14.1). Leaf counts from East Gore (fig. 4.6.1; fig. 4.11.1), stem length measurements of Skye Glen's poplar (fig. 4.9.1, 4.10.1), and stem counts of wood crops amended with paper mill sludge were markedly greater than that of the control in August 2020, though these results were not supported by analysis of variance (not statistically significant). In fall 2020, all measured aspects of poplar and willow treated with paper mill sludge were significantly different from the control for East Gore data. Skye Glen's PS-amended poplar measurements were also notably distinct from the control, but not statistically significant. Though research into the influence of paper mill sludge on poplar and willow is somewhat limited, Campbell et al. (1995) and Quaye et al. (2011) both reported inconsequential or negative effects on poplar and willow biomass accumulation (respectively). Conversely, Carpenter and Fernandez (2000) found poplar grown in a paper mill sludge/sand substrate to have significantly higher stem length and width compared to those from the sandy loam control.

Tissue nutrient concentration data from Miscanthus at both sites during fall 2019 (fig. 4.2.1, 4.2.2) and 2020 (fig. 4.26.1, 4.26.2) showed the paper mill sludge group values as being either lower or marginally higher compared to the control group. Tissue potassium concentration of the PS treatment group from East Gore in fall 2019 (fig. 4.2.1), for example, was significantly lower than the control group. However, these results may be due to the dilution effect, where an increase in dry matter accumulation and nutrient uptake results in a lower concentration of an element per unit of plant tissue (Jarrell & Beverly 1981). Considering both tissue nutrient concentration and dry plant yield, in 2019 the nitrogen yield of PS-treated Miscanthus was statistically higher than the control for both sites (fig. 4.3.1, 4.3.2), and for phosphorus yield of Skye Glen (fig. 4.3.2). The potassium yield for Skye Glen Miscanthus was notably larger as well (fig. 4.3.2), though this does not apply to the potassium content of East Gore Miscanthus. Nutrient yield of Miscanthus tissues treated with PS was also notable for 2020 data, though no results were statistically significant (relative to the control).

Because of its low mineral nutrient content, the growth benefits of treating soils with paper mill sludge arises from its properties as a soil amendment, not a direct fertilizer (Bellamy et al. 1995). Paper mill sludge is reported to improve soil fertility (i.e. the soil's ability to accommodate the needs of plants (Abbott and Murphy 2007)) through physical and chemical processes, such as increasing the activity and biomass of soil microbes (Gagnon et al. 2000). This is a result of the large amount of organic matter that paper mill sludge contains, such as cellulose and lignin (Camberator et al. 1997; Diacono and Montemurro 2009). After its addition to the soil, the organic matter of paper mill sludge is decomposed by heterotrophic microorganisms (Murphy et al. 2007), prompting plant-available nutrients (e.g. N, P, S) to be mineralized and diffused (Luna et al. 2016).

Maintenance of soil microbes via amendments can affect crop yield as the condition of these communities (activity, abundance, composition) influences their function in processes vital to plant performance, such as the carbon cycle and nutrient metabolism (Heijden et al. 2008; Falkowski et al. 2008). Abdi et al. (2016) found improved carbon and nitrogen content in both the soil and its associated microbial biomass three years following application of paper mill sludge. Sludge decomposition increased alongside application rate, implying a correlation between microbial activity and biomass volume. Additionally, Fahim et al. (2018) demonstrated a near 2-fold increase in plant nutrient content (N, P, Ca) compared to the control group as a result of paper mill sludge treatment. This caused their plant subjects (lady finger and garden mint) to experience a marked boost to nitrogen uptake and end yield. A performance gap between paper mill sludge and chemical fertilizers was also present, though it was minor.

Sufficient fertilization at establishment has been shown to improve yield in poplar, and the outcome of establishment has a ripple effect on the continued productivity of a plantation (Guillemette & DesRochers 2008). For example, poplar will allocate additional nitrogen to shoots (Sarker et al. 2017) and expand the leaf system under suitable conditions (i.e. larger, more numerous leaves) (Li et al. 2012). Inversely, a lack of nitrogen can reduce productivity, impacting processes that contribute to growth such as photosynthesis and the citric cycle (Song et al. 2019).

High yields of short-rotation willow grown in cooler regions is thought to be limited by access to water and nutrients (Weih 2004), though other studies have shown fertilization to confer little to no yield improvements (Sevel et al. 2013). This has been explained through differences in nutrition requirements between genotypes, as well as site composition (Labrecque & Teodorescu 2001; Weih & Nordh 2005). Indeed, the yield response of willow to nitrogen and its general fertilization needs are still contested in the literature (Stoof et al. 2015). A review paper by Fabio and Smart (2018) demonstrates this, as while most papers report that nitrogen fertilization has a positive effect on willow growth, the exact extent of this response remains unclear.

In summation, paper mill sludge may have enhanced poplar and willow yield by increasing the availability of nutrients as a result of soil microorganisms processing its organic matter content. However, as the relationship between plant performance and fertilization is more site and species dependent in willow, this explanation becomes more ambiguous.

By referencing weather station data (section 3.16), it is apparent that monthly temperatures were highest from June to September in 2020. Significant drops in monthly total precipitation for June (1.1 mm; Halifax Stanfield International Airport station near East Gore; fig. 3.16.10) and September (1.2 mm; Cheticamp Highlands National Park station near Skye Glen; fig. 3.16.11) suggests that water availability was also unstable during this period. Additionally, several sharp declines in soil moisture are present in East Gore data during this time (fig. 4.46.2), representing the lowest values from that dataset. The Government of Canada's drought monitor reported abnormal dryness to moderate drought conditions across most of Nova Scotia from June to September 2020 as well. It's therefore possible that drought-like conditions were present at both sites to some capacity during the summer of 2020. With this in mind, another way in which paper mill sludge could have benefitted the growth of poplar and willow was by enhancing the water holding capacity of the soil.

Paper mill sludge amendments can change the water holding capacity of the soil due to their organic matter content. After paper mill amendments are applied, binding agents associated with organic matter perform complex interactions with the soil, which results in enhanced soil aggregation (Abiven et al. 2008). For example, decomposition of organic matter via microorganisms produces polysaccharides that improve cohesion by absorbing mineral particles (Abiven et al. 2008). Aggregation allows for more water to be retained by increasing pore space, which also benefits root and microbial growth (Leon et al. 2006). A growth experiment by Foley & Cooperband (2002) demonstrated this through a 5 to 45% improvement in plant-available water (compared to the control) as a result of amending food crops (potato, snap bean, cucumber) with paper mill residues. The amount of water that needed to be applied to potato also decreased by 5 to 30%. These reductions were correlated with the amount of carbon added to the soil, supporting the influence of organic matter on soil aggregation.

Willow and highly productive species of poplar are typically vulnerable to drought (Ogasa et al. 2013; Monclus et al. 2006). In fact, poplar is among the most drought-sensitive tree species of the northern hemisphere (Pallardy and Kozlowski 1981). In response to such stressors, these trees can have reduced growth, translating to comparatively smaller stem lengths and leaf areas (Jaleel et al. 2009). Specifically, reductions in leaf function of poplar leads to lowered chlorophyll content and stomatal closure, ultimately impacting photosynthetic and transpiration rates (Wang et al. 2017). Willow is particularly vulnerable to drought because of an existing cavitation susceptibility (Ogasa et al. 2013). Changes in willow morphology such as reducing leaf size and expanding root systems relative to shoots occur in order to minimize potential water loss (Bonosi et al. 2010; Markus-Michalczyk et al. 2016). However, an experiment by Doffo et al. (2017) showed this response to be variable among different willow hybrids, though reductions in dry matter as a result of drought were consistent. Therefore, an increase in plant-available water as a result of paper mill sludge amendment could have helped poplar and willow to avoid the drought-like conditions that occurred during the summer of 2020. This, in turn, would allow the growth of these species to be uninhibited by drought stress.

5.2 Effects of paper mill sludge on Miscanthus and switchgrass

Nearly all aspects of Miscanthus growth were improved over the control as a result of the paper mill sludge amendment at both sites. This includes yield (2019/2020) (fig. 4.1, 4.24), tiller count (fig. 4.16.1), leaf length/area (fig. 4.17.1, 4.18.1), and total leaf area (4.19.1). East Gore's yield in 2019 and many of the Skye Glen results (2019 yield, leaf length, leaf area, total leaf area) were also statistically significant. The yield of PS-treated switchgrass was significantly greater than the control's at the Skye Glen site in 2019 (fig. 4.1.2), becoming comparable in 2020 (fig. 4.24.2). For switchgrass at the East Gore site, its yield was reduced compared to the control (fig. 4.1.1), especially so in 2020 (fig. 4.22.1). Paper mill sludge amended Miscanthus tissues generally had a higher nutrient yield than the control for East Gore and Skye Glen data in 2019 (fig. 4.3.1, 4.3.2), with many results having a statistically significant difference. Nitrogen and phosphorus yield was high among the primary macronutrients in 2019. The disparity between the control and the PS treatment generally continued in 2020 nutrient yield data (4.27.1, 4.27.2), though no results were statistically significant.

Paper mill sludge is high in organic carbon, as evidenced by the high percent content in table 3.1. Though results vary depending on site condition, treating soils with organic carbon (typically at high application rates) can benefit crop yields by stimulating microbial communities to expand (Chen et al. 2003; Diacono and Montemurro 2009). The propagation of soil microbes is most often restricted by the availability of carbon, as it is used by these organisms for energy production (such as through oxidizing carbohydrates) (Chen et al. 2003). Some of these microbes are nitrogen-fixing, converting atmospheric nitrogen gas (N_2, which cannot be used by plants) into the plant-available form ammonia, ultimately providing crops with nutrients (Delgado et al. 2002; Chen et al. 2003).

While the N needs of *Miscanthus* × *giganticus* and *Panicum virgatum* are lessened compared to other commercial crops (Lewandowski & Heinz 2003), grass productivity is generally considered to be nitrogen limited (Epstein et al. 1996). Indeed, experiments from Ercoli et al. (1999) and Owens et al. (2013) demonstrate a positive growth response from Miscanthus and switchgrass, respectively, on nitrogen-fertilized soils. Therefore, an increase in nitrogen-fixing bacteria resulting from a paper mill sludge amendment would likely benefit Miscanthus and switchgrass yield. Lalande et al. (2003) explored the effects of a paper mill sludge and manure mixture on soil activity and found that treatment groups had notable enhancements in enzymatic activity (+33%) and microbial biomass carbon content (+50%) compared to the control. These effects extended into the first two years after application, but became less pronounced during the second year. Mineral fertilizers had (relatively minor) effects on enzyme activity, but not microbial biomass, when added to the existing treatment.

The yield of another macronutrient, phosphorus, was also notably increased as a result of the paper mill sludge amendment, the mechanics of which may be explained by Fierro et al. (1999). Their experiment set out to reclaim marginal land using a wild grass species (tall wheatgrass) treated with a combination of nitrogen/phosphorus fertilizer, and paper mill sludge. While wheatgrass yield responded positively to the mineral fertilizers, especially phosphorus, yields were further enhanced by paper mill sludge. An increase in P uptake (as only paper mill sludge improved P tissue content) was explained through the sludge's ability to lower soil bulk density (allowing for an expansive root system) and enhance nutrient flow (increased water availability via its water holding capacity). Therefore, the increased yield of switchgrass and Miscanthus from the paper mill sludge amendment in this experiment could have been the result of improvements in physical (bulk density, water holding capacity) and physiological fertilization (expansion of soil microbiota) occurring simultaneously.

As previously discussed, it is somewhat likely that drought-like conditions occurred during the summer of 2020 based on precipitation, soil moisture, and drought mapping data. Also, it was observed that plants amended with paper mill sludge were surrounded by areas more saturated with moisture (corresponding to the locations in which the PS was buried) relative to the overall conditions of the field site during this period. Relevantly, organic materials such as paper mill sludge can potentially increase the amount of water that is accessible by plants (water in a pressure range of -1.5 to -0.07 MPa), thus improving water holding capacity (Zibilske et al. 2000). This effect is due in part to its fibrous structure, which can lower soil bulk density (Boni et al. 2003). Lower bulk density allows root systems to better penetrate the soil, and facilitates growth by improving access to nutrients and water (Stirzaker et al. 1996).

Generally, grass performance is thought to be restricted by access to water (Epstein et al. 1996), an aspect of fertility that can be improved through amending soils with paper mill sludge. However, when viewing the moisture content data for switchgrass (fig. 4.23.1) and Miscanthus (fig 4.25.1), it is clear that the amount of water in the tissues of crops treated with PS was not significantly different than the control. This conflict could be explained through the dilution effect (Jarrell & Beverly 1981), or the fact that the moisture content of these plants during the fall was not reflective of the water deficient conditions of the summer. Additionally, Miscanthus and switchgrass both possess expansive root systems and use a more water-efficient method of photosynthesis (relative to C3) through the C4 pathway, making them innately drought tolerant (van der Weijde 2016; Ashworth et al. 2016).

While Miscanthus and switchgrass have the capacity to persist under drought-like conditions, the quantity and quality of their biomass can still be negatively impacted. Under drought stress, the composition of the cell wall (e.g. lignin content) may change to make the conversion of polysaccharides to fermentable sugars more difficult (Himmel & Picataggio 2008; Zhao et al. 2012). Experiments by Van Der Weijde et al. (2017) and Barney et al. (2009) show yield reductions of 45% on average and up to 80% and for Miscanthus and switchgrass (respectively) under drought stress. Considering this, the paper mill sludge treatment could have created an environment more conducive to Miscanthus growth (relative to the control) by ameliorating drought stress. Similarly, an increase in the soil's water holding capacity via paper mill sludge may have assisted in switchgrass establishment, but became less of a benefit afterwards (compared to the control) due to its inherent drought resistance.

5.3 Effects of anaerobic digestate on poplar and willow

The effects of anaerobic digestate on the measured growth parameters of poplar and willow were marginal at both sites relative to the control group. The one exception to this was for the total stem length of East Gore willow in August 2020 (fig. 4.33.1), though the treatment group mean possessed high variation and was not statistically significant. A potential explanation for the minimal effects of the AD treatment may be explained through the application method used. As explained in a review paper by Nkoa (2013), ammonia volatilization and runoff can result from applying AD directly onto the soil surface, reducing the amendment's fertilizing potential. Additionally, temperature and wind conditions present at application could also contribute to volatilization (Holm-Nielsen et al. 2009). Ammonia volatilization is the transformation of ammonium to ammonia gas when exposed to a high pH environment, in turn decreasing the amount of nitrogen available to crops (Schwenke 2014). While other application strategies such as injection and incorporation have been found to minimize ammonia losses, shallow application methods (namely trailing shoe) are likely the most optimal when considering factors like efficiency and crop damage (IEA 2010).

In comparing our results to the literature, it can be seen that an anerobic digestate treatment can directly improve the growing conditions of woody plants. Badagliacca et al. (2020) was able to restore the physical and chemical fertility of a no-tillage olive and a citrus orchard after digestate treatment. However, this reaction was dependent on the acidity and texture of the soil, as the availability of carbon and nitrogen was negatively impacted in rougher, alkaline environments. Additionally, a greenhouse experiment by Holm and Heinsoo (2014) tested pig slurry digestate on the development of *Salix viminalis* (basket willow), which outperformed both the control and a mineral fertilizer by way of biomass accumulation. The disparity between mineral and digestate fertilizers was explained by the digestate possessing nutrients in more plant-available forms, and its ability to stimulate nutrient fixing soil microbes. Notably, the aboveground biomass of digestate-treated willow did not show increased production until a year after establishment, which is a pattern that could also be reflected in this experiment. However, Svensson et al. (2004) concluded that anaerobic digestate was not suitable as a standalone fertilizer because of its deficient phosphorus content after observing the resulting yield from digestate-treated barley.

As the effectiveness of anaerobic digestates are, at the least, comparable to mineral fertilizers (Nkoa et al. 2013), the subdued growth response of our woody crops (poplar, willow) to the AD treatment (relative to Miscanthus/switchgrass) could be explained through their fertilization needs. For instance, a common management strategy for poplar production is through nitrogen fertilization, which can also improve willow yield by an average of 40% (Fabio and Smart 2018; Hu et al. 2020). Using the application rate (16,250 L/ha), estimated density (0.99 kg/L), and chemical composition of anaerobic digestate (table 3.2), the amount of N applied via our digestate amendment could be estimated at roughly 28 kg/ha (Schiavon et al. 2018). This is markedly lower than the optimal range of N fertilization reported in the literature, at 60-250 and 150-400 kg/ha of N suggested for poplar and willow, respectively (Caslin et al. 2010; Ghezehei et al. 2021). Combined with the nutrient efficiency of Miscanthus and Switchgrass discussed in the previous section, this gives credence to the possibility of digestate providing an adequate amount of mineral nutrients to the tested grasses, but not to the woody crops.

5.4 Effects of anaerobic digestate on Miscanthus and switchgrass

The notable effects of anaerobic digestate (relative to the control) on Miscanthus was seen in the high potassium tissue concentrations for both sites in 2019 (significant in EG only; fig. 4.2.1, 4.2.2), increased leaf length (significant in EG only; 4.17.1), area (significant in EG only; 4.18.1), and total area (statistically nonsignificant; fig. 4.19.1) in August 2020, the highest biomass accumulated in fall 2020 for East Gore data (statistically nonsignificant; fig. 4.24.1), and an increased plant tissue potassium concentration in fall

2020 (statistically nonsignificant; fig. 4.26.1, 4.26.2). For switchgrass, its dry weight was highest in subplots treated with digestate for fall 2019 and 2020, exclusively in East Gore (statistically nonsignificant; fig. 4.1.1, 4.22.1). Moisture content also followed a similar pattern (fig. 4.23.1). Additionally, the dual application of anaerobic digestate had higher values for mean dry weight and moisture compared to the single application.

In referencing the tissue nutrient concentration data from our indicator species (Miscanthus), the most dominant nutrient associated with the anaerobic digestate treatment was potassium. Digestate can be a K resource for crops as its liquid phase can be especially abundant in free K+ ions, which is a plant-available form (Insam 2015; Sogn et al. 2018). This digestate-assisted increase in available potassium is demonstrated in Kataki et al. (2019), wherein a manure digestate maximized the amount of K available in the soil, and almost all the remaining tested digestates performed at least as well as a mineral fertilizer in terms of potassium added. Tampio et al. (2016) also found potassium to be the most prevalent among the macronutrient content of its four liquid digestate treatments. Potassium is a vital component of a variety of plant physiological processes, most importantly photosynthesis, where it is involved in the production of ATP, works as an enzyme activator, and regulates CO2 uptake, among other roles (Marschner 1995). Furthermore, the literature indicates that a plant's capacity to photosynthesize can be directly correlated with the amount of available K in the environment (Jin et al. 2011). Potassium has the potential to simulate leaf growth in grass species and can influence the growth of crops when applied on K-deprived soils (such as marginal land) (Simpson et al. 1988; Kering et al. 2013). This may explain the significant effect of the anerobic digestate treatment on the leaf length and area of East Gore Miscanthus in August 2020.

Potassium is also an important factor for the performance of crops under a water deficit. The osmotic potential of the vacuole and cytosol of the plant cell is dependent on K ions, so a plant's ability to maintain turgor pressure through osmotic adjustment relies on its supply of potassium (Mengel & Aerneke 1982; Lindhauer 1985; Marschner 1995). Improvements to osmotic adjustment could also support the acquisition of water (Wang et al. 2013), and a positive correlation has been found between the water use efficiency of plants and the availability of potassium in the soil (Zhu et al. 2020). Additionally, potassium can control the functioning of stomata, helping to maintain the absorption of carbon dioxide under drought conditions which allows for the continued production of oxygen and sugars via photosynthesis (Farooq et al. 2009; Zahoor et al. 2017). This explanation for the enhanced growth of digestated-amended Miscanthus is questionable as its moisture content did not significantly differ from the control. However, these moisture data may not accurately reflect its status during the summer, when drought-like conditions, and the differences in moisture content between treatment groups, would have been more prominent. Conversely, the moisture content of switchgrass treated with DG is noticeably higher than the control value, though it is not a statistically significant difference. As mentioned prior, there is potential for yield decreases in switchgrass and Miscanthus as a result of drought-like conditions. Thus, the benefits digestate could have arisen through soil moisture differences between the East Gore and Skye Glen sites. In observing these data (fig. 4.46.2, 4.46.4), it is apparent that the daily moisture of East Gore's soil was more variable than Skye Glen's from May to August 2021, when drought-like conditions were most likely to have occurred. Additionally, the daily water content of the soil at East Gore was at an average of 31% around this time compared to Skye Glen's average of 41%. Importantly, this period occurs within the growing season (May – June), during which the availability of water would influence yield as crops undergo a state of growth. The addition of K via the digestate amendment may have therefore provided these grasses with a resistance to drought-like conditions that were more prevalent at the East Gore site.

The effects of the anaerobic digestate treatment appear more distinct for crops grown in the East Gore location, which may be explained through differences in site condition. As mentioned prior, the benefits of potassium (the most prominent mineral added by the DG treatment) fertilization are greatest when applied to soils that are deficient in K (Kering et al. 2013). As the initial soil analysis shows Skye Glen as having a higher potash (K_2O) content than East Gore at a 16-30 cm depth, the addition of K via the digestate amendment might have had a less dramatic effect on plant growth at the Skye Glen site as its soils already contained an adequate amount of potassium.

5.5 Effects of *Ascophyllum nodosum* extract on poplar and willow

Treating willow with *Ascophyllum nodosum* extract (ANE) did not produce any notable effects. However, enhanced plant growth was observed in poplar at the Skye Glen, but not the East Gore site. This included increases in leaf count (fig. 4.6.1) and total stem length (relative to the control; fig. 4.10.1), as well as possessing the highest poplar stem count among Skye Glen’s August 2020 data (fig. 4.8.1), though these results were not statistically significant. Both being aerial plant parts, the increase in leaf count and stem length/count are likely connected. Total stem length was also notable but statistically nonsignificant for Skye Glen’s poplar in fall 2020 (fig. 4.29.1), with the dual application of ANE (SE2) having a higher treatment group mean than the single application (SE1).

The value of *Ascophyllum nodosum* extract as a soil amendment is not as a direct fertilizer, but as a biostimulant, as it has very low concentrations of micro- and macronutrients (Khan et al. 2009; Spann & Little 2011). The hormone content of this seaweed extract is also present in trace amounts, though its capacity to physiologically regulate plant growth is unhindered even in highly diluted concentrations (Craigie 2011). Chief among these hormones is cytokinin, which is listed as an active ingredient in ANE products (Bradshaw et al. 2013). Cytokinin is believed to influence the functioning of meristems, and therefore the production of stems and leaves in growing plants (Werner & Schmülling 2009). Studies have shown that deficiencies in cytokinin can result in the malfunction of shoot apical meristems and developing aerial plant structures (Werner & Schmülling 2009). The seaweed extract's fucosterol content also promotes shoot and root growth and makes up important cell wall constituents for plants (Govindan et al. 1993; Zhang & Ervin 2004). An experiment by MacDonald et al. (2012) found diluted ANE stimulated the production of long and short roots in a greenhouse experiment involving pine seedlings. This was hypothesized to improve the plant's tolerance to drought conditions during field establishment. Conversely, Bradshaw et al. (2013) did not find significant improvements in overall apple cultivar productivity (e.g. tree growth, fruit yield/quality) as a result of applying *A. nodosum* amendments.

If the application of ANE enhanced root growth for poplar in Skye Glen and East Gore as described above, then the distinguishing factor between sites may have been water availability. The water content for Skye Glen's Miscanthus was higher than East Gore's, despite SG Miscanthus having more biomass. A dilution effect caused by Skye Glen's higher yield is therefore not applicable. In terms of total precipitation data (fig. 3.16.10, 3.16.11), the East Gore site appears to have had more precipitation than the Skye Glen site. However, because these results only account for weather conditions near the site, they are not as objective as the soil water content data. As explained prior, these measures (fig.

4.46.2, 4.46.4) show the average daily water content of Skye Glen's soil (41%) as being higher than East Gore's (31%), which could have been the result of differences in soil composition. This suggests that poplar treated with ANE in Skye Glen had a greater opportunity to obtain water resources that were committed towards growth, more so than the control due to its expansive root system.

In addition to directly influencing crop physiological processes, the use of *Ascophyllum nodosum* extract may also affect microbes in the soil. The combination of plant growth hormones and trace nutrients in ANE could help to stimulate and expand the soil microbiome, whose activity is known to enhance crop yields (Singh et al. 2011; Santoyo et al. 2012; Zhang & Thomsen 2019; Hussain et al. 2021). Though the exact impacts of ANE treatment on soil microbe functioning is relatively underexplored in the literature, studies such as those by Alam et al. (2013) and Hussain et al. (2021) demonstrate positive effects. For instance, Alam et al. (2014) revealed that *A. nodosum* extract to significantly enhance the overall yield of carrot across two cultivars. Measures of the soil microbiome also increased under the ANE treatment, including population counts and metabolic activity. Though, whether the ANE treatment produced root growth which in turn influenced microbial yield, or vice versa, remained inconclusive. Considering this, the composition of the soil microbiome could have varied between the East Gore and Skye Glen sites due to differences in location, environment, and soil type. Therefore, the soils of Skye Glen may have contained microbes more conducive to poplar growth than East Gore's, the yield and activity of which being stimulated as a result of the *A. nodosum* amendment.

5.6 Effect of *Ascophyllum nodosum* extract on Miscanthus and switchgrass

For Skye Glen data, the effects of *Ascophyllum nodosum* extract (ANE) on Miscanthus are notable only in 2020, with marginal (statistically nonsignificant) performance increases. ANE appears to have had no effect on Miscanthus growth (relative to the control) for East Gore results. Tissue N, P, and Fe concentrations in Miscanthus tissues are notable (but statistically nonsignificant) for 2020 results (fig. 4.26.1), with the dual application (SE2) being higher than the single application (SE1). ANE as an amendment is used more for its stimulatory effects rather than as a direct fertilizer (Khan et al. 2009). Thus, the difference in tissue nutrient concentration data between 2019 (no standout effects) and 2020 (notable but statistically nonsignificant increase in macronutrient content compared to control) may be explained through physiological processes.

While the yield of Miscanthus treated with SE1 was notably high relative to the control (SG site, 2020), tissue nutrient concentration was low comparatively. Though this phenomenon may simply be due to the dilution effect (Jarrell & Beverly 1981), a more complicated comparison remains between the SE1- and SE2-treated Miscanthus. Manufacturers recommend increasing the frequency, not the rate, of seaweed extract applications when necessary, especially near periods of drought or frost stress (Agriculture Solutions 2020). Despite this, SE1-treated Miscanthus had higher yields on average compared to SE2. Notably, previously discussed experiments by MacDonald et al. (2012) and Alam et al. (2014) also run counter to these recommendations, with the results of both showing inconsequential increases in root yield between application frequencies. However, this still does not explain how Miscanthus under a single application of ANE outperformed those treated with a dual application. As the optimal rate, frequency, and timing of ANE applications depends not only on crop type but also its environment, the dynamics of ANE on Miscanthus could differ from the experiments mentioned prior (Craigie 2011; Bulgari et al. 2015). While it may be possible that the dual application of ANE had an antagonistic effect on Miscanthus growth compared to the single application, given the low application rates used in this experiment, and the fact that yield results were not statistically significant, it is more likely that differences in growth between application rates arose from natural variation.

Ascophyllum nodosum extract, especially for the dual application, created the highest biomass accumulation for switchgrass at Skye Glen in 2020, with a large yield disparity being present between sites. Moisture data may indicate how ANE affected switchgrass, as the moisture content of ANE-treated switchgrass in East Gore was higher than the control, even though its yield was comparatively lower. This suggests that the mechanism influencing plant growth was not water related, such as enhancing root yield.

A previous study by Fei et al. (2017) had found no notable yield enhancements via ANE application on *Panicum virgatum* L. from field trials. However, their method of establishment differed from this experiment as switchgrass was germinated in lab and developed into seedlings under greenhouse conditions before being planted at field sites. Brown seaweed products have been shown to improve both the germination rate and timing of numerous plant species (reviewed by Sharma et al. 2014). This effect is thought to be a result of the bioactive compounds (proteins, amino acids, lipids, etc.) contained within ANE (Altindal 2019). Although ANE was applied too late after planting to affect the initial germination of switchgrass during 2019, several plants were observed in reproductive life stages during summer 2020 at the Skye Glen site. Therefore, the increased yield of ANE-treated switchgrass in Skye Glen both between years (2019/2020) and between application rates (SE2 yield > SE1 yield) may be explained through the extract's ability to stimulate the germination of new seeds in 2020, resulting in higher fall biomass.

Yield differences between sites can also be explained through switchgrass establishment. As mentioned in the materials and methods section, weeds had very little presence at Skye Glen compared to the East Gore site during the first year (2019). As weed pressure is a major impediment to switchgrass establishment, the development of this crop would have been facilitated by the conditions of the Skye Glen site (Mitchell & Vogel 2012).

5.7 Comparison of wood crop performance (poplar/willow)

In the determination of the most practical energy crop for use in Nova Scotia, one of the most important measures of plant growth is yield. For our woody crops in 2019, the highest yields were for those amended with paper mill sludge (PS). Poplar (PO) in East Gore (EG) had almost twice the yield of willow (WW) with 115.7 and 66.0 kg/ha, respectively (statistically nonsignificant). However, at Skye Glen (SG) the opposite was true, though not to the same extent with PO at 122.3 kg/ha and WW at 186.0 kg/ha (statistically nonsignificant). While yield was not directly obtained during fall 2020, measures of tree growth were integrated into a stem volume estimate (ESV). These results revealed much of the same patterns as in 2019, with PS-amended trees having the highest stem volume overall and poplar having nearly double the stem volume of willow in East Gore (statistically significant; PO and WW at 2.8 and 1.6 cm^3, respectively). At Skye Glen, willow had a higher stem volume than poplar (statistically significant; PO and WW at 20.7

and 26.3 cm^3, respectively). Relevantly, stem count data from August 2020 showed willow as having more stems on average (EG data was statistically nonsignificant: PO and WW had 5.2 and 5.7 stems, respectively; SG data was statistically significant: PO and WW had 5.6 and 9.3 stems, respectively), with the highest counts being from the paper mill sludge treatment (sans SG poplar, where it was seaweed extract).

From these results it could be argued that poplar amended with paper mill sludge would be the ideal woody crop as it performed adequately at both sites. However, this conclusion does not factor in the composition of the biomass being produced, which could directly influence biofuel quality. Ash, for example, is an undesirable biomass component that contributes to fouling and air pollution in combustion systems (Natural Resources Canada 2017). Based on compositional analyses by Karbowniczak et al. (2018), the wood and bark of poplar contains less ash content and has a higher gross calorific value relative to willow. Researchers integrated multiple measures of biomass quality into a single measure known as the fuel value index (FVI), using an equation originally developed by Goel and Behl (1996) (FVI = (Calorific value × Density) ÷ (Ash content × Moisture content)). From this value, it was found that willow had the highest overall FVI compared to poplar and three other tree species. Specifically, its average FVI was roughly 30% greater than poplar's. The researchers concluded that while willow was the highest performing species, both it and poplar were the most suitable sources of wood biomass. Fernandez et al. (2016) reported similarly high quality for poplar biomass grown on marginal land two years after planting, citing low N content and favorable ash characteristics. However, the quality and quantity of the woody biomass obtained was found to fluctuate between years, with three-year-old poplar having more ash content, lower calorific values, and lower yields. Conversely, Gouker et al. (2021) found an inverse relationship between cellulose/hemicellulose and ash/lignin content in willow biomass over time, the former components increasing with successive harvests. Additionally, the calorific values of their willow biomass were in the range of 17.62 to 19.02 MJ/kg, compared to an average of 18.25 MJ/kg for the poplar of Fernandez et al. (2016) and the standard of 19 MJ/kg for wood biomass.

Based on compositional analyses from aforementioned studies (cited above), it is clear that the biofuel qualities (ash content, calorific value, etc.) of poplar and willow biomass are comparable overall. In choosing the most optimal woody crop, performance across sites must therefore be considered. Willow outperformed poplar at the Skye Glen site (52% higher yield in 2019, 27% higher ESV in 2020, higher stem count) and underperformed poplar at the East Gore site (57% lower yield in 2019; 56% lower ESV in 2020; lower stem count). As discussed previously, it's possible that harsher, more water-stressed conditions were present at the East Gore site compared to the Skye Glen site. In assessing the growth of poplar and willow under drought stress, Cochard et al. (2007) found yield to be positively correlated with the crop's susceptibility to cavitation, positing that increased productivity may come at the cost of stem and root biomass. Stolarski et al. (2019) also reported willow yield to vary significantly depending on the type of marginal soil it was grown in. Considering this, willow might be an ideal option if the conditions of the field site are assessed beforehand. Otherwise, hybrid poplar may produce more consistent yields across a variety of marginal areas in Nova Scotia.

5.8 Comparison of grass crop performance (Miscanthus/switchgrass)

In comparing the yield of the two tested grass crops, it becomes clear that Miscanthus significantly outperformed switchgrass overall. Though the yield of switchgrass at the Skye Glen site in 2019 was nearly twice that of Miscanthus (SG and MS at 779.2 and 426.3 kg/ha, respectively), Miscanthus eventually dwarfed switchgrass yield in fall 2020 by a factor of 10.7 (SG and MS at 1035.9 and 11,132.5 kg/ha, respectively). At the East Gore site, Miscanthus yield was consistently higher than switchgrass by a factor of 2.1 in 2019 (SG and MS at 201.7 and 426.3 kg/ha, respectively) and 2020 (SG and MS at 945.9 and 1,978.5 kg/ha, respectively). Interestingly, the soil amendments associated with the highest yields of both crops varied between years. In 2019, the highest yields of Miscanthus (at EG and SG) and switchgrass (at SG) were from subplots treated with paper mill sludge. Anaerobic digestate treatment resulted in the highest yield of EG switchgrass in 2019 as well. Subplots treated with paper mill sludge (SG Miscanthus), anaerobic digestate (EG Miscanthus for single application; EG switchgrass for dual application), and *Ascophyllum nodosum* extract (SG switchgrass for dual application) generated the highest yields in 2020.

The disparity between switchgrass and Miscanthus yields was likely due to the well-documented difficulties of switchgrass establishment. For example, its long dormancy can delay seed germination for up to 2 years, though cold stratification can ameliorate this problem (Shen et al. 2001; Burson et al. 2009). Indeed, the application rate used in this research was reflective of the low germination rate of our seeds, at roughly 30%. Soil temperature, moisture, and weed pressure are environmental factors that can also influence establishment, especially regarding the timing of planting (Keyser et al. 2016; Mayton et al. 2019). It's reported that switchgrass planted before the growing season may perform better due to lack of weed pressure, though low soil temperatures can hinder establishment (Seepaul et al. 2011). In this experiment, planting near the end of the growing season may have allowed for ideal soil temperatures but could have ultimately impeded performance due to the shorter timespan to establish roots for overwintering (Mayton et al. 2019). These requirements may have been reflected in the performance of this grass during 2019 at Skye Glen due to the site's lack of weed pressure. In the following year, the weed pressure at this site would worsen.

While switchgrass is known to thrive under numerous environmental conditions, including marginal land, the results of this experiment do not reflect this claim (Moser et al. 2004). Furthermore, if the low performance of this crop is to extend into the reported period of maximum yield potential (two to three years following planting), then switchgrass may not be an ideal choice for a Nova Scotian bioindustry (Mayton et al. 2019). The literature reports yields of 2,000 to 25,000 kg/ha (Wright and Turhollow 2010; Casler et al. 2017), with calorific values ranging from 18 to 19 MJ/kg (Boateng et al. 2007; He et al. 2009). An experiment by Mani et al. (2004) even found the calorific value of switchgrass biomass to be greater than that of wheat, barley, and corn stover. Additionally, its nitrogen and ash concentration can be minimized for conversion processes by harvesting late into the year (Wilson et al. 2013). Switchgrass may represent an appealing biomass source for energy production as it's inexpensive to establish, though its need for field inputs (especially N) may increase when grown for energy (Kering et al. 2013; Popp et al. 2018; Zanetti et al. 2019). More research is therefore required to determine whether these growth patterns apply to switchgrass established in other marginal regions in Nova Scotia.

If the lower yields of switchgrass were a product of complications during establishment, then it would follow that the higher yields of Miscanthus may be related to its method of establishment. Unlike switchgrass, Miscanthus was planted as greenhouse-grown plantlets rather than seeds, in contrast to typical planting methods (Anderson et al. 2011). An experiment by Hauser (1983) compared the growth of four grass species (including switchgrass) established via seeding or transplanting, and found transplants to have much higher yields than all other treatment groups. Transplant performance was attributed to increased resistances against weed pressure and damage relative to seedlings. In terms of general performance, the calorific value of Miscanthus is reported to be in the range of 16 to 18 MJ/kg, though this value can go up to 20 MJ/kg depending on agronomic practices (Sorensen 2008; Baxter et al. 2014). Miscanthus yield is also similar to switchgrass at an average 20,000 kg/ha or more depending on the age of the crop (Lewandowski et al. 2000; Sorensen 2008). This, combined with its superior performance at both the East Gore and Skye Glen sites, makes Miscanthus the more practical biomass grass crop.

5.9 Determination of high yielding crop/treatment combinations

In determining the highest performing crops from this experiment, a comparison between grass and wood crops must be made. As stated prior, the practical choices from these groups are Miscanthus and poplar which both have similar calorific values of around 16 to 20 megajoules per kilogram (Sorensen 2008; Baxter et al. 2014; Fernandez et al. 2016). The combustible components of Miscanthus biomass are also reported to be analogous to wood biomass, though ash content appears to be higher (although still lower than most grasses) (Schwarz et al. 1994; Gucho et al. 2015; Joachimiak et al. 2019). In terms of biomass accumulation, the reported yield of hybrid poplar grown in North America is roughly 10,000 kg/ha per year, compared to Miscanthus' yield of 20,000 kg/ha per year (Lewandowski et al. 2000; Sannigrahi et al. 2010). In 2019, Miscanthus yield differed from poplar's by a factor of 3.7 at the East Gore site (PO and MS at 115.65 and 426.27 kg/ha, respectively) and 4.0 at the Skye Glen site (PO and MS at 122.26 and 486.19 kg/ha, respectively). Differences in establishment performance between crop types (grass versus wood) as well as the relevancy of yield data obtained in the establishing year must also be considered. Additionally, the absence of yield data for poplar in 2020 does not allow for direct comparison with Miscanthus. Therefore, a more qualitative approach must be employed.

East Gore results demonstrate crop performance under more adverse conditions (relative to the Skye Glen site), with woody crop growth being moderate in general. This was apparent in the leaf data of August 2020, where the leaf area and count for East Gore's poplar (section 4.6, 4.7) in the control group were around half that of Skye Glen's, and the leaf area of willow at the East Gore site could not be destructively measured due to their scarcity and small size. The yield of Miscanthus fared relatively better (compared to poplar), increasing over three-fold between 2019 and 2020. Miscanthus can also be harvested sooner and more frequently (start at year two, annual harvest) than poplar (start at year three, triannual harvest) (Tharakan et al. 2003; Jacobson 2013). Therefore, Miscanthus is likely the more practical crop overall due to its consistent performance at the East Gore site and its continual yield following establishment.

The high performance of poplar and Miscanthus would not have arose without the presence of soil amendments. Assessing the most beneficial poplar amendment is straightforward, as paper mill sludge created the highest yields/ESV for both sites in 2019 and 2020. The benefits of paper mill sludge on poplar growth (as discussed in section 5.1) can be achieved by increasing the activity and biomass of soil microbes as well as the soil's ability to hold water (Gagnon et al. 2000). Specifically, the high organic matter content of paper mill sludge (e.g. cellulose, lignin) promotes the mineralization of plant nutrients via microorganism-induced decomposition (Camberator et al. 1997; Murphy et al. 2007;

Diacono and Montemurro 2009; Luna et al. 2016). This organic matter also contains the binding agents responsible for enhanced soil aggregation and subsequent improvements in water-holding capacity (Abiven et al. 2008). This trait is of particular interest given the drought-like conditions of summer 2020. Additionally, Jackson et al. (2000) reported increases in stem diameter of up to 66% (over the control) from pine trees amended with paper mill sludge. It was speculated that an increase in the water holding capacity and nitrogen availability (through the amendment directly and ammonification) of the soil via the paper mill sludge treatment caused these effects.

Assessing the most beneficial Miscanthus amendment is not as straightforward, as single application digestate yield was greater than paper mill sludge for EG Miscanthus in 2020, though this disparity was only around 7.5%. As discussed prior (section 5.2), some growth-promoting mechanisms of paper mill sludge for Miscanthus potentially include the expansion of soil microbe communities by providing carbon (as it is often limited) (Chen et al. 2003; Diacono and Montemurro 2009). Some of these microbes can convert atmospheric nitrogen gas into forms usable by plants (Delgado et al. 2002; Chen et al. 2003). Paper mill sludge can lower the bulk density of the soil for better root growth and improve the soil's water holding capacity (which also enhances nutrient flow) (Fierro et al. 1999). This treatment could have therefore ameliorated drought stress by increasing the availability of water. Phillips et al. (1997) also found soil quality (as a measure of organic carbon content) to significantly increase following paper mill sludge treatment, with the greatest improvement in carbon quantity (relative to the control) being seen in the grass plots.

While the amendment's effects on yield are important, its impact on quality can outweigh them. Heavy metals added to the soil through amendment treatments (e.g. Pb, Cr, As, Zn, Cd, Cu) could, for instance, increase the concentration of ash, nitrogen, and potassium in plant tissues. This contaminated biomass could not only damage combustion equipment (through slagging and ash deposition), but also increase the amount of nitrogen oxide emissions generated when combusted (Wuana and Okieimen 2014; Van der Weijde et al. 2017). However, statistical analyses did not reveal any significant differences between the control and paper mill sludge/digestate treatment groups for soil heavy metal concentrations (section 4.21) and Miscanthus tissue nutrient concentrations (section 4.26). Additionally, a significant decrease in biomass accumulation is the most prominent impact for plants grown on contaminated land, in contrast to the amendment effects seen in this experiment (Barbosa et al. 2018). While the comparable effects of anaerobic digestate (single application) and paper sludge on Miscanthus growth are confounding, the benefits of the paper mill sludge treatment across both poplar and Miscanthus make it the most beneficial amendment overall. Its influence on Miscanthus yield in 2019 may indicate greater benefits to establishment as well, which could be better illustrated on more marginal sites.

5.10 Site-specific impacts on plant growth

The most significant disparity in our data was between plants grown in the East Gore and Skye Glen sites. For instance, the yield of Miscanthus (control group) differed between sites by a factor of 5.6 in 2020 (EG and SG at 1,205.1 and 7,114.6 kg/ha, respectively). This difference demonstrates the variability of Nova Scotian marginal land in terms of its effects on plant performance. It is therefore important to characterize the environmental factors that influenced our results so that appropriate sites can be selected in future. Although some factors may have had more of an impact on growth than others, our data likely resulted from a combination of different factors working simultaneously.

One of the most straightforward growth-influencing factors would be the soil itself, as it provides plants with vital building blocks such as water and macronutrients. Indeed, soil quality was the first data obtained in this project, and soil function is considered as a deciding factor for plant survival (Doran and Parkin 1994). Relevantly, differences in site histories (East Gore: agricultural land, crop production; Skye Glen: highly underutilized, forest soil) may translate to differences in soil quality. Cochran et al. (1989) reported the microbe activity of agricultural and forest soils to fluctuate over time, with agricultural soils having higher activity in the early season and forest soils having higher activity in the late season. Sprynskyy et al. (2011) also found the composition of agricultural soils to more easily absorb harmful heavy metals compared to forest soils. However, little difference was found in the initial soil chemical analysis between the East Gore and Skye Glen site (table 3.3). Additionally, CLI information (fig. 1) shows both areas as having comparable soil fertility at an acceptable quality (CLI 3). Considering the broad assessment of the CLI map, the potential undesirables of Skye Glen's soil (e.g. low permeability, excess soil moisture) are likely unapplicable as well.

Another quality indicator of the soil is its ability to retain moisture. Outside of a potential microclimate, weather data (fig. 3.16.10; 3.16.11) suggests the Skye Glen site may have received less rainfall overall compared to the East Gore site. However, soil moisture data from Skye Glen shows less intense concentration troughs (relative to East Gore) from May to August 2020. Importantly, this occurs during the growing season (April – October), when water availability would have the greatest impact on plant growth. Various growth studies have cited the effects of soil moisture on the success (or failure) of poplar, willow, Miscanthus, and switchgrass establishment (Barney et al. 2009; Phillips et al. 2014; Anderson et al. 2015). Considering these factors, the site-wide increase in plant productivity at Skye Glen could have likely resulted from reduced water stress rather than an abundance of water resources.

A difference in temperature was also noted during planting at the Skye Glen site, being much hotter than that of East Gore. While air temperature is known to influence plant productivity (Hatfield and Prueger 2015), both weather station (fig. 3.16.5; 3.16.6) and soil data (fig. 4.46.1; 4.46.3) were nearly identical between sites. Additionally, the perceived increase in temperature at the Skye Glen site was likely caused by a lack of wind exposure due to the surrounding trees, not an actual increase in air temperature. This suggests that temperature was not a distinguishing factor for crop growth between sites.

Management of weeds at the Skye Glen site, or more accurately, the lack thereof, provided the most apparent site differences during the first year (2019). Site preparation buried the previously unplowed seedbed at Skye Glen, virtually eliminating the propagation of weeds. While any crop would benefit from the removal of this pressure, the establishment of biomass species (short-rotation woody and perennial herbaceous crops) have been noted for their vulnerability to weeds (Buhler et al. 1997). Indeed, the lowest reported poplar yields in the literature are from sites with little to no weed management, and the control of weed pressure by poplar relies on closure of the leaf canopy at maturity (Trnka et al. 2008). Albertsson et al. (2014) found yields of willow to differ according to its clonal variant (both commercial and breeding clones included), though significant (up to ~95%) reductions in growth occurred under weed pressure regardless of clone. An assessment of initial Miscanthus yield (first three years) in France by Lesur-Dumoulin et al. (2016) similarly found the worst yields in sites with the most prevalent weeds, and the difficulty of switchgrass seedling establishment under weed pressure is described in section 5.8. As the success of establishment directly correlates to future yields, the benefits of low weed pressure the Skye Glen site are clear. Based on the disparity between East Gore and Skye Glen data, it can be assumed that site condition is one of the most important factors influencing crop growth. The selection of location, not crop or amendment treatment, may therefore decide the success of establishing field sites in Nova Scotia.

5.11 Wider context of research

Given the broader application of this research, it is valuable to speculate on how our methodology could translate to an industrial scale. The commercial application of paper mill sludge (PS), for example, could induce a different growth response than what was observed in this experiment. Scott and Smith (1995) suggested that PS could be disposed through integration with existing fertilizers. Following this logic, the commercial application method for this PS fertilizer could be similar to those seen in the literature (Zibilske et al. 2000; Aitken et al. 2006), where PS is spread across and incorporated into the soil surface prior to planting. It could also be assumed that this method would enhance the effects of PS (relative to this experiment) over time, as its broad application would allow the amendment to continually influence an expanding root system. For instance, Rodriguez et al. (2018) found spreading PS atop the soil surface and incorporating it via rotary spading to aged willow (17 years old) significantly increased its measures of growth (from 24 to 127%) compared to the control. The higher application rates used in these experiments (relative to our own; ~12,000 kg/ha) might also contribute to the effectiveness of this amendment. The status of Miscanthus as a high yielding crop in this experiment is notable given the plants have yet to reach their maximum potential at three years after planting (Clifton-Brown et al. 2001). In fact, the yield of Skye Glen Miscanthus in 2020 (11,132.5 kg/ha) rivals the average yield of perennial C_4 grasses grown in Eastern Canada (8,000 to 11,000 kg/ha) (Tubeileh et al. 2015). The distinguishing factor of Miscanthus in this experiment could have arose from its method of establishment, as the majority of Miscanthus is grown from rhizomes rather than plantlets (Anderson et al. 2011). Due to factors such as increased size and active buds, Miscanthus plantlets are reported to have reduced establishment mortality compared to rhizomes (Ouattara et al. 2020). This was reflected in the high survival rates of section 4.5. Because yield is a function of both biomass accumulation and survival, our use of plantlets could have therefore improved the yield of Miscanthus. However, estimates suggest the cost of establishing Miscanthus plantlets could more than double that of rhizomes, making it less feasible on an industrial scale (Xue et al. 2015).

As of writing, the highest temperature ever recorded in Canada was recently set in Saskatchewan (Environment Canada 2021). The increasingly dry and temperate conditions brought about by climate change exacerbate the need to "future-proof" current investments. This entails the creation/adoption of plant species that are resistant to these environmental stressors, similar to the traits of our biomass crops that grant survival on marginal land (Richards 2006; van Etten et al. 2019). The photosynthetic rate of Miscanthus, for instance, can dynamically change based on based on ambient temperature (Weng and Ueng 1998). The resistant traits of these crops have implications relating to the future of soil fertility. Marginal land is characterized by poor agricultural productivity, be it through low soil moisture, nutrient value, or a variety of other conditions hostile to plant growth (Qin et al. 2015). Under climate change, the presence of marginal land is likely to increase as rising sea levels and extreme temperatures (without accompanying precipitation) contribute to soil salinity and desiccation (Lobell and Burke 2008; Reynolds et al. 2010). Our choice of soil amendments is also applicable to climate change, as paper mill sludge can counteract drought-like conditions by retaining soil moisture (Zibilske et al. 2000). Utilizing waste byproducts such as paper mill sludge and anaerobic digestate also avoids landfilling, instead helping to produce a renewable source of energy.

6.0 CONCLUSION

The need to address our experimental limitations is heightened by the novelty of this research. Crop performance from our two field sites, for example, cannot be considered indicative of the entire province. Under the environmental conditions of western and eastern Nova Scotia, the results of this experiment would likely differ from what is reported here. Additionally, we were somewhat restricted by the use of a single indicator species, requiring the composition of poplar, willow, and switchgrass tissues to be inferred from that of Miscanthus's. The quality of our biomass, and the biofuels that could be produced from it, was harder to objectively define because of this limitation. Additionally, experimentation of woody crop site design across Canada has determined that the double row design is not necessary to maximize yields. Wide, single row designs should therefore be considered in future to reduce anthropogenic crop damage. Overall, further research into other marginal regions is required to assess the potential of these energy crops across Nova Scotia.

Considering the performance of our tested biomass crops, especially for those grown in the Skye Glen site, the objectives of this research can be addressed. Yes, certain biomass crops are capable of successful establishment under the growing conditions of Nova Scotia's marginal land. However, this success is dependent on site condition and crop type, as poplar and willow yields were lower at the East Gore site and switchgrass heavily underperformed at both sites. Considering its low rate of establishment and potentially high input requirements, switchgrass is likely not an ideal choice for an economical bioindustry in Nova Scotia (Popp et al. 2018). Additionally, the majority of tested soil amendments (especially paper mill sludge) had a positive impact on establishment, resulting in higher measures of yield (or yield approximations) compared to the control. Soil amendments similar to these should therefore be considered in future experiments to maximize the potential yield of biomass crops on marginal Nova Scotian land. Our hypotheses were also supported by the findings of this research, with plant performance differing between crop types (e.g. Miscanthus and switchgrass yields), site-specific characteristics (e.g. crops generally performed better at Skye Glen compared to East Gore), and some amendments (e.g. paper mill sludge) having statistically significant impacts on plant growth compared to other treatments.

These determinations have implications for the feasibility of a Nova Scotian bioindustry due to the abundance of marginal areas across the province (over 400,000 hectares in total), including unused farmland. As biofuels can produce reduced (i.e. less NOx through burning) or negative pollutants (i.e. through carbon sequestration) relative to fossil fuels, the absence of this industry creates losses in potential profits as well as the province's ability to reduce its greenhouse gas output (Robertson et al. 2000; West & Post 2002). This is especially important due to Nova Scotia's reliance on coal burning for energy, being responsible for nearly 45% of its greenhouse gas production (Canada Energy Regulator 2020). Therefore, assessing the potential of biomass crops in Nova Scotia through this research represents a first step in the province-wide adoption of cleaner, more renewable sources of energy.

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8.0 APPENDIX

8.1. Biomass yield (2019)

Table 8.1.1 ANOVA: Treatment effects on yield (kg/ha) for Miscanthus grown in the East Gore 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	107885	12	82717	5.217	0.0155 *

Table 8.1.2 Tukey’s test: Treatment effects on yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	68.11	58.71	1.160	0.6521
PS – CT	188.94	58.71	3.218	0.0069 **
SE – CT	-21.76	58.71	-0.371	0.9826

Table 8.1.3 Effect of soil amendments on Miscanthus yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	426.27	a
Anerobic digestate	305.44	ab
Control	237.33	b
A. nodosum extract	215.56	b

Table 8.1.4 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the East Gore 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	19481	12	21027	3.7059	0.0427 *

Table 8.1.5 Tukey's test: Treatment effects on yield (kg/ha) for switchgrass grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	30.39	29.60	1.027	0.7338
PS – CT	-33.28	29.60	-1.124	0.6746
SE – CT	-62.53	29.60	-2.112	0.1491

Table 8.1.6 Effect of soil amendments on switchgrass yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Anerobic digestate	201.70	a
Control	171.31	ab
Paper sludge	138.04	ab
A. nodosum extract	108.79	b

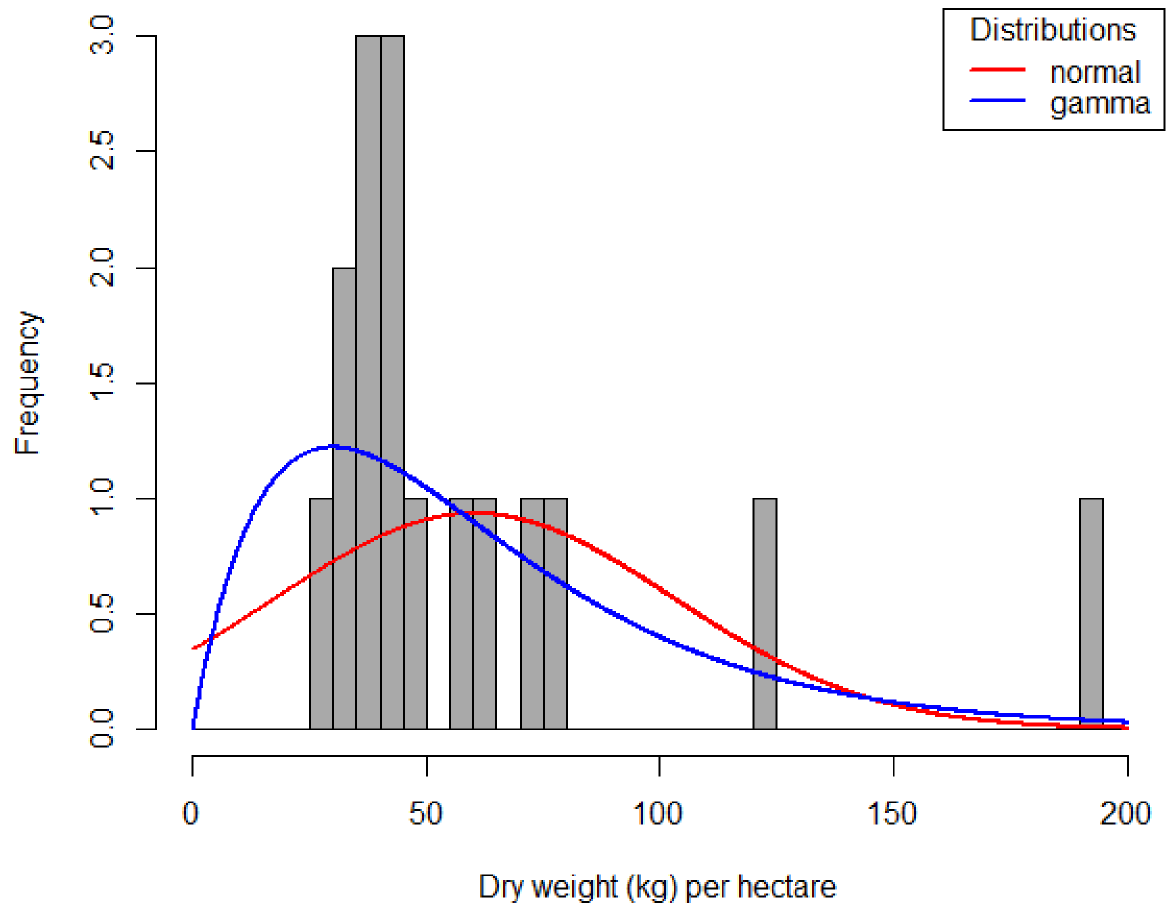

Figure 8.1.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar yield (kg/ha) from the East Gore site.

Table 8.1.7 ANOVA: Treatment effects on yield (kg/ha) for poplar grown in the East Gore 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	3.5821	12	1.3598	9.945	0.0014 **

Table 8.1.8 Tukey's test: Treatment effects on yield (kg/ha) for poplar grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.0267	0.2450	0.109	0.9995
PS – CT	1.0104	0.2450	4.124	0.0002 ***

SE – CT	-0.0521	0.2450	-0.213	0.9966

Table 8.1.9 Effect of soil amendments on poplar yield (kg/ha) from the East Gore 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	115.65	a
Anaerobic digestate	43.24	b
Control	42.11	b
A. nodosum extract	39.97	b

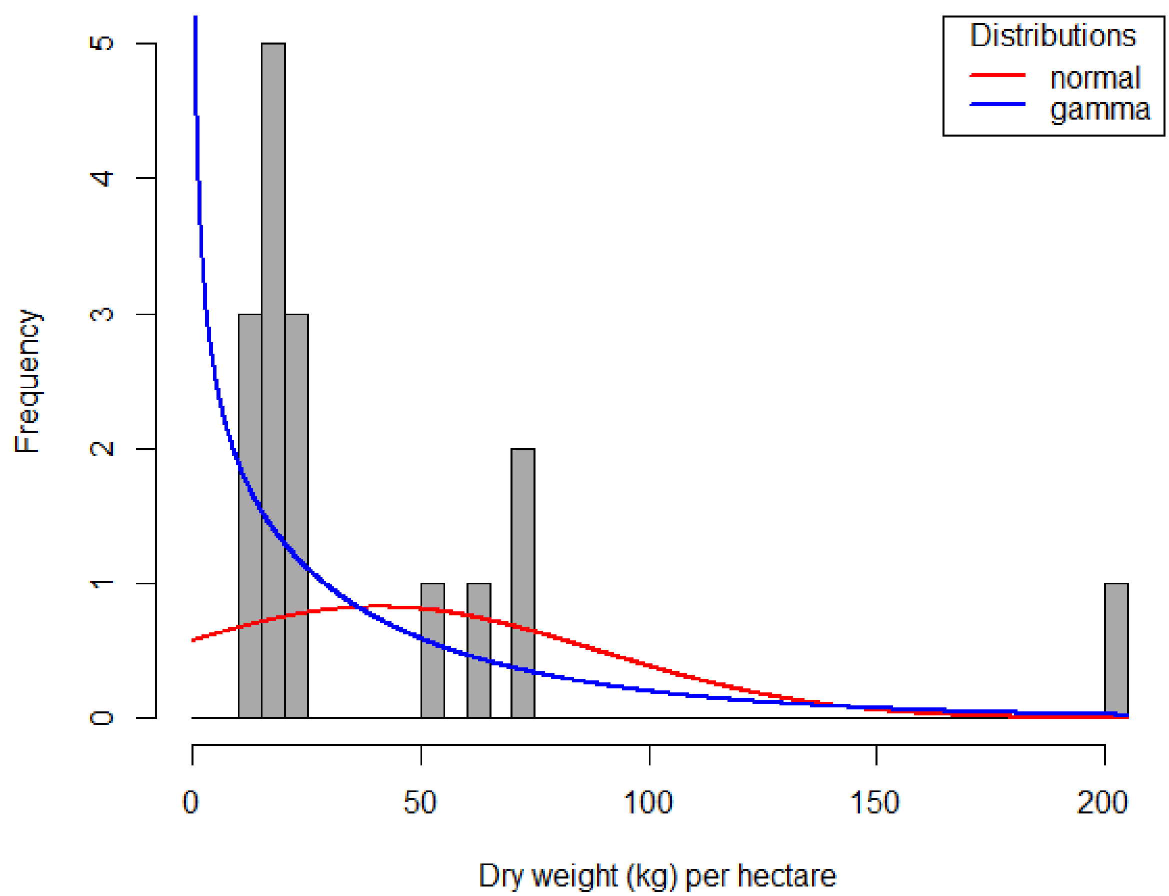

Figure 8.1.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow yield (kg/ha) from the East Gore site.

Table 8.1.10 ANOVA: Treatment effects on dry yield (kg/ha) for willow grown in the East Gore 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	6.513	12	6.3808	3.6424	0.0447 *

Table 8.1.11 Tukey's test: Treatment effects on yield (kg/ha) for willow grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.0179	0.5459	0.033	1.0000
PS – CT	1.3545	0.5459	2.481	0.0632
SE – CT	1.3008	0.5459	2.383	0.0805

Table 8.1.12 Effect of soil amendments on willow yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	65.97	a
A. nodosum extract	62.52	a
Anaerobic digestate	17.33	a
Control	17.03	a

Table 8.1.13 ANOVA: Treatment effects on yield (kg/ha) for Miscanthus grown in the Skye Glen 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	155536	12	129846	4.7914	0.0203 *

Table 8.1.14 Tukey's test: Treatment effects on yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	27.96	73.55	0.380	0.9813
PS – CT	252.95	73.55	3.439	0.0033 **
SE – CT	117.38	73.55	1.596	0.3810

Table 8.1.15 Effect of soil amendments on Miscanthus yield (kg/ha) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	486.19	a
A. nodosum extract	305.62	ab

Anerobic digestate	261.20	b
Control	233.24	b

Table 8.1.16 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Skye Glen 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	421439	12	128171	13.152	0.0004 ***

Table 8.1.17 Tukey's test: Treatment effects on yield (kg/ha) for switchgrass grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	-21.62	73.08	-0.296	0.991
PS – CT	374.81	73.08	5.129	< 1e-5 ***
SE – CT	28.37	73.08	0.388	0.980

Table 8.1.18 Effect of soil amendments on switchgrass yield (kg/ha) from the Skye Glen 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	779.21	a
A. nodosum extract	432.78	b
Control	404.40	b
Anerobic digestate	382.78	b

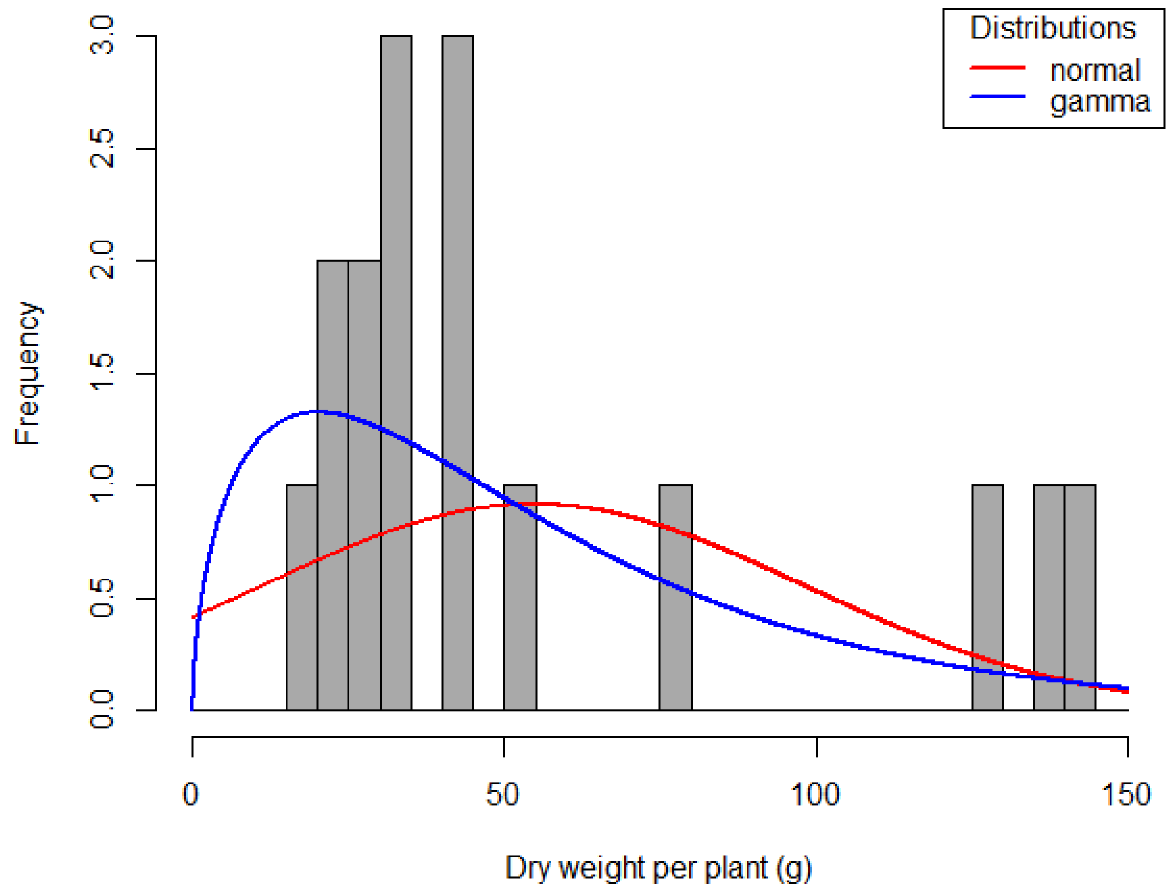

Figure 8.1.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar yield (kg/ha) from the Skye Glen site.

Table 8.1.19 ANOVA: Treatment effects on yield (kg/ha) for poplar grown in the Skye Glen 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	6.491	12	1.2580	19.828	6e-5 ***

Table 8.1.20 Tukey's test: Treatment effects on yield (kg/ha) for poplar grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.2493	0.2336	1.067	0.710
PS – CT	1.5101	0.2336	6.465	< 1e-4 ***
SE – CT	0.2465	0.2336	1.055	0.717

Table 8.1.21 Effect of soil amendments on poplar yield (kg/ha) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. yield (kg/ha)	Groups
Paper sludge	122.26	a
Anaerobic digestate	34.65	b
A. nodosum extract	34.55	b
Control	27.00	b

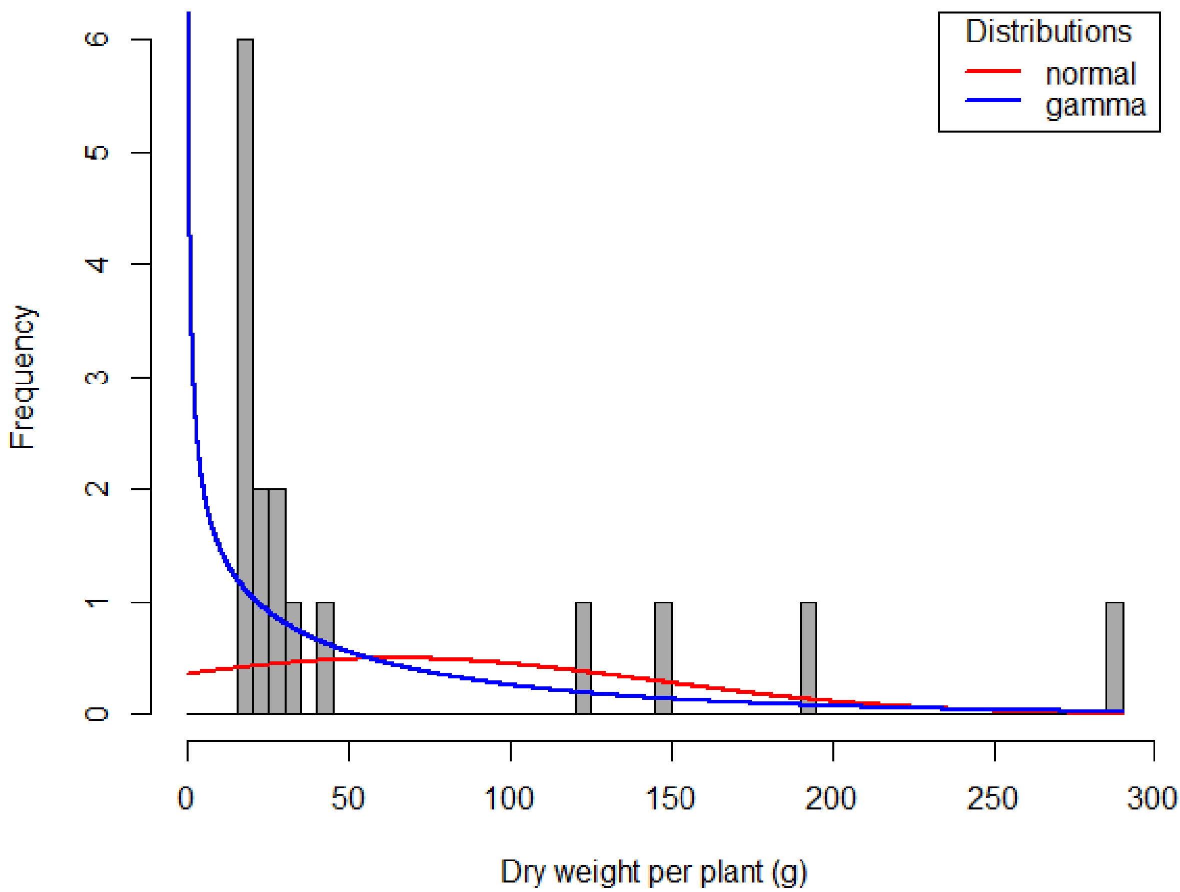

Figure 8.1.4 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow dry weights (per hectare) from the Skye Glen site.

Table 8.1.22 ANOVA: Treatment effects on yield (kg/ha) for willow grown in the Skye Glen 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	15.883	12	1.2335	48.42	6e-7 ***

Table 8.1.23 Tukey's test: Treatment effects on yield (kg/ha) for willow grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	-0.2127	0.2338	-0.910	0.800
PS – CT	1.9469	0.2338	8.327	< 1e-5 ***
SE – CT	-0.2052	0.2338	-0.878	0.816

Table 8.1.24 Effect of soil amendments on willow yield (kg/ha) from the Skye Glen 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	186.03	a
Control	26.55	b
A. nodosum extract	21.62	b
Anaerobic digestate	21.46	b

8.2. Miscanthus tissue nutrient concentrations (2019)

Table 8.2.1. Chemical analysis of Miscanthus biomass grown in the East Gore site (2019).

	Mean nutrient concentration ± standard error								
Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P (%)	Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Control	1.2 ± 0.09	0.6 ± 0.04	0.5 ± 0.03	0.2 ± 0.02	0.3 ± 0.04	0.02 ± 0.002	51.1 ± 5.96	93.9 ± 4.79	22.8 ± 0.81
Anaerobic digestate	1.4 ± 0.06	0.5 ± 0.01	0.8 ± 0.07	0.2 ± 0.01	0.3 ± 0.03	0.03 ± 0.001	48.2 ± 2.12	70.1 ± 8.06	21.8 ± 0.84
Paper mill sludge	1.4 ± 0.04	0.6 ± 0.01	0.3 ± 0.05	0.3 ± 0.03	0.2 ± 0.03	0.02 ± 0.004	45.2 ± 1.59	199.0 ± 26.29	18.3 ± 0.64
A. nodosum extract	1.3 ± 0.09	0.5 ± 0.01	0.5 ± 0.05	0.3 ± 0.01	0.3 ± 0.06	0.02 ± 0.002	44.0 ± 0.75	88.7 ± 8.40	21.8 ± 0.66

Table 8.2.2. Chemical analysis of Miscanthus biomass grown in the Skye Glen site (2019).

	Mean nutrient concentration ± standard error								
Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P (%)	Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Control	2.4 ± 0.04	0.4 ± 0.02	1.3 ± 0.08	0.3 ± 0.02	0.2 ± 0.01	0.07 ± 0.005	516.8 ± 79.71	96.6 ± 5.22	21.5 ± 1.47

Anaerobic digestate	2.6 ± 0.10	0.4 ± 0.01	1.5 ± 0.03	0.3 ± 0.02	0.3 ± 0.01	0.07 ± 0.005	359.6 ± 43.78	102.9 ± 14.60	22.4 ± 0.76
Paper mill sludge	2.4 ± 0.07	0.4 ± 3e-3	1.2 ± 0.05	0.4 ± 0.02	0.2 ± 0.01	0.06 ± 0.004	556.8 ± 249.72	217.2 ± 26.35	23.6 ± 0.60
A. nodosum extract	2.5 ± 0.06	0.4 ± 0.03	1.4 ± 0.07	0.3 ± 0.01	0.3 ± 0.01	0.07 ± 0.004	639.2 ± 238.51	108.7 ± 6.32	25.1 ± 1.03

Table 8.2.3 ANOVA: Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the East Gore 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	0.0681	12	0.2469	1.1027	0.386

Table 8.2.4 Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen concentration (%)	Groups
Anaerobic digestate	1.3725	a
Paper mill sludge	1.3625	a
Ascophyllum nodosum extract	1.2725	a
Control	1.2150	a

Table 8.2.5 ANOVA: Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Skye Glen 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	0.1183	12	0.2693	1.7567	0.2088

Table 8.2.6 Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen concentration (%)	Groups
Anaerobic digestate	2.5750	a
Ascophyllum nodosum extract	2.5425	a
Paper mill sludge	2.4325	a
Control	2.3600	a

Table 8.2.7 ANOVA: Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the East Gore 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	0.0268	12	0.0864	1.24	0.3383

Table 8.2.8 Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus concentration (%)	Groups
Control	0.3268	a
Ascophyllum nodosum extract	0.3195	a
Anaerobic digestate	0.2818	a
Paper mill sludge	0.2235	a

Table 8.2.9 ANOVA: Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the Skye Glen 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	0.0025	12	0.0047	2.1174	0.1514

Table 8.2.10 Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus concentration (%)	Groups
Anaerobic digestate	0.2643	a
Ascophyllum nodosum extract	0.2598	a
Paper mill sludge	0.2488	a
Control	0.2318	a

Table 8.2.11 ANOVA: Treatment effects on average potassium concentration (%) for Miscanthus grown in the East Gore 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	0.4654	12	0.1186	15.696	0.0002 ***

Table 8.2.12 Tukey's test: Treatment effects on average potassium concentration (%) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT),

paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG – CT	0.2845	0.0703	4.047	<0.001 ***
PS – CT	-0.1938	0.0703	-2.756	0.0295 *
SE – CT	0.0015	0.0703	0.021	1.0000

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

Soil amendment	Avg. Potassium concentration (%)	Groups
Anaerobic digestate	0.7620	a
Ascophyllum nodosum extract	0.4790	b
Control	0.4775	b
Paper mill sludge	0.2838	c

Table 8.2.14 ANOVA: Treatment effects on average potassium concentration (%) for Miscanthus grown in the Skye Glen 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	0.2071	12	0.1809	4.5797	0.0233 *

Table 8.2.15 Tukey's test: Treatment effects on average potassium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG – CT	0.1543	0.0868	1.777	0.2845
PS – CT	-0.1470	0.0868	-1.693	0.3273
SE – CT	0.0948	0.0868	1.091	0.6948

Table 8.2.16 Treatment effects on average potassium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potassium concentration (%)	Groups
Anaerobic digestate	1.4665	a
Ascophyllum nodosum extract	1.4070	a
Control	1.3123	ab
Paper mill sludge	1.1653	b

Table 8.2.17 ANOVA: Treatment effects on average calcium concentration (%) for Miscanthus grown in the East Gore 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	0.0153	12	0.0271	2.2617	0.1336

Table 8.2.18 Treatment effects on average calcium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium concentration (%)	Groups
Control	0.5640	a
Paper mill sludge	0.5515	a
Ascophyllum nodosum extract	0.5435	a
Anaerobic digestate	0.4835	a

Table 8.2.19 ANOVA: Treatment effects on average calcium concentration (%) for Miscanthus grown in the Skye Glen 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	0.0097	12	0.0162	2.3941	0.1193

Table 8.2.20 Treatment effects on average calcium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium concentration (%)	Groups
Paper mill sludge	0.4358	a
Ascophyllum nodosum extract	0.4065	a
Control	0.3788	a
Anaerobic digestate	0.3743	a

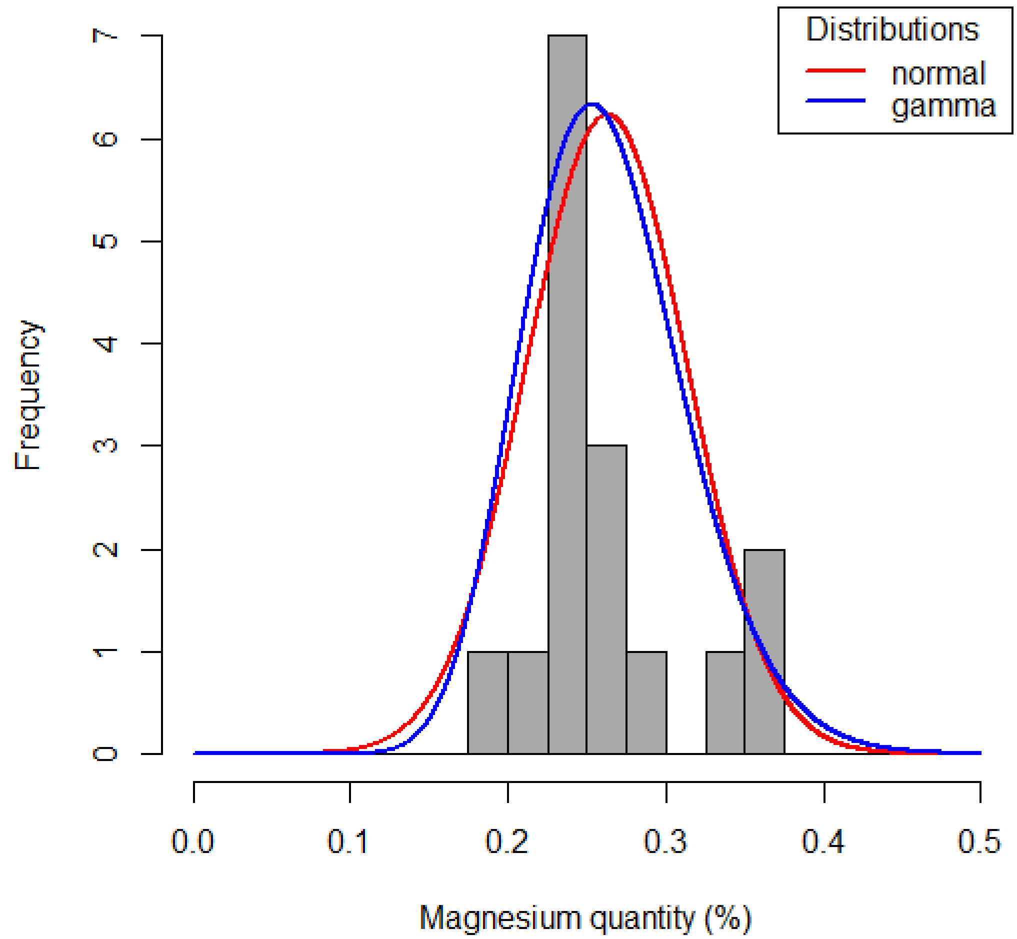

Figure 8.2.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus magnesium concentration (%) from the East Gore site.

Table 8.2.21 ANOVA: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the East Gore 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	0.3117	12	0.2226	6.0233	0.0096 **

Table 8.2.22 Tukey's test: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value

DG – CT	0.0043	0.0929	0.046	1.0000
PS – CT	0.3374	0.0929	3.633	0.0016 **
SE – CT	0.1019	0.0929	1.097	0.6911

Table 8.2.23 Treatment effects on average magnesium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium concentration (%)	Groups
Paper mill sludge	0.3265	a
Ascophyllum nodosum extract	0.2580	ab
Anaerobic digestate	0.2340	b
Control	0.2330	b

Table 8.2.24 ANOVA: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the Skye Glen 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	0.0208	12	0.0153	5.4353	0.0136 *

Table 8.2.25 Tukey's test: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG – CT	0.0170	0.0253	0.672	0.9076
PS – CT	0.0943	0.0253	3.728	<0.001 ***
SE – CT	0.0223	0.0253	0.880	0.8152

Table 8.2.26 Treatment effects on average magnesium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium concentration (%)	Groups
Paper mill sludge	0.3963	a
Ascophyllum nodosum extract	0.3243	b
Anaerobic digestate	0.3190	b
Control	0.3020	b

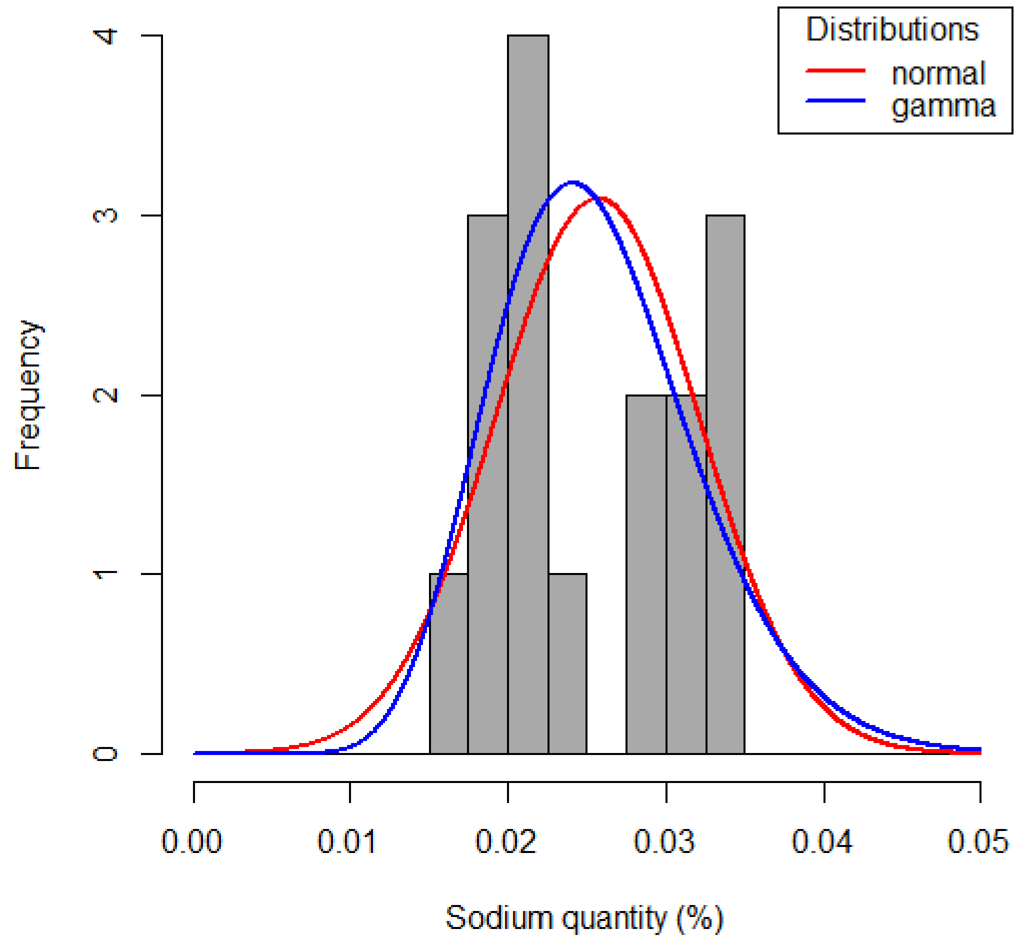

Figure 8.2.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus sodium concentration (%) from the East Gore site.

Table 8.2.27 ANOVA: Treatment effects on average sodium concentration (%) for Miscanthus grown in the East Gore 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	0.4007	12	0.5391	2.6694	0.0949

Table 8.2.28 Treatment effects on average sodium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium concentration (%)	Groups
Anaerobic digestate	0.0330	a

Control	0.0243	a
Paper mill sludge	0.0230	a
Ascophyllum nodosum extract	0.0225	a

Table 8.2.29 ANOVA: Treatment effects on average sodium concentration (%) for Miscanthus grown in the Skye Glen 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	0.0003	12	0.0010	1.3711	0.2987

Table 8.2.30 Treatment effects on average sodium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium concentration (%)	Groups
Anaerobic digestate	0.0713	a
Control	0.0710	a
Ascophyllum nodosum extract	0.0670	a
Paper mill sludge	0.0600	a

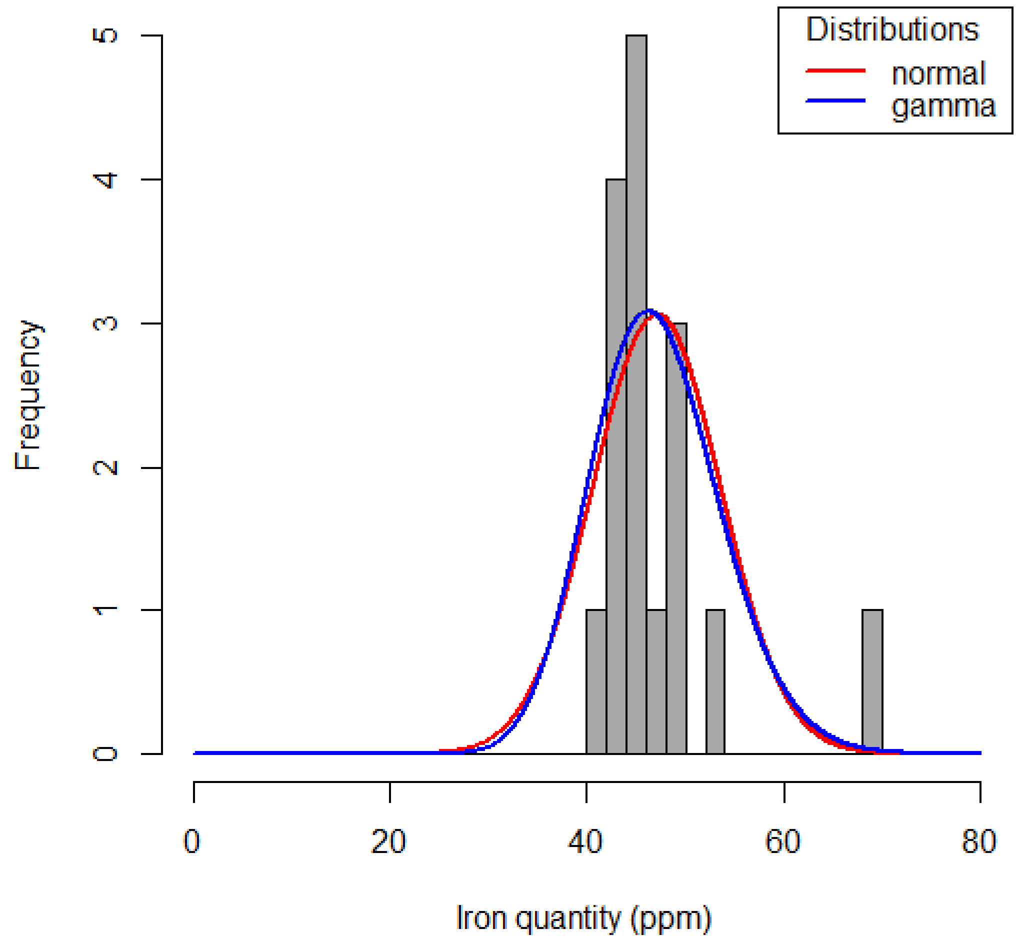

Figure 8.2.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus iron concentration (ppm) from the East Gore site.

Table 8.2.31 ANOVA: Treatment effects on average iron concentration (ppm) for Miscanthus grown in the East Gore 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	0.0543	12	0.1900	1.0593	0.4025

Table 8.2.32 Treatment effects on average iron concentration (ppm) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron concentration (ppm)	Groups
Control	51.1150	a

Anaerobic digestate	48.1525	a
Paper mill sludge	45.1775	a
Ascophyllum nodosum extract	44.0175	a

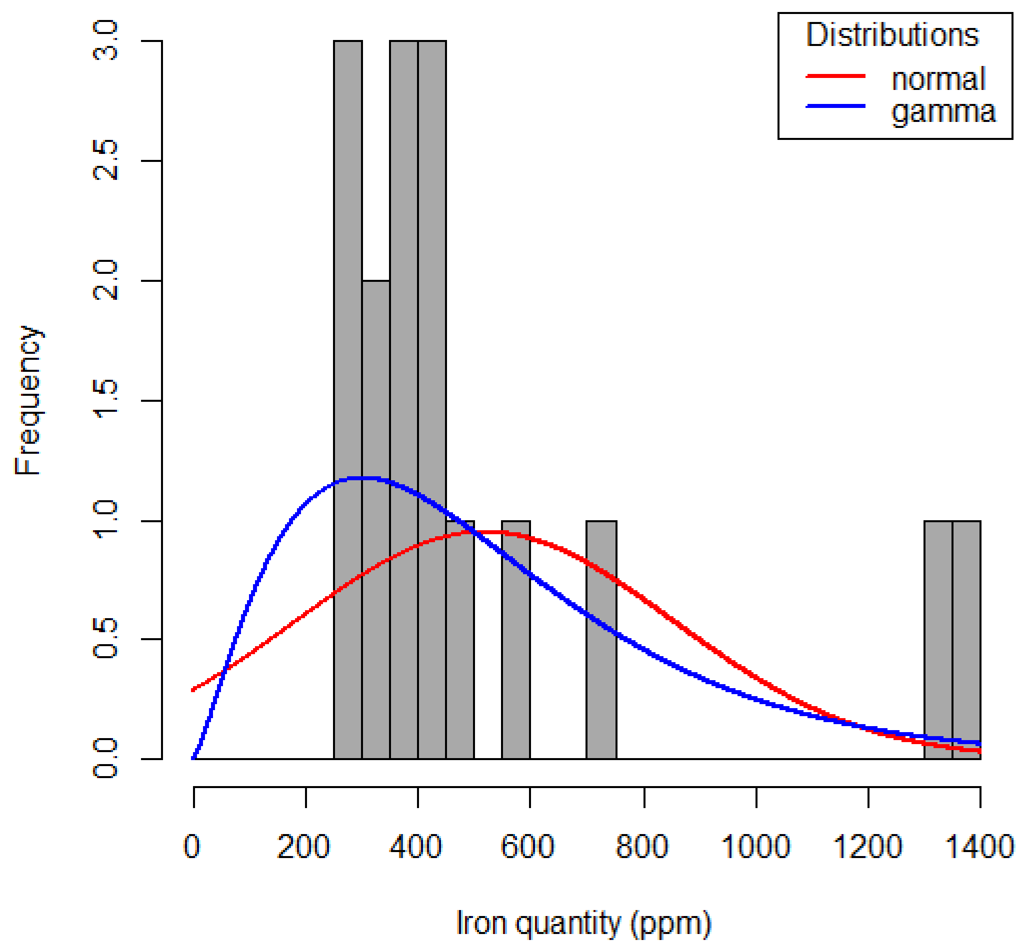

Figure 8.2.4 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus iron concentration (ppm) from the Skye Glen site.

Table 8.2.33 ANOVA: Treatment effects on average iron concentration (ppm) for Miscanthus grown in the Skye Glen 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	0.6850	12	3.6955	0.6025	0.6257

Table 8.2.34 Treatment effects on average iron concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Iron concentration (ppm)	Groups
Ascophyllum nodosum extract	639.175	a
Paper mill sludge	556.810	a
Control	516.760	a
Anaerobic digestate	359.560	a

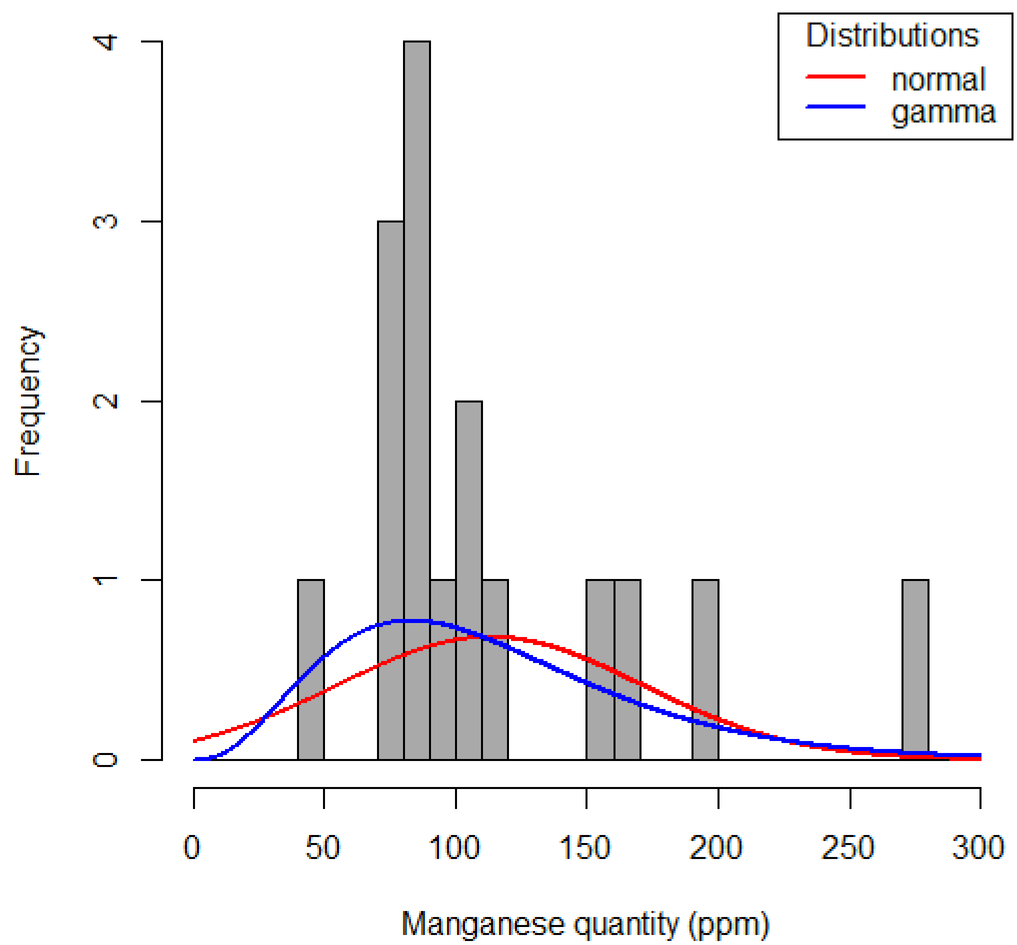

Figure 8.2.5 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus manganese concentration (ppm) from the East Gore site.

Table 8.2.35 ANOVA: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the East Gore 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	0.5047	21.24	4e-5 ***

Table 8.2.36 Tukey's test: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG – CT	-0.2927	0.1453	-2.014	0.182
PS – CT	0.7509	0.1453	5.168	<0.001 ***
SE – CT	-0.0574	0.1453	-0.395	0.979

Table 8.2.37 Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the East Gore 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 mill sludge	199.0375	a
Control	93.9375	b
Ascophyllum nodosum extract	88.6950	b
Anaerobic digestate	70.1025	b

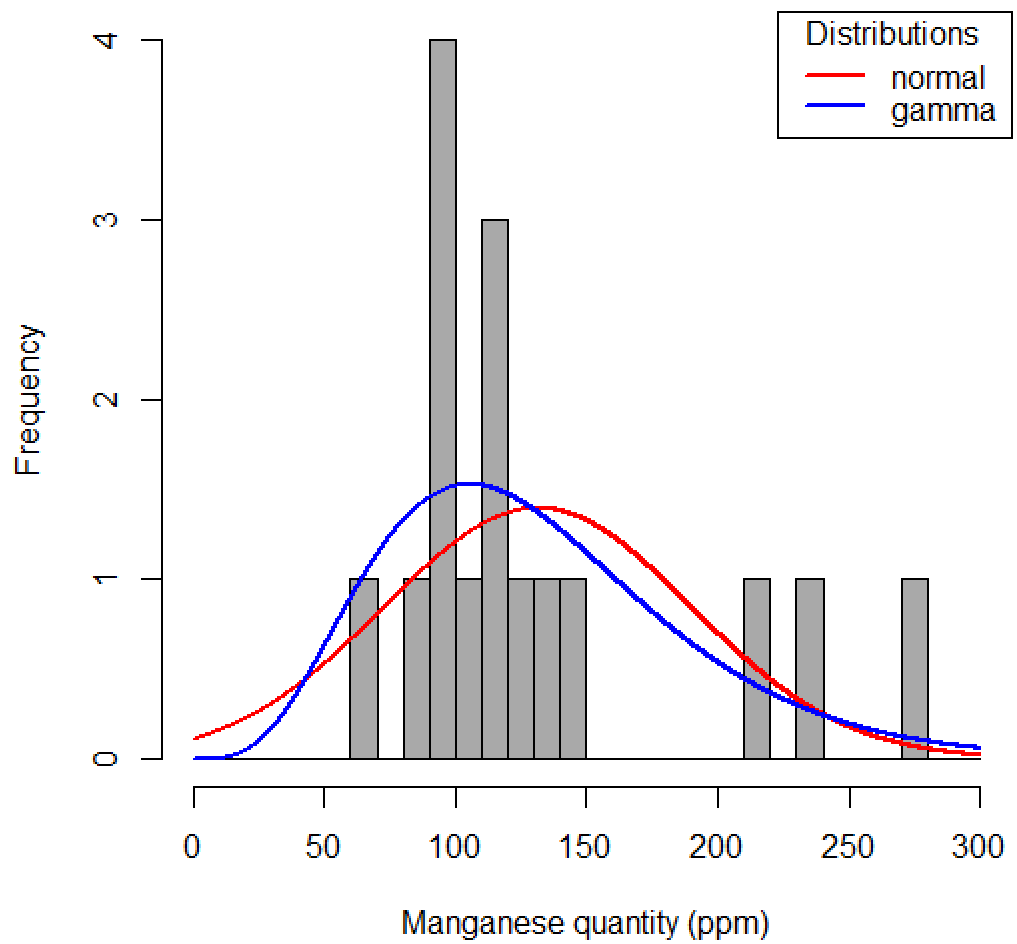

Figure 8.2.5 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus manganese concentration (ppm) from the Skye Glen site.

Table 8.2.38 ANOVA: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the Skye Glen 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	1.9019	12	0.5407	15.405	0.0002 ***

Table 8.2.39 Tukey's test: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value

DG – CT	0.0637	0.1434	0.444	0.971
PS – CT	0.8105	0.1434	5.650	< 1e-5 ***
SE – CT	0.1180	0.1434	0.823	0.844

Table 8.2.40 Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the Skye Glen 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 mill sludge	217.1850	a
Ascophyllum nodosum extract	108.6725	b
Anaerobic digestate	102.9275	b
Control	96.5725	b

Table 8.2.41 ANOVA: Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the East Gore 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	45.43	12	26.389	6.8861	0.0060 **

Table 8.2.42 Tukey's test: Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper mill sludge (PS), liquid *A. nodosum* extract (SE) and anaerobic digestate (DG). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG – CT	-0.9325	1.0486	-0.889	0.8105
PS – CT	-4.4250	1.0486	-4.220	<0.001 ***
SE – CT	-0.9900	1.0486	-0.944	0.7810

Table 8.2.43 Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc concentration (ppm)	Groups
Control	22.7725	a
Anaerobic digestate	21.8400	a
Ascophyllum nodosum extract	21.7825	a
Paper mill sludge	18.3475	b

Table 8.2.44 ANOVA: Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the Skye Glen 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	29.151	12	49.935	2.3351	0.1254

Table 8.2.45 Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc concentration (ppm)	Groups
Ascophyllum nodosum extract	25.1275	a
Paper mill sludge	23.5650	a
Anaerobic digestate	22.3775	a
Control	21.5350	a

8.3. Miscanthus nutrient yield (2019)

Table 8.3.1 ANOVA: Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the East Gore 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	25.304	12	14.837	6.8217	0.0062 **

Table 8.3.2 Tukey's test: Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	1.3190	0.7863	1.678	0.3356
PS – CT	2.9533	0.7863	3.756	0.0011 **
SE – CT	-0.1877	0.7863	-0.239	0.9952

Table 8.3.3 Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. N yield (kg) per hectare	Groups
Paper sludge	5.87	a
Anaerobic digestate	4.23	ab
Control	2.91	b
A. nodosum extract	2.72	b

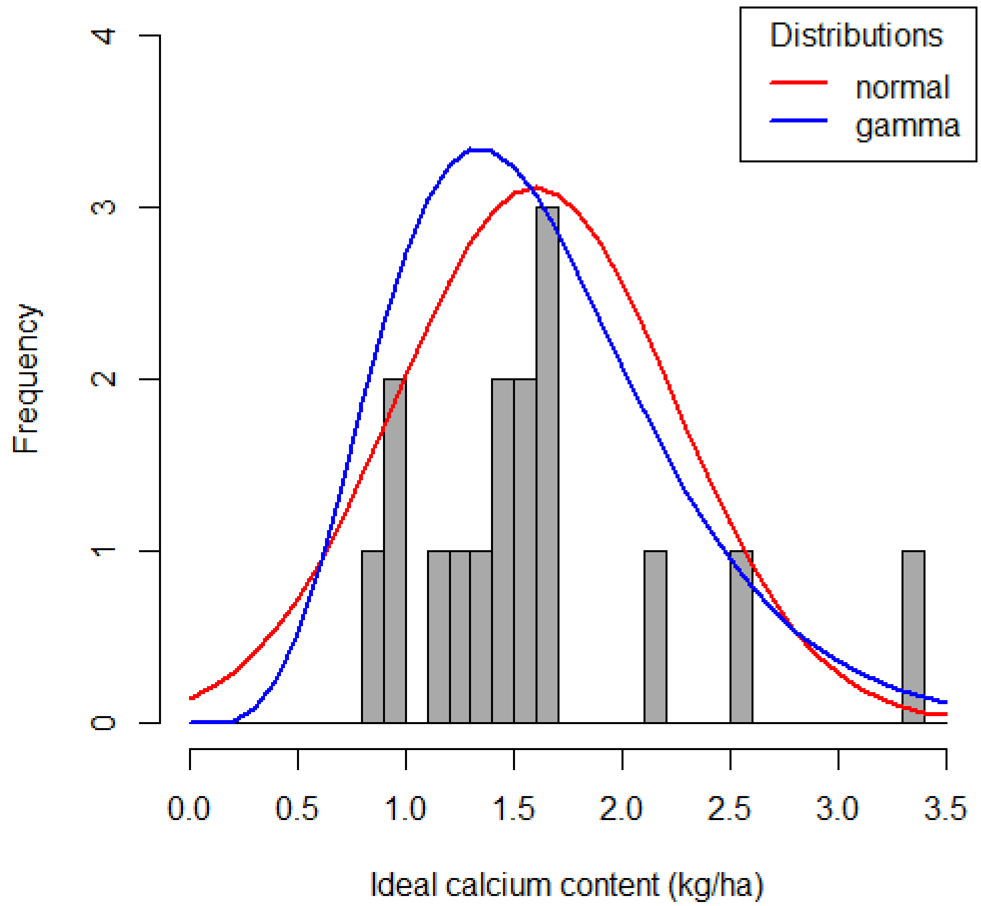

Figure 8.3.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus calcium yield (kg/ha) from the East Gore site.

Table 8.3.4 ANOVA: Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the East Gore 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	1.2252	12	0.8438	6.0762	0.0093 **

Table 8.3.5 Tukey's test: Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.1021	0.1833	0.557	0.9446
PS – CT	0.5702	0.1833	3.110	0.0101 *

SE – CT	-0.1469	0.1833	-0.801	0.8538

Table 8.3.6 Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Ca yield (kg) per hectare	Groups
Paper sludge	2.39	a
Anerobic digestate	1.49	ab
Control	1.35	b
A. nodosum extract	1.16	b

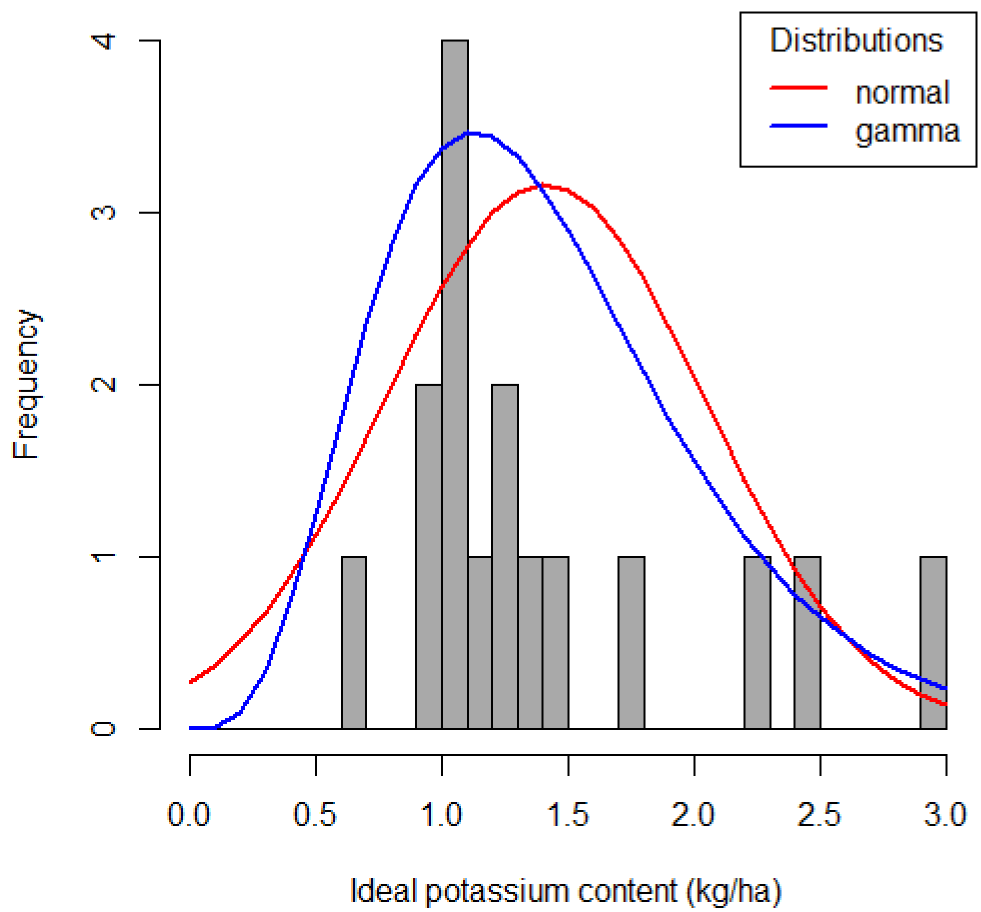

Figure 8.3.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus potassium yield (kg/ha) from the East Gore site.

Table 8.3.7 ANOVA: Treatment effects on potassium yield (kg/ha) for Miscanthus grown in the East Gore 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	1.9905	12	0.5922	14.222	0.0003 ***

Table 8.3.8 Tukey's test: Treatment effects on potassium yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.7380	0.1527	4.832	< 1e-5 ***
PS – CT	0.0077	0.1527	0.051	1.000
SE – CT	-0.0945	0.1527	-0.619	0.926

Table 8.3.9 Treatment effects on potassium yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. K yield (kg) per hectare	Groups
Anerobic digestate	2.35	a
Paper sludge	1.13	b
Control	1.12	b
A. nodosum extract	1.02	b

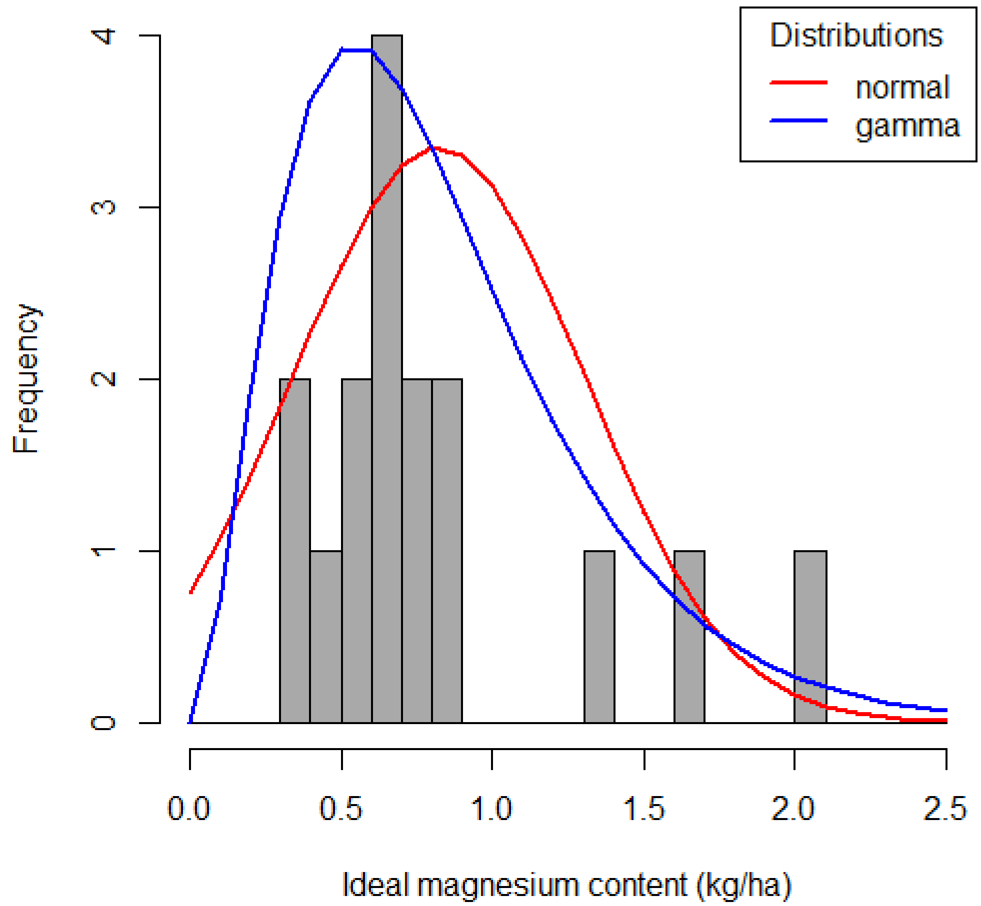

Figure 8.3.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus magnesium yield (kg/ha) from the East Gore site.

Table 8.3.10 ANOVA: Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the East Gore 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	2.6411	12	1.3339	8.7144	0.0024 **

Table 8.3.11 Tukey's test: Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.2587	0.2248	1.151	0.6578

PS – CT	0.9472	0.2248	4.214	< 1e-3 ***
SE – CT	0.0022	0.2248	0.010	1.0000

Table 8.3.12 Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Mg yield (kg) per hectare	Groups
Paper sludge	1.44	a
Anaerobic digestate	0.73	b
Control	0.56	b
A. nodosum extract	0.56	b

Table 8.3.13 ANOVA: Treatment effects on phosphorus yield (kg/ha) for Miscanthus grown in the East Gore 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	0.2539	12	0.9781	1.0385	0.4106

Table 8.3.14 Treatment effects on phosphorus yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. P yield (kg) per hectare	Groups
Paper sludge	1.00	a
Anaerobic digestate	0.86	a
Control	0.79	a
A. nodosum extract	0.65	a

Table 8.3.15 ANOVA: Treatment effects on sodium yield (kg/ha) for Miscanthus grown in the East Gore 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	0.0087	12	0.0027	12.645	0.0005 ***

Table 8.3.16 Tukey's test: Treatment effects on sodium yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.0463	0.0107	4.328	< 1e-3 ***
PS – CT	0.0358	0.0107	3.346	0.0050 **

SE – CT	-0.0090	0.0107	-0.842	0.8343

Table 8.3.17 Treatment effects on sodium yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Na yield (kg) per hectare	Groups
Anaerobic digestate	0.10	a
Paper sludge	0.09	a
Control	0.06	b
A. nodosum extract	0.05	b

Table 8.3.18 ANOVA: Treatment effects on iron yield (kg/ha) for Miscanthus grown in the East Gore 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	0.0002	4.0533	0.0333 *

Table 8.3.19 Tukey's test: Treatment effects on iron yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.0028	0.0029	0.938	0.7846
PS – CT	0.0073	0.0029	2.472	0.0644
SE – CT	-0.0025	0.0029	-0.852	0.8293

Table 8.3.20 Treatment effects on iron yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Fe yield (kg) per hectare	Groups
Paper sludge	0.0195	a
Anaerobic digestate	0.0150	ab
Control	0.0123	ab
A. nodosum extract	0.0097	b

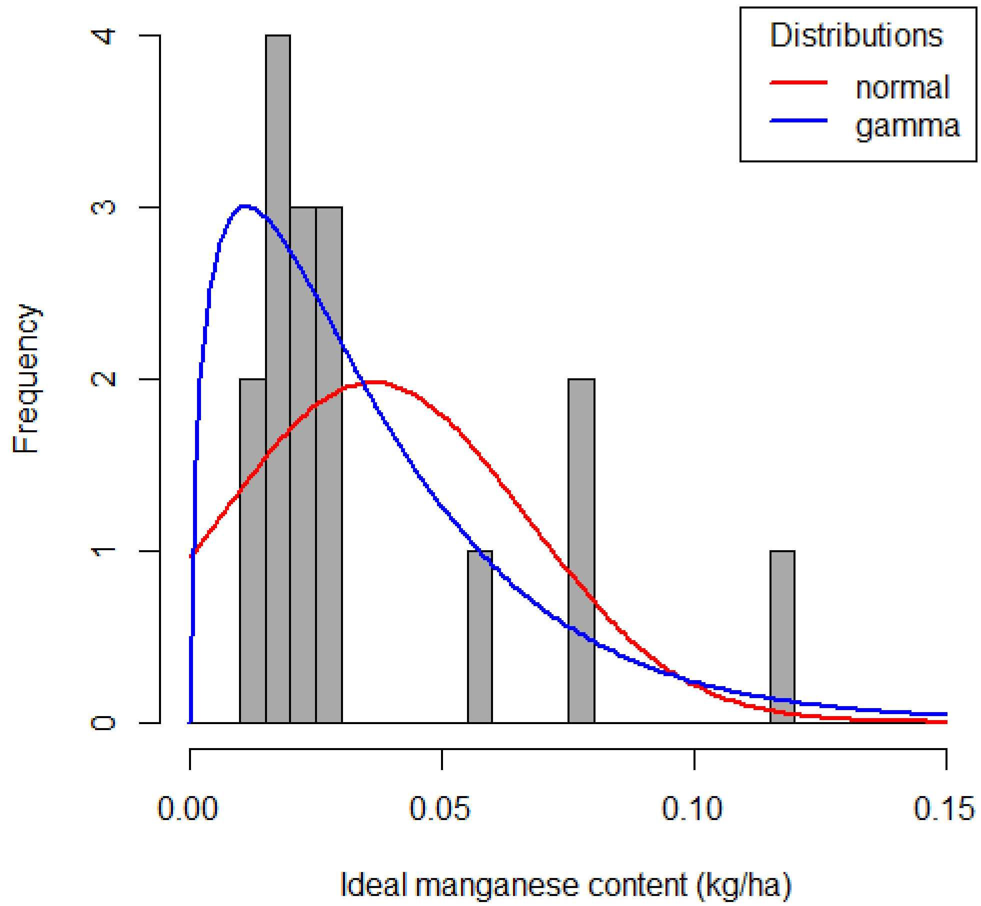

Figure 8.3.4 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus manganese yield (kg/ha) from the East Gore site.

Table 8.3.21 ANOVA: Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the East Gore 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	6.8192	12	0.9064	29.728	8e-6 ***

Table 8.3.22 Tukey's test: Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	-0.0113	0.1955	-0.058	1.000

PS – CT	1.3165	0.1955	6.733	< 1e-5 ***
SE – CT	-0.1846	0.1955	-0.944	0.781

Table 8.3.23 Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Mn yield (kg) per hectare	Groups
Paper sludge	0.083	a
Control	0.022	b
Anaerobic digestate	0.022	b
A. nodosum extract	0.019	b

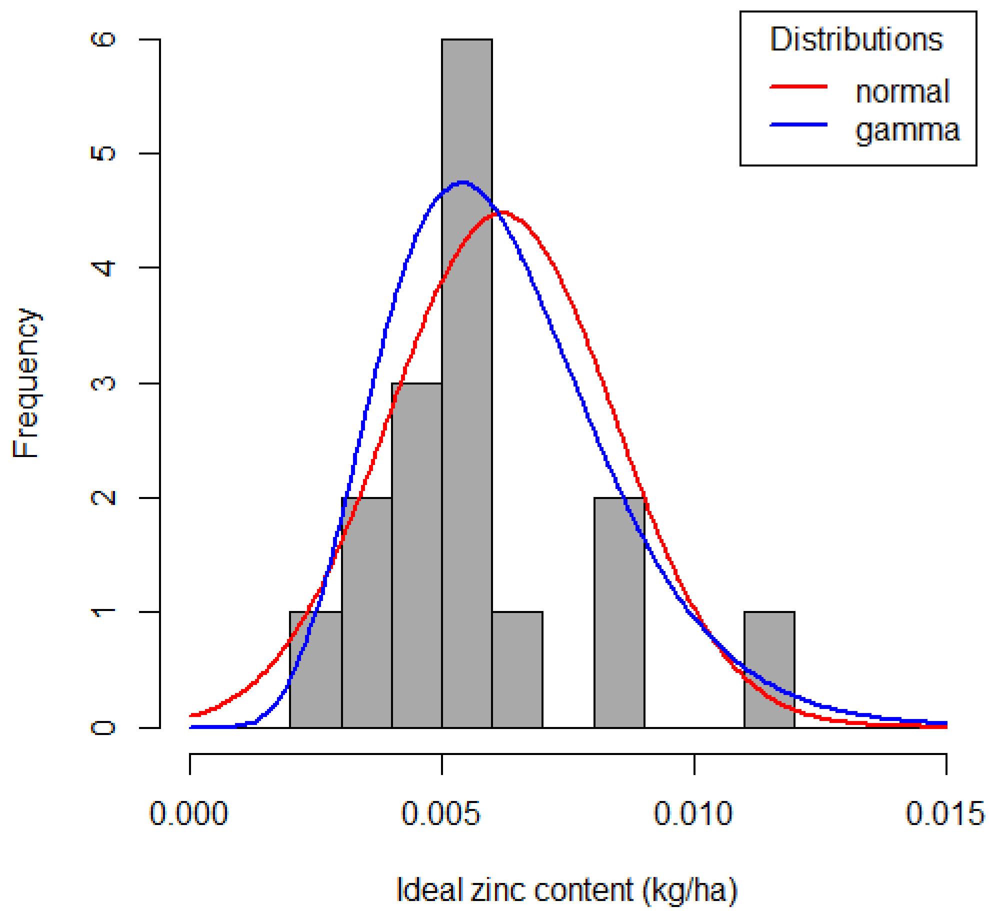

Figure 8.3.5 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus zinc yield (kg/ha) from the East Gore site.

Table 8.3.24 ANOVA: Treatment effects on zinc yield (kg/ha) for Miscanthus grown in the East Gore 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	0.6781	12	1.0922	2.456	0.1133

Table 8.3.25 Treatment effects on zinc yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Zn yield (kg) per hectare	Groups
Paper sludge	0.00800	a
Anerobic digestate	0.00675	a
Control	0.00525	a
A. nodosum extract	0.00475	a

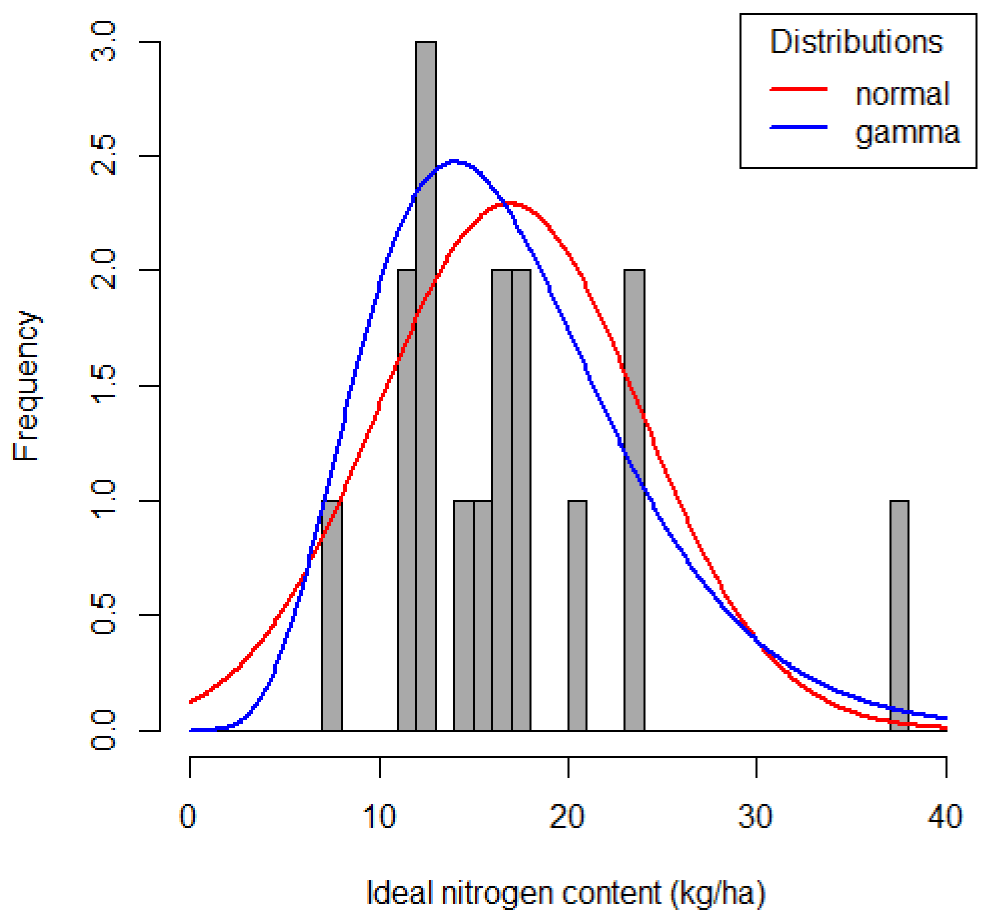

Figure 8.3.6 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus nitrogen yield (kg/ha) from the Skye Glen site.

Table 8.3.26 ANOVA: Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the Skye Glen 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	1.2404	12	0.9138	5.3533	0.0143 *

Table 8.3.27 Tukey's test: Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.1508	0.1965	0.768	0.8691
PS – CT	0.7277	0.1965	3.703	0.0011 **
SE – CT	0.3038	0.1965	1.546	0.4101

Table 8.3.28 Treatment effects on nitrogen yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. N yield (kg) per hectare	Groups
Paper sludge	25.04	a
A. nodosum extract	16.39	ab
Anerobic digestate	14.06	b
Control	12.09	b

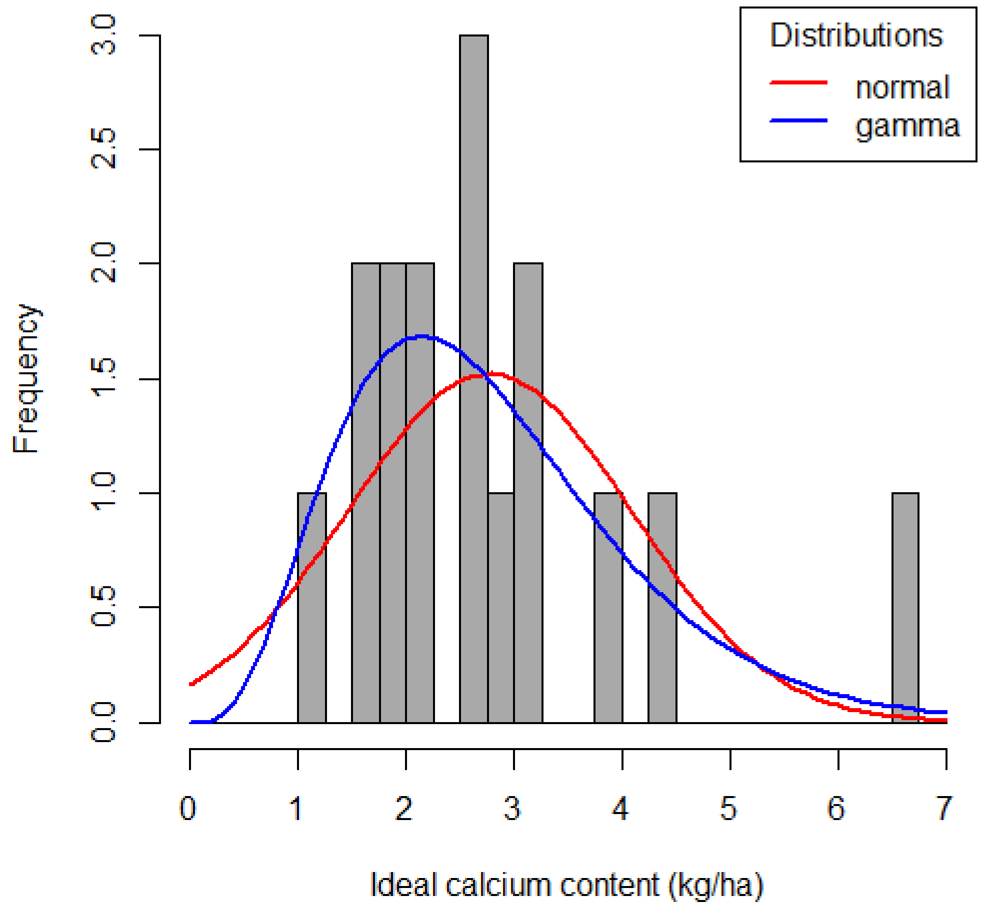

Figure 8.3.7 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus calcium yield (kg/ha) from the Skye Glen site.

Table 8.3.29 ANOVA: Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	1.8445	12	1.0229	7.5098	0.0043 **

Table 8.3.30 Tukey's test: Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.0512	0.2023	0.253	0.9943
PS – CT	0.8260	0.2023	4.082	< 1e-3 ***

SE – CT	0.2900	0.2023	1.433	0.4784

Table 8.3.31 Treatment effects on calcium yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Ca yield (kg) per hectare	Groups
Paper sludge	4.46	a
A. nodosum extract	2.61	ab
Anerobic digestate	2.06	b
Control	1.95	b

Table 8.3.32 ANOVA: Treatment effects on potassium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	60.933	12	124.27	1.9614	0.1737

Table 8.3.33 Treatment effects on potassium yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. K yield (kg) per hectare	Groups
Paper sludge	12.13	a
A. nodosum extract	9.15	a
Anerobic digestate	8.10	a
Control	6.85	a

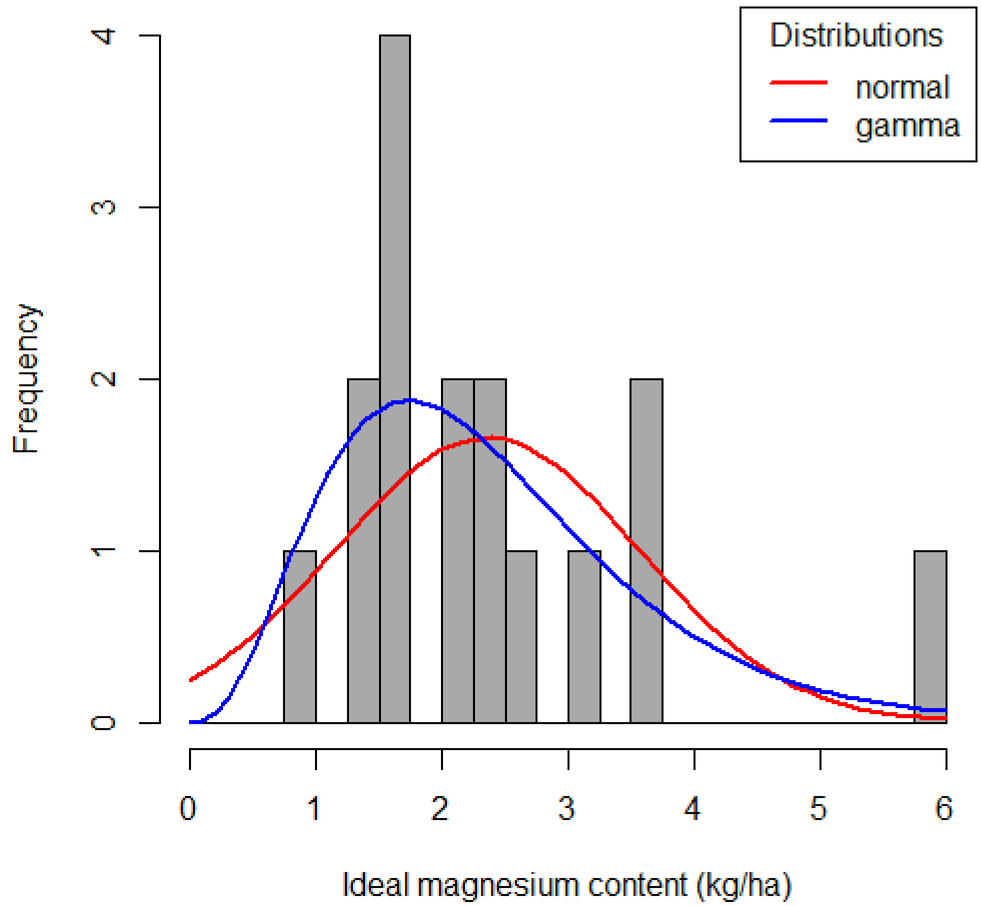

Figure 8.3.8 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus magnesium yield (kg/ha) from the Skye Glen site.

Table 8.3.34 ANOVA: Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	2.3201	12	1.0392	8.8885	0.0022 **

Table 8.3.35 Tukey's test: Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.1323	0.2086	0.634	0.9210

PS – CT	0.9470	0.2086	4.540	< 1e-3 ***
SE – CT	0.2868	0.2086	1.375	0.5150

Table 8.3.36 Treatment effects on magnesium yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Mg yield (kg) per hectare	Groups
Paper sludge	4.01	a
A. nodosum extract	2.07	b
Anerobic digestate	1.78	b
Control	1.56	b

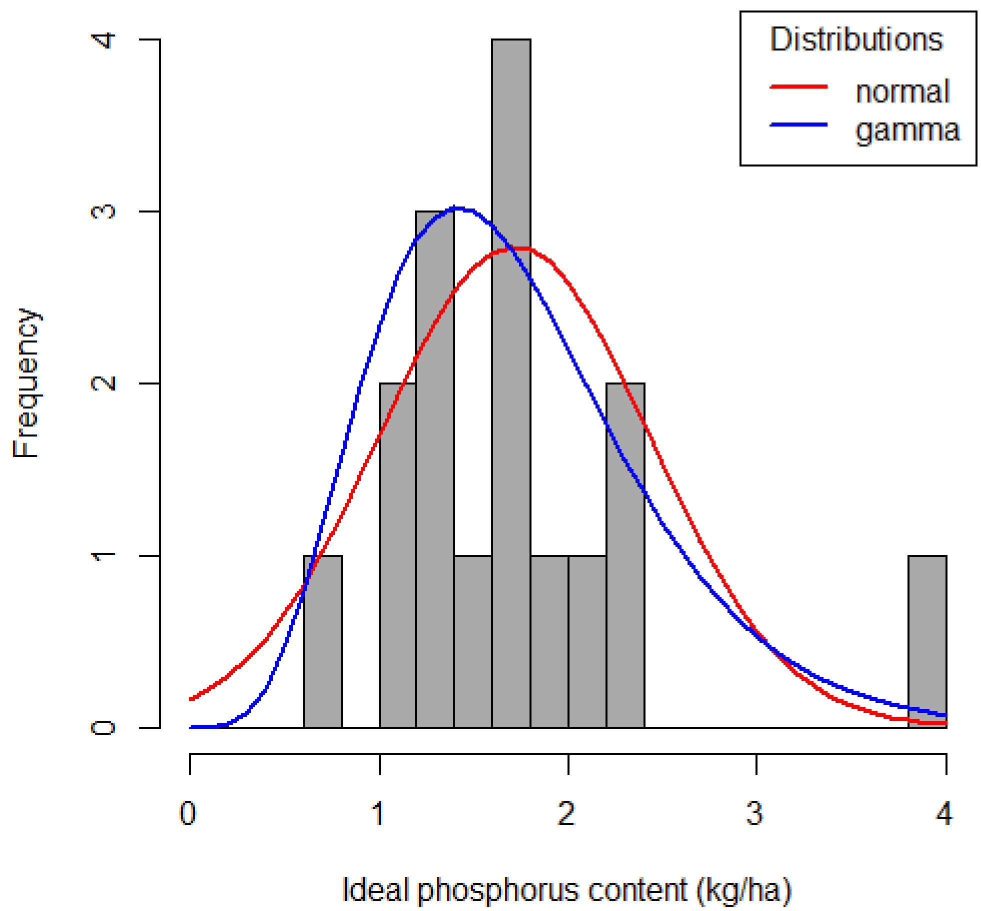

Figure 8.3.9 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus phosphorus yield (kg/ha) from the Skye Glen site.

Table 8.3.37 ANOVA: Treatment effects on phosphorus yield (kg/ha) for Miscanthus grown in the Skye Glen 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	1.3201	12	0.9375	5.7014	0.0116 *

Table 8.3.38 Tukey's test: Treatment effects on phosphorus yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.2002	0.1964	1.019	0.7384
PS – CT	0.7669	0.1964	3.904	< 1e-3 ***
SE – CT	0.3441	0.1964	1.752	0.2970

Table 8.3.39 Treatment effects on phosphorus yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. P yield (kg) per hectare	Groups
Paper sludge	2.55	a
A. nodosum extract	1.67	ab
Anerobic digestate	1.45	ab
Control	1.19	b

Table 8.3.40 ANOVA: Treatment effects on sodium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	0.1521	12	0.2434	2.5	0.1092

Table 8.3.41 Treatment effects on sodium yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Na yield (kg) per hectare	Groups
Paper sludge	0.61	a
A. nodosum extract	0.44	a
Anerobic digestate	0.39	a
Control	0.37	a

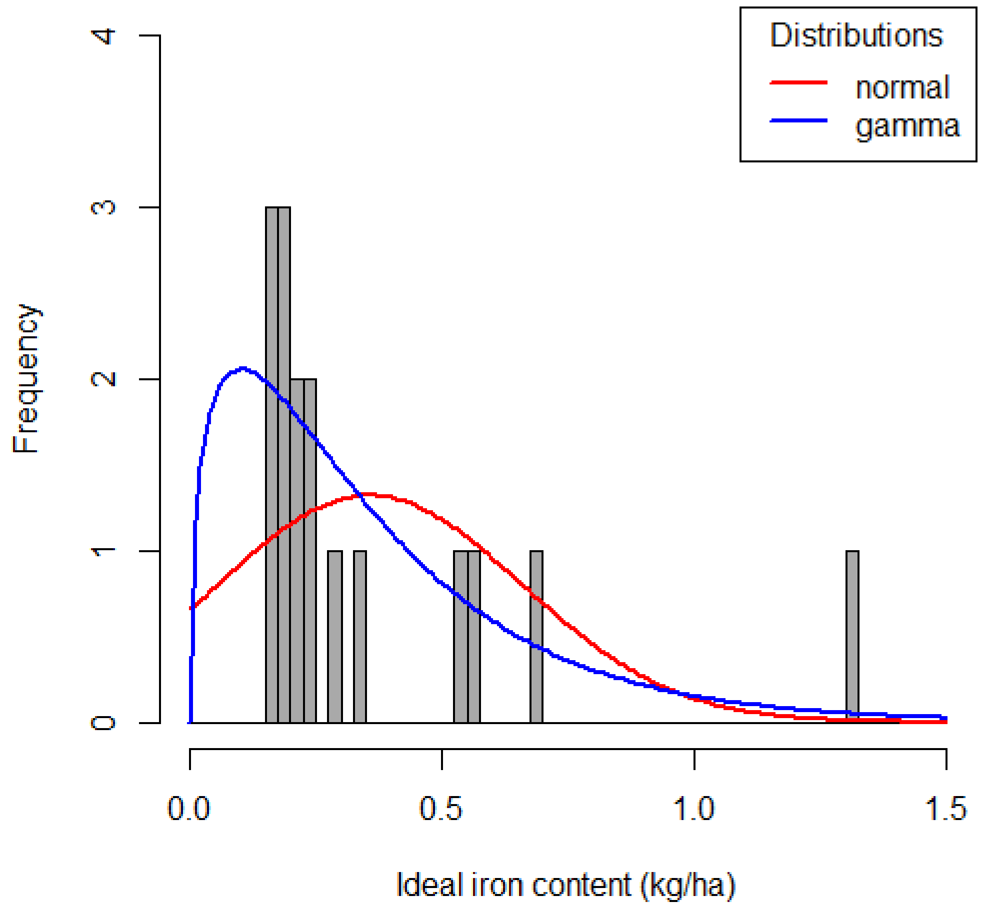

Figure 8.3.10 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus iron yield (kg/ha) from the Skye Glen site.

Table 8.3.42 ANOVA: Treatment effects on iron yield (kg/ha) for Miscanthus grown in the Skye Glen 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	2.6004	12	4.2252	2.23	0.1373

Table 8.3.43 Treatment effects on iron yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Fe yield (kg) per hectare	Groups
Paper sludge	0.58	a
A. nodosum extract	0.38	a
Control	0.28	a
Anaerobic digestate	0.19	a

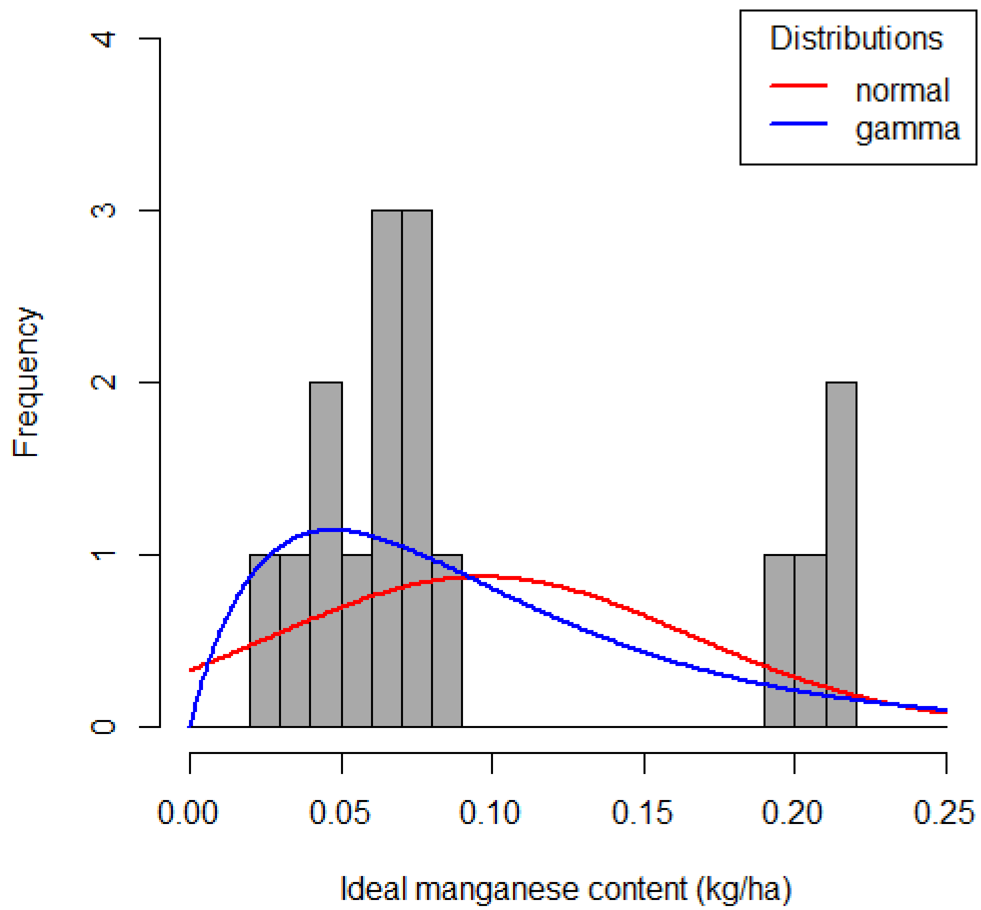

Figure 8.3.11 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus manganese yield (kg/ha) from the Skye Glen site.

Table 8.3.44 ANOVA: Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the Skye Glen 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	5.8303	12	1.0237	23.466	3e-5 ***

Table 8.3.45 Tukey's test: Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value

DG – CT	0.1205	0.2035	0.592	0.934
PS – CT	1.4166	0.2035	6.961	< 1e-4 ***
SE – CT	0.3072	0.2035	1.510	0.432

Table 8.3.46 Treatment effects on manganese yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Mn yield (kg) per hectare	Groups
Paper sludge	0.209	a
A. nodosum extract	0.069	b
Anaerobic digestate	0.057	b
Control	0.051	b

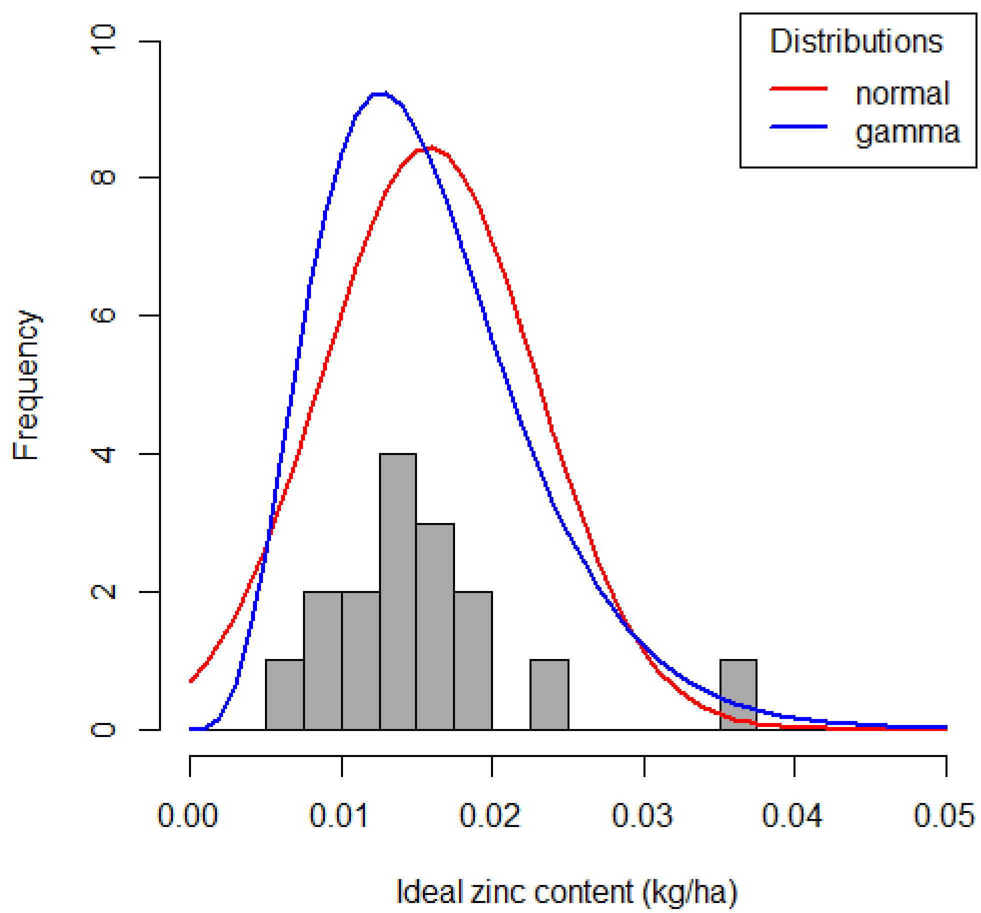

Figure 8.3.12 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus zinc yield (kg/ha) from the Skye Glen site.

Table 8.3.47 ANOVA: Treatment effects on zinc yield (kg/ha) for Miscanthus grown in the Skye Glen 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	1.5414	12	1.0722	5.7667	0.0111 *

Table 8.3.48 Tukey's test: Treatment effects on zinc yield (kg/ha) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	0.0645	0.2111	0.306	0.9901
PS – CT	0.7681	0.2111	3.639	0.0014 **
SE – CT	0.3365	0.2111	1.594	0.3819

Table 8.3.49 Treatment effects on zinc yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zn yield (kg) per hectare	Groups
Paper sludge	0.024	a
A. nodosum extract	0.016	ab
Anaerobic digestate	0.012	b
Control	0.011	b

8.4. Woody crop planting survival (2019)

Table 8.4.1 ANOVA: Treatment effects on woody crop survival counts. P-values lower than the alpha (0.05) would indicate that variances are not equal, and there is a significant difference in survival counts between two (or more) treatments.

Site	**Crop**	**P-value**
East Gore	Poplar	0.9943
	Willow	0.9643
Skye Glen	Poplar	0.9742
	Willow	0.9924

8.5. Survival rate, 2020

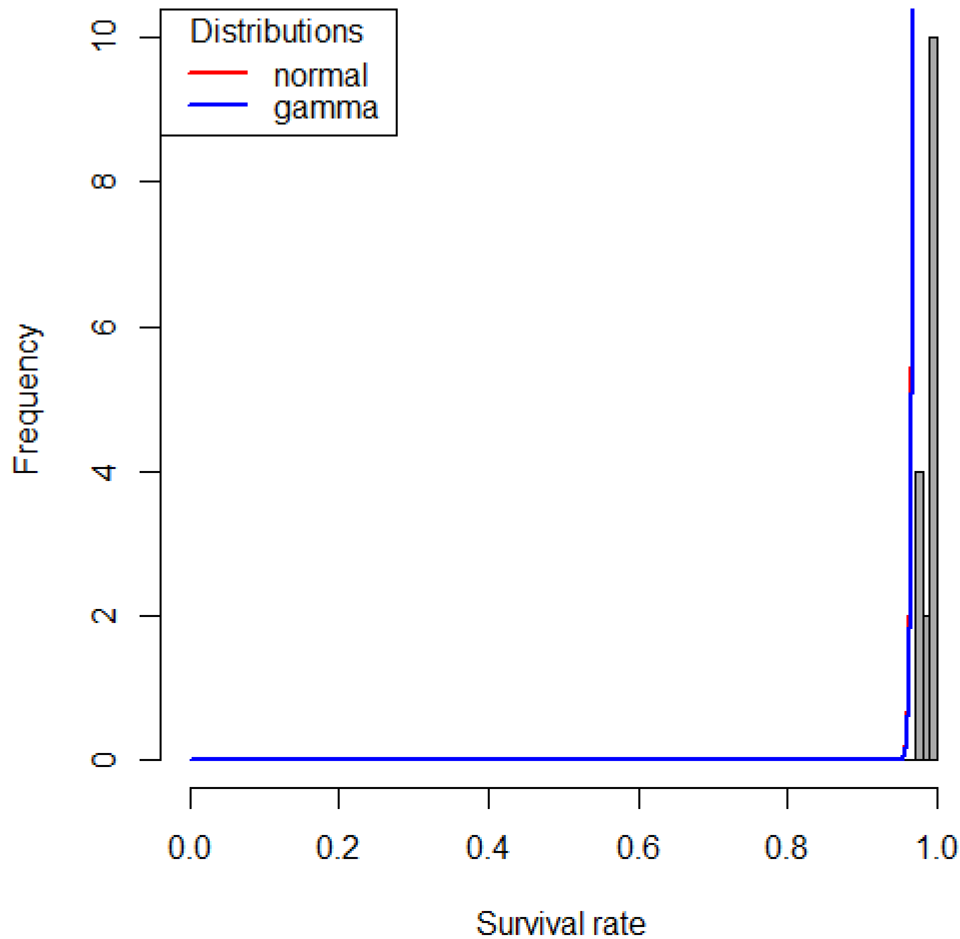

Figure 8.5.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus survival rate from the East Gore site.

Table 8.5.1 ANOVA: Treatment effects on survival rate for Miscanthus grown in the East Gore 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	0.0004	12	0.0008	2.2488	0.1351

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

Soil amendment	Avg. survival rate	Groups
Control	1.000	a
A. nodosum extract	0.998	a
Paper sludge	0.990	a

Anaerobic digestate	0.988	a

Table 8.5.3 ANOVA: Treatment effects on survival rate for poplar grown in the East Gore 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	0.0161	12	0.0789	0.8174	0.5087

Table 8.5.4 Treatment effects on survival rate for poplar grown in the East Gore 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	0.93	a
A. nodosum extract	0.92	a
Anaerobic digestate	0.88	a
Control	0.85	a

Table 8.5.5 ANOVA: Treatment effects on survival rate for willow grown in the East Gore 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	0.1052	12	0.1474	2.8545	0.0817

Table 8.5.6 Treatment effects on survival rate for willow grown in the East Gore 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	0.908	a
Anaerobic digestate	0.750	a
A. nodosum extract	0.745	a
Control	0.690	a

Table 8.5.7 ANOVA: Treatment effects on survival rate for poplar grown in the Skye Glen 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	0.0209	12	0.1427	0.5851	0.6361

Table 8.5.8 Treatment effects on survival rate for poplar grown in the Skye Glen 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	0.755	a
Anaerobic digestate	0.740	a
Control	0.720	a
A. nodosum extract	0.660	a

Table 8.5.9 ANOVA: Treatment effects on survival rate for willow grown in the Skye Glen 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	0.0086	12	0.0553	0.6201	0.6153

Table 8.5.10 Treatment effects on survival rate for willow grown in the Skye Glen 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	0.875	a
Control	0.840	a
Anaerobic digestate	0.823	a
A. nodosum extract	0.815	a

8.6. Poplar leaf count (August 2020)

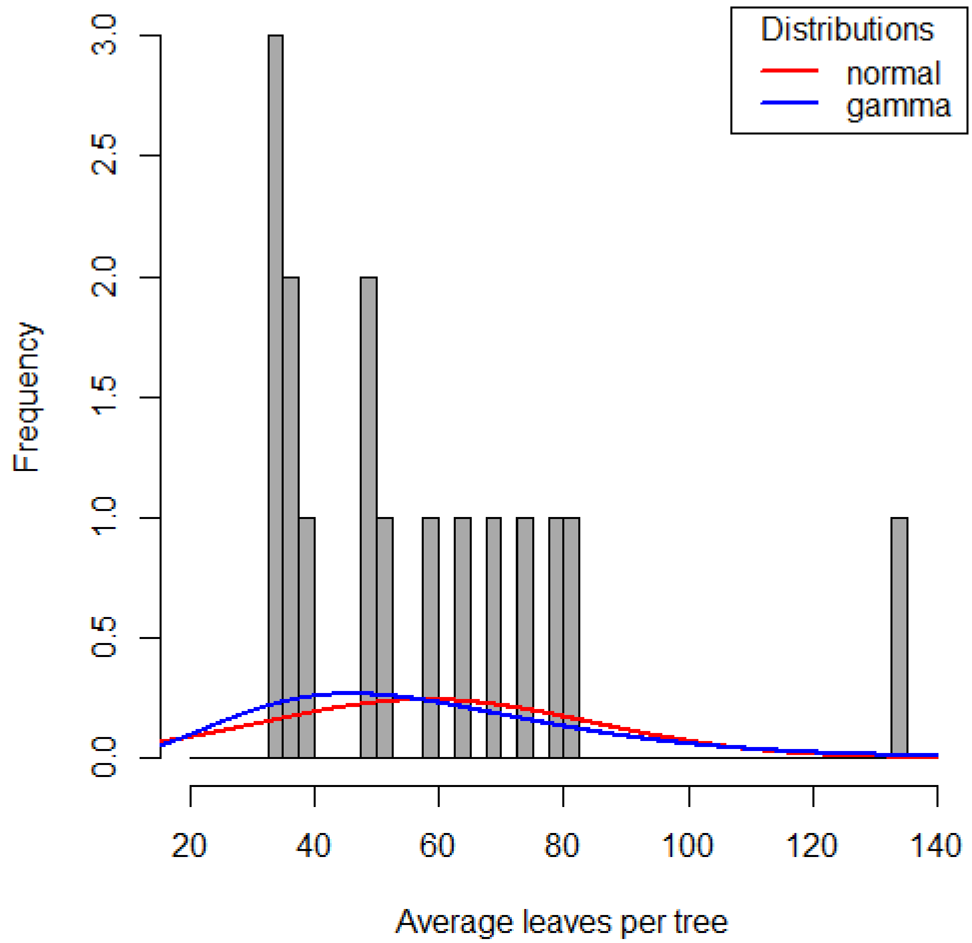

Figure 8.6.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar leaf count from the East Gore site.

Table 8.6.1 ANOVA: Treatment effects on leaf count for poplar grown in the East Gore 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	0.7855	12	1.7858	1.6772	0.2245

Table 8.6.2 Treatment effects on leaf count for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf count	Groups
Paper sludge	81.20	a
Anaerobic digestate	54.13	a
Control	49.98	a

A. nodosum extract	46.73	a

Table 8.6.3 ANOVA: Treatment effects on leaf count for poplar grown in the Skye Glen 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	2475.8	12	3947.8	2.5086	0.1084

Table 8.6.4 Treatment effects on leaf count for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf count	Groups
A. nodosum extract	114.90	a
Paper sludge	108.05	a
Control	95.35	a
Anaerobic digestate	82.38	a

8.7. Poplar leaf area (August 2020)

Table 8.7.1 ANOVA: Treatment effects on leaf area (cm^2) for poplar grown in the East Gore 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	145.54	12	106.30	5.4766	0.0132 *

Table 8.7.2 Tukey's test: Treatment effects on leaf area (cm^2) for poplar grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.5944	2.1046	0.282	0.9922
PS – CT	6.9918	2.1046	3.322	0.0053 **
SE – CT	-0.3767	2.1046	-0.179	0.9980

Table 8.7.3 Treatment effects on leaf area (cm^2) for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf area (cm^2)	Groups
Paper sludge	19.16	a
Anaerobic digestate	12.76	b
Control	12.17	b

A. nodosum extract	11.79	b

Table 8.7.4 ANOVA: Treatment effects on leaf area (cm^2) for poplar grown in the Skye Glen 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	431.32	12	919.48	1.8764	0.1874

Table 8.7.5 Treatment effects on leaf area (cm^2) for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf area (cm^2)	Groups
Paper sludge	55.68	a
Control	44.95	a
Anaerobic digestate	43.60	a
A. nodosum extract	42.88	a

8.8. Poplar stem count (August 2020)

Table 8.8.1 ANOVA: Treatment effects on stem count for poplar grown in the East Gore 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	0.1185	12	0.4407	0.9826	0.4334

Table 8.8.2 Treatment effects on stem count for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. stem count	Groups
Paper sludge	5.20	a
Control	4.40	a
Anaerobic digestate	4.28	a
A. nodosum extract	4.20	a

Table 8.8.3 ANOVA: Treatment effects on stem count for poplar grown in the Skye Glen 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	3.39	12	7.95	1.7057	0.2188

Table 8.8.4 Treatment effects on stem count for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. stem count	Groups
A. nodosum extract	5.575	a
Control	4.675	a
Anaerobic digestate	4.575	a
Paper sludge	4.375	a

8.9. Poplar average stem length (August 2020)

Table 8.9.1 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	775.12	12	218.67	14.179	0.0003 ***

Table 8.9.2 Tukey's test: Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	4.808	3.018	1.593	0.3826
PS – CT	17.489	3.018	5.794	< 1e-4 ***
SE – CT	1.052	3.018	0.349	0.9855

Table 8.9.3 Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	37.3	a
Anaerobic digestate	24.6	b
A. nodosum extract	20.9	b
Control	19.8	b

Table 8.9.4 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the Skye Glen 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	2087	12	3248.2	2.5701	0.103

Table 8.9.5 Treatment effects on average stem length (cm) for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. stem length (cm)	Groups
Paper sludge	104.2	a
A. nodosum extract	86.8	a
Anaerobic digestate	80.5	a
Control	73.3	a

8.10. Poplar total stem length (August 2020)

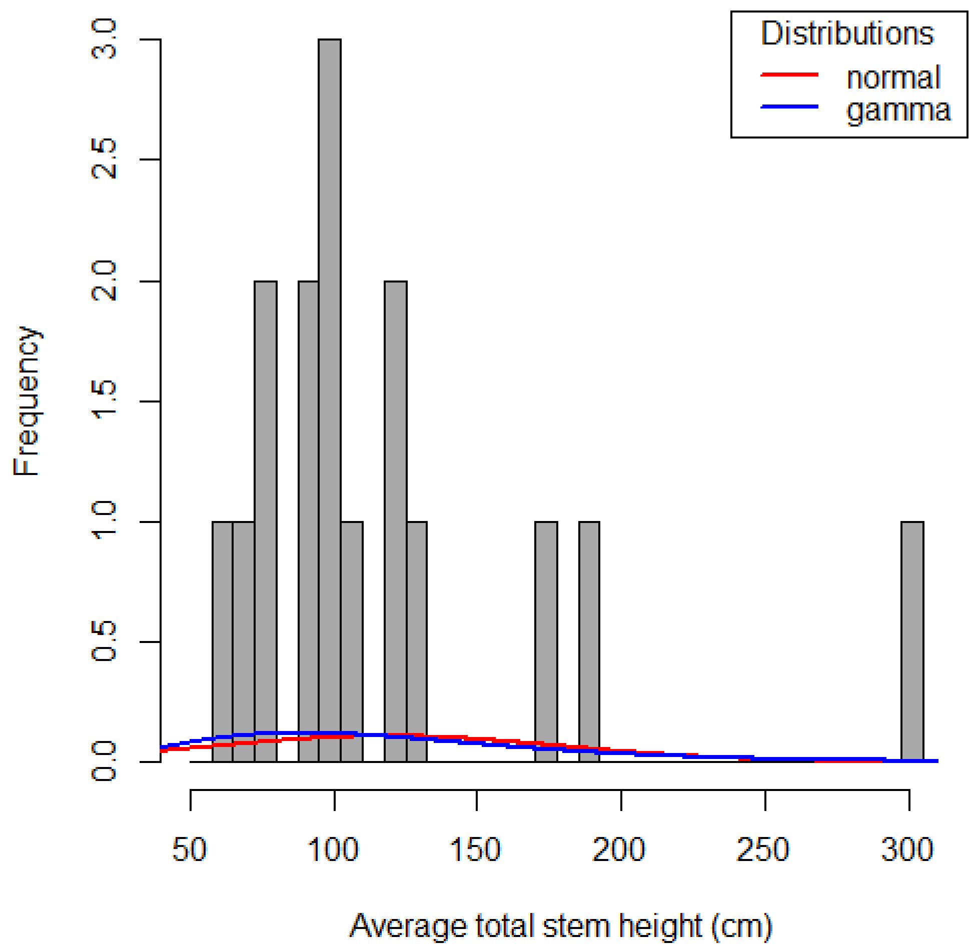

Figure 8.10.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of total poplar stem height from the East Gore site.

Table 8.10.1 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the East Gore 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	1.9564	12	0.8534	8.6883	0.0025 **

Table 8.10.2 Tukey's test: Treatment effects on total stem length (cm) for poplar grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.1778	0.1937	0.918	0.7955
PS – CT	0.8022	0.1937	4.141	< 1e-3 ***
SE – CT	-0.0210	0.1937	-0.108	0.9996

Table 8.10.3 Treatment effects on total stem length (cm) for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	196.1	a
Anaerobic digestate	105.0	b
Control	87.9	b
A. nodosum extract	86.1	b

Table 8.10.4 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the Skye Glen 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	5013	12	8202	2.445	0.1143

Table 8.10.5 Treatment effects on total stem length (cm) for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
A. nodosum extract	476.9	a
Paper sludge	450.8	a
Anaerobic digestate	361.8	a
Control	346.2	a

8.11. Willow leaf count (per tallest stem; August 2020)

Table 8.11.1 ANOVA: Treatment effects on leaf count for willow grown in the East Gore 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	260.56	12	422.53	2.4667	0.1122

Table 8.11.2 Treatment effects on leaf count for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf count	Groups
Paper sludge	30.2	a
Anaerobic digestate	24.3	a
Control	21.3	a
A. nodosum extract	19.5	a

Table 8.11.3 ANOVA: Treatment effects on leaf count for willow grown in the Skye Glen 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	331.43	12	424.34	3.1242	0.066

Table 8.11.4 Treatment effects on leaf count for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf count	Groups
Paper sludge	67.4	a
Anaerobic digestate	65.5	a
Control	64.4	a
A. nodosum extract	55.5	a

8.12. Willow leaf area (per tallest stem; August 2020)

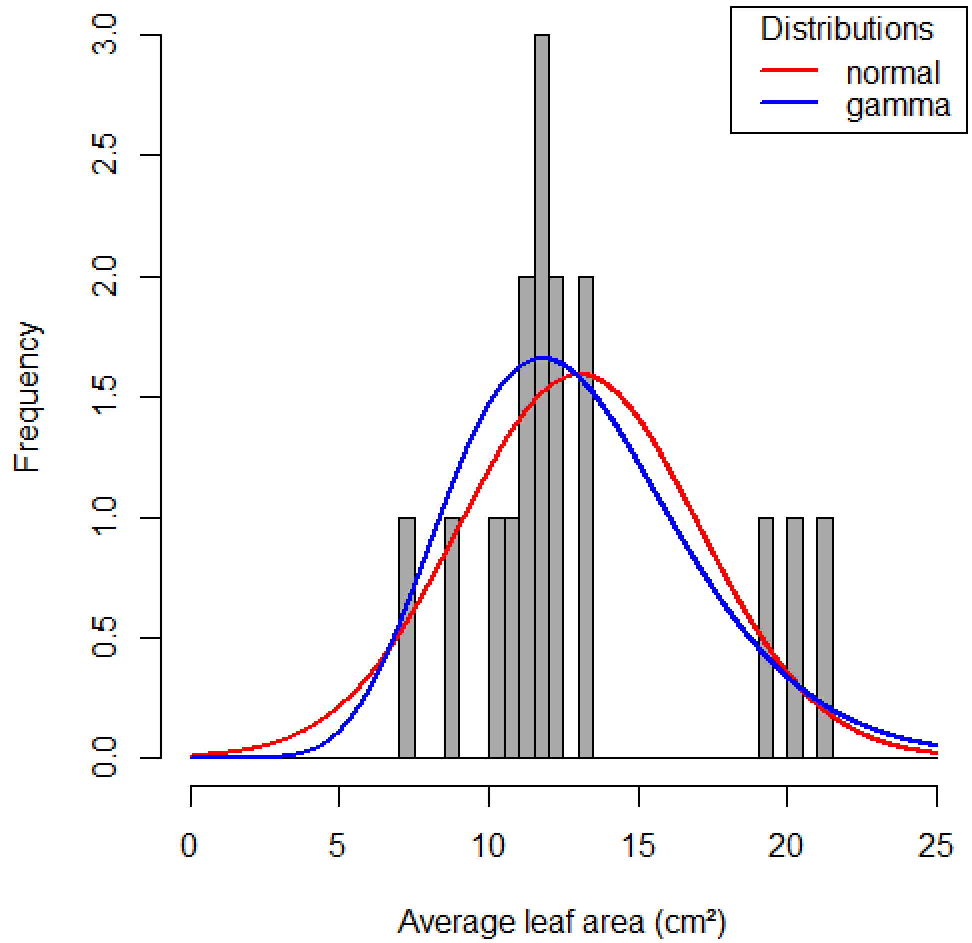

Figure 8.12.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow leaf area from the Skye Glen site.

Table 8.12.1 ANOVA: Treatment effects on leaf area (cm^2) for willow grown in the Skye Glen 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	0.8860	12	0.3947	10.275	0.0012 **

Table 8.12.2 Tukey's test: Treatment effects on leaf area (cm^2) for willow grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	-0.0890	0.1199	-0.742	0.8799

PS – CT	0.3685	0.1199	3.074	0.0112 *
SE – CT	-0.2636	0.1199	-2.199	0.1235

Table 8.12.2 Treatment effects on leaf area (cm^2) for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. leaf area (cm^2)	Groups
Paper sludge	18.3	a
Control	12.6	b
Anaerobic digestate	11.6	b
A. nodosum extract	9.7	b

8.13. Willow stem count (August 2020)

Table 8.13.1 ANOVA: Treatment effects on stem count for willow grown in the East Gore 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	9.785	12	14.545	2.691	0.0932

Table 8.13.2 Treatment effects on stem count for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. stem count	Groups
Paper sludge	5.68	a
Anaerobic digestate	4.50	a
A. nodosum extract	3.78	a
Control	3.75	a

Table 8.13.3 ANOVA: Treatment effects on stem count for willow grown in the Skye Glen 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	38.808	12	24.490	6.3385	0.0080 **

Table 8.13.4 Tukey's test: Treatment effects on stem count for willow grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	-0.75	1.01	-0.742	0.8799

PS – CT	2.50	1.01	2.475	0.0639
SE – CT	-1.70	1.01	-1.683	0.3327

Table 8.13.5 Treatment effects on stem count for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. stem count	Groups
Paper sludge	9.33	a
Control	6.83	ab
Anaerobic digestate	6.08	b
A. nodosum extract	5.13	b

8.14. Willow average stem length (August 2020)

Table 8.14.1 ANOVA: Treatment effects on average stem length (cm) for willow grown in the East Gore 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	432.91	12	736.21	2.3521	0.1236

Table 8.14.2 Treatment effects on average stem length (cm) for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. stem length (cm)	Groups
Paper sludge	27.5	a
Anaerobic digestate	19.9	a
Control	15.2	a
A. nodosum extract	14.4	a

Table 8.14.3 ANOVA: Treatment effects on average stem length (cm) for willow grown in the Skye Glen 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	561.1	12	459.49	4.8846	0.0191 *

Table 8.14.4 Tukey's test: Treatment effects on average stem length (cm) for willow grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	7.825	4.376	1.788	0.2789

PS – CT	12.225	4.376	2.794	0.0265 *
SE – CT	-2.525	4.376	-0.577	0.9390

Table 8.14.5 Treatment effects on average stem length (cm) for willow grown in the Skye Glen 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	99.3	a
Anaerobic digestate	94.9	ab
Control	87.0	b
A. nodosum extract	84.5	b

8.15. Willow total stem length (August 2020)

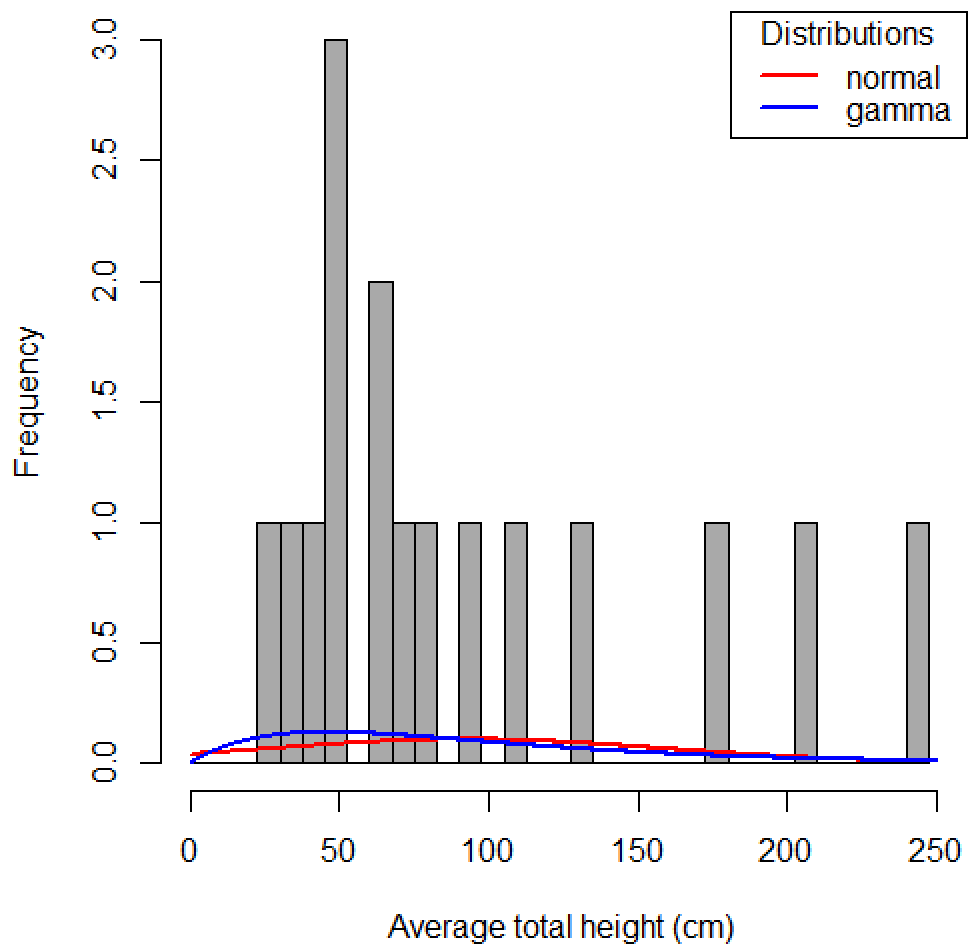

Figure 8.15.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of total willow stem length (cm) from the East Gore site.

Table 8.15.1 ANOVA: Treatment effects on total stem length (cm) for willow grown in the East Gore 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	3.1004	12	3.5739	3.4851	0.0502

Table 8.15.2 Tukey's test: Treatment effects on total stem length (cm) for willow grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	0.5863	0.3851	1.523	0.4239
PS – CT	1.0072	0.3851	2.616	0.0438 *
SE – CT	-0.0435	0.3851	-0.113	0.9995

Table 8.15.3 Treatment effects on total stem length (cm) for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	156.00	a
Anaerobic digestate	102.40	ab
Control	57.98	b
A. nodosum extract	54.55	b

Table 8.15.4 ANOVA: Treatment effects on total stem length (cm) for willow grown in the Skye Glen 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	539438	12	268369	8.0403	0.0033 **

Table 8.15.5 Tukey's test: Treatment effects on total stem length (cm) for willow grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	-11.27	105.75	-0.107	0.9996
PS – CT	341.85	105.75	3.233	0.0068 **
SE – CT	-158.87	105.75	-1.502	0.4360

Table 8.15.6 Treatment effects on total stem length (cm) for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	931.18	a
Control	589.33	b
Anaerobic digestate	578.05	b
A. nodosum extract	430.45	b

8.16. Miscanthus tiller count (August 2020)

Table 8.16.1 ANOVA: Treatment effects on tiller count for Miscanthus grown in the East Gore 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	49.68	12	85.18	2.333	0.126

Table 8.16.2 Treatment effects on tiller count for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. tiller count	Groups
Paper sludge	12.78	a
Anaerobic digestate	11.65	a
Control	9.15	a
A. nodosum extract	8.48	a

Table 8.16.3 ANOVA: Treatment effects on tiller count for Miscanthus grown in the Skye Glen 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	31.52	12	99.30	1.27	0.329

Table 8.16.4 Treatment effects on tiller count for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. tiller count	Groups
Paper sludge	21.08	a
A. nodosum extract	18.78	a
Control	18.13	a
Anaerobic digestate	17.30	a

8.17. Miscanthus leaf length (per tallest tiller; August 2020)

Table 8.17.1 ANOVA: Treatment effects on leaf length (cm, per tallest stem) for Miscanthus grown in the East Gore 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	1941.1	12	1999.6	3.883	0.0376 *

Table 8.17.2 Tukey's test: Treatment effects on leaf length (cm, per tallest stem) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	23.800	9.128	2.607	0.0450 *
PS – CT	21.200	9.128	2.323	0.0930
SE – CT	1.125	9.128	0.123	0.9993

Table 8.17.3 Treatment effects on leaf length (cm; per tallest stem) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. leaf length (cm)	Groups
Anaerobic digestate	128.1	a
Paper sludge	125.5	ab
A. nodosum extract	105.4	ab
Control	104.3	b

Table 8.17.4 ANOVA: Treatment effects on leaf length (cm, per tallest stem) for Miscanthus grown in the Skye Glen 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	2976.7	12	2602.3	4.5755	0.0234 *

Table 8.17.5 Tukey's test: Treatment effects on leaf length (cm, per tallest stem) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	21.50	10.41	2.065	0.1647
PS – CT	38.33	10.41	3.681	0.0013 **
SE – CT	22.80	10.41	2.190	0.1259

Table 8.17.6 Treatment effects on leaf length (per tallest stem) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. leaf length (cm)	Groups
Paper sludge	225.7	a
A. nodosum extract	210.2	ab
Anaerobic digestate	208.9	ab
Control	187.4	b

8.18. Miscanthus leaf area (per tallest tiller; August 2020)

Table 8.18.1 ANOVA: Treatment effects on leaf area (cm^2, per tallest stem) for Miscanthus grown in the East Gore 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	474.02	12	526.51	3.6012	0.0461 *

Table 8.18.2 Tukey's test: Treatment effects on leaf area (cm^2, per tallest stem) for Miscanthus grown in the East Gore 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	Standard error	Z-value	P-value
DG – CT	12.9233	4.6838	2.759	0.0295 *
PS – CT	8.8574	4.6838	1.891	0.2318
SE – CT	0.8134	4.6838	0.174	0.9981

Table 8.18.3 Treatment effects on leaf area (per tallest stem) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. area (cm^2)	Groups
Anaerobic digestate	67.4	a
Paper sludge	63.4	ab
A. nodosum extract	55.3	b
Control	54.5	b

Table 8.18.4 ANOVA: Treatment effects on leaf area (cm^2, per tallest stem) for Miscanthus grown in the Skye Glen 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	422.53	12	6.1255	5.1103	0.0091 **

Table 8.18.5 Tukey's test: Treatment effects on leaf area (cm^2, per tallest stem) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	11.2610	4.1959	2.684	0.0577
PS – CT	17.7596	4.1959	4.233	< 0.001 ***
SE – CT	10.2825	4.1959	2.451	0.0699

Table 8.18.6 Treatment effects on leaf area (per tallest stem) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. area (cm^2)	Groups
Paper sludge	110.0	a
Anaerobic digestate	103.5	a
A. nodosum extract	102.5	ab
Control	92.3	b

8.19. Miscanthus total leaf area (per tallest tiller; August 2020)

Table 8.19.1 ANOVA: Treatment effects on total leaf area (cm^2, per tallest stem) for Miscanthus grown in the East Gore 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	22915	12	85729	1.069	0.399

Table 8.19.2 Treatment effects on total leaf area (cm^2, per tallest stem) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total area (cm^2)	Groups
Anaerobic digestate	424.25	a
Paper sludge	393.50	a
A. nodosum extract	340.92	a
Control	332.35	a

Table 8.19.3 ANOVA: Treatment effects on total leaf area (cm^2, per tallest stem) for Miscanthus grown in the Skye Glen 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	72986	12	28576	10.216	0.0013 **

Table 8.19.4 Tukey's test: Treatment effects on total leaf area (cm^2, per tallest stem) for Miscanthus grown in the Skye Glen 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	Standard error	Z-value	P-value
DG – CT	134.670	34.506	3.903	< 1e-3 ***
PS – CT	127.873	34.506	3.706	0.0012 **
SE – CT	182.278	34.506	5.283	< 1e-3 ***

Table 8.19.5 Treatment effects on total leaf area (cm^2, per tallest stem) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total area (cm^2)	Groups
Paper sludge	868.88	a
Anaerobic digestate	821.27	a
A. nodosum extract	814.47	a
Control	686.60	b

8.20. Soil compositional analysis (August 2020)

Table 8.20.1 ANOVA: Treatment effects on soil pH from the East Gore 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	4	0.00438	15	0.22887	0.0718	0.9896

Table 8.20.2 Treatment effects on soil pH from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. pH	Groups
Control	6.5050	a
Paper mill sludge	6.4825	a
Single app. anaerobic digestate	6.4750	a
Dual app. anaerobic digestate	6.4650	a
Ascophyllum nodosum extract	6.4650	a

Table 8.20.3 ANOVA: Treatment effects on soil pH from the Skye Glen 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	4	0.0777	15	0.3318	0.8785	0.4999

Table 8.20.4 Treatment effects on soil pH from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. pH	Groups
Dual app. anaerobic digestate	5.8625	a
Single app. anaerobic digestate	5.8025	a
Control	5.7275	a
Paper mill sludge	5.7075	a
Ascophyllum nodosum extract	5.7025	a

Table 8.20.5 ANOVA: Treatment effects on soil buffer pH from the East Gore 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	4	0.0016	15	0.0273	0.2155	0.9257

Table 8.20.6 Treatment effects on soil buffer pH from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Buffer pH	Groups
Control	7.7475	a
Dual app. anaerobic digestate	7.7475	a
Single app. anaerobic digestate	7.7450	a
Paper mill sludge	7.7300	a
Ascophyllum nodosum extract	7.7275	a

Table 8.20.7 ANOVA: Treatment effects on soil buffer pH from the Skye Glen 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	4	0.0088	15	0.0882	0.3753	0.8227

Table 8.20.8 Treatment effects on soil buffer pH from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Buffer pH	Groups
Ascophyllum nodosum extract	7.8125	a
Dual app. anaerobic digestate	7.8025	a
Single app. anaerobic digestate	7.7800	a
Control	7.7625	a
Paper mill sludge	7.7600	a

Table 8.20.9 ANOVA: Treatment effects on soil organic matter concentration (%) from the East Gore 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	4	0.085	15	0.9325	0.3418	0.8455

Table 8.20.10 Treatment effects on soil organic matter concentration (%) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Organic matter (%)	Groups
Single app. anaerobic digestate	6.450	a
Paper mill sludge	6.325	a
Dual app. anaerobic digestate	6.300	a
Control	6.275	a
Ascophyllum nodosum extract	6.275	a

Table 8.20.11 ANOVA: Treatment effects on soil organic matter concentration (%) from the Skye Glen 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	4	0.507	15	1.805	1.0533	0.4131

Table 8.20.12 Treatment effects on soil organic matter concentration (%) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Organic matter (%)	Groups
Control	3.175	a
Single app. anaerobic digestate	2.950	a
Dual app. anaerobic digestate	2.900	a
Paper mill sludge	2.900	a
Ascophyllum nodosum extract	2.675	a

Table 8.20.13 ANOVA: Treatment effects on soil nitrogen concentration (%) from the East Gore 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	4	0.0004	15	0.0043	0.3208	0.8596

Table 8.20.14 Treatment effects on soil nitrogen concentration (%) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Paper mill sludge	0.3250	a
Dual app. anaerobic digestate	0.3225	a
Single app. anaerobic digestate	0.3200	a
Ascophyllum nodosum extract	0.3175	a
Control	0.3125	a

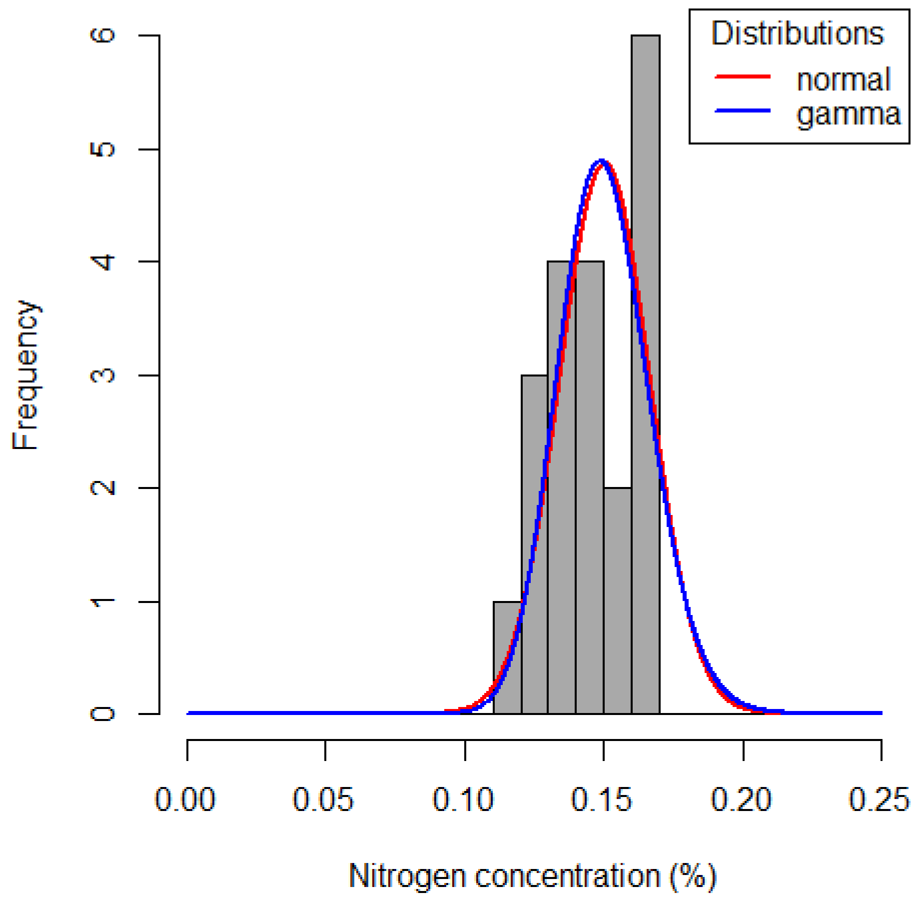

Figure 20.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil nitrogen concentration (%) from the Skye Glen site.

Table 8.20.15 ANOVA: Treatment effects on soil nitrogen concentration (%) from the Skye Glen 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	4	0.0616	15	0.1683	1.369	0.2913

Table 8.20.16 Treatment effects on soil nitrogen concentration (%) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Control	0.1600	a
Single app. anaerobic digestate	0.1575	a
Paper mill sludge	0.1525	a
Dual app. anaerobic digestate	0.1450	a
Ascophyllum nodosum extract	0.1375	a

Table 8.20.17 ANOVA: Treatment effects on soil phosphate yield (kg/ha) from the East Gore 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	4	2224.3	15	9246.2	0.9021	0.4873

Table 8.20.18 Treatment effects on soil phosphate yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphate yield (kg/ha)	Groups
Dual app. anaerobic digestate	205.25	a
Single app. anaerobic digestate	204.75	a
Paper mill sludge	202.00	a
Control	199.25	a
Ascophyllum nodosum extract	177.00	a

Table 8.20.19 ANOVA: Treatment effects on soil phosphate yield (kg/ha) from the Skye Glen 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	4	265.3	15	747.5	1.3309	0.3038

Table 8.20.20 Treatment effects on soil phosphate yield (kg/ha) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphate yield (kg/ha)	Groups
Dual app. anaerobic digestate	50.50	a
Control	46.25	a
Paper mill sludge	42.75	a

Single app. anaerobic digestate	42.50	a
Ascophyllum nodosum extract	40.00	a

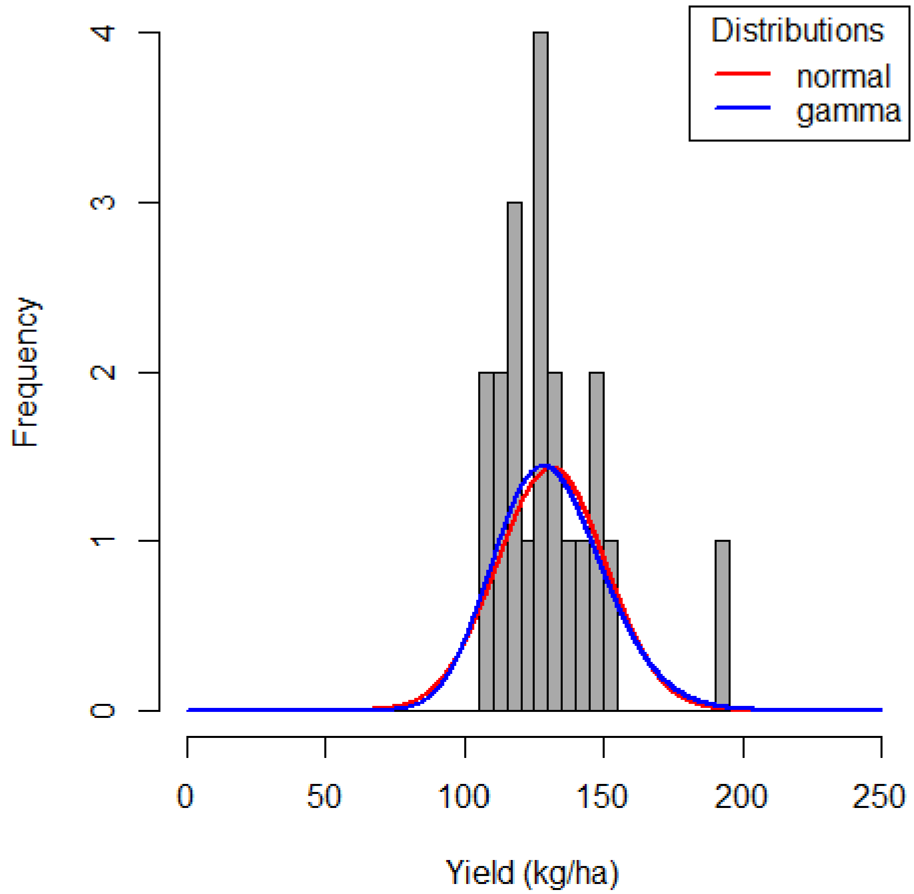

Figure 20.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil potash yield (kg/ha) from the East Gore site.

Table 8.20.21 ANOVA: Treatment effects on soil potash yield (kg/ha) from the East Gore 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	4	0.1596	15	0.2203	2.5359	0.0836

Table 8.20.22 Treatment effects on soil potash yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Potash yield (kg/ha)	Groups
Dual app. anaerobic digestate	145.00	a

Single app. anaerobic digestate	142.00	a
Paper mill sludge	131.50	a
Control	124.75	a
Ascophyllum nodosum extract	113.25	a

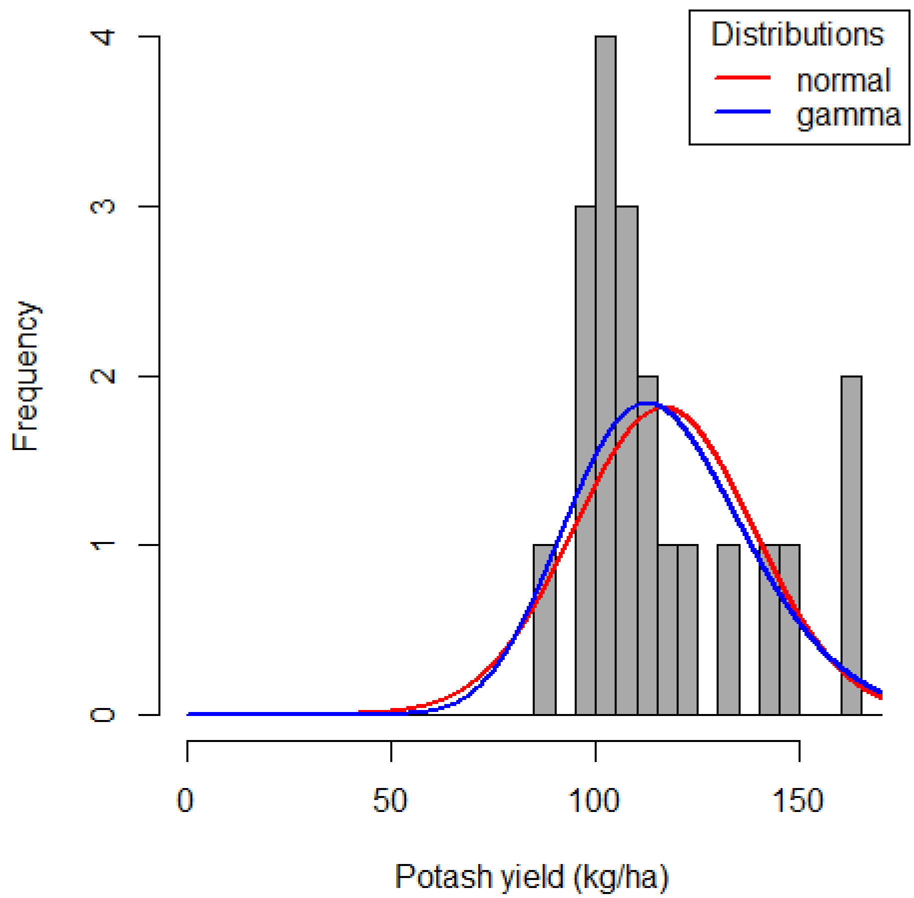

Figure 20.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil potash yield (kg/ha) from the Skye Glen site.

Table 8.20.23 ANOVA: Treatment effects on soil potash yield (kg/ha) from the Skye Glen 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	4	0.4373	15	0.1817	8.6298	0.0008 ***

Table 8.20.24 Tukey's test: Treatment effects on soil potash yield (kg/ha) from the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), seaweed extract (SE), and two application rates of anaerobic digestate (DG1/DG2).

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

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.1823	0.0796	2.291	0.1478
DG2 – CT	0.4341	0.0796	5.454	<0.001 ***
PS – CT	0.1023	0.0796	1.285	0.7005
SE – CT	0.1297	0.0796	1.629	0.4785

Table 8.20.25 Treatment effects on soil potash yield (kg/ha) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Potash yield (kg/ha)	Groups
Dual app. anaerobic digestate	150.5	a
Single app. anaerobic digestate	117.0	b
Ascophyllum nodosum extract	111.0	b
Paper mill sludge	108.0	b
Control	97.5	b

Table 8.20.26 ANOVA: Treatment effects on soil calcium yield (kg/ha) from the East Gore 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	4	157223	15	564842	1.0438	0.4174

Table 8.20.27 Treatment effects on soil calcium yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Calcium yield (kg/ha)	Groups
Single app. anaerobic digestate	3280.50	a
Control	3274.00	a
Paper mill sludge	3171.00	a
Ascophyllum nodosum extract	3087.75	a
Dual app. anaerobic digestate	3071.25	a

Table 8.20.28 ANOVA: Treatment effects on soil calcium yield (kg/ha) from the Skye Glen 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	4	216987	15	241949	3.3631	0.0374 *

Table 8.20.29 Tukey's test: Treatment effects on soil calcium yield (kg/ha) from the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), seaweed extract (SE), and two application rates of anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	45.50	89.81	0.507	0.9867
DG2 – CT	-160.00	89.81	-1.782	0.3843
PS – CT	-43.00	89.81	-0.479	0.9893
SE – CT	-236.00	89.81	-2.628	0.0654

Table 8.20.30 Treatment effects on soil calcium yield (kg/ha) from the Skye Glen 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
Single app. anaerobic digestate	2278.5	a
Control	2233.0	ab
Paper mill sludge	2190.0	ab
Dual app. anaerobic digestate	2073.0	ab
Ascophyllum nodosum extract	1997.0	b

Table 8.20.31 ANOVA: Treatment effects on soil magnesium yield (kg/ha) from the East Gore 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	4	278.3	15	1237.5	0.8433	0.5192

Table 8.20.32 Treatment effects on soil magnesium yield (kg/ha) from the East Gore 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
Dual app. anaerobic digestate	110.50	a
Single app. anaerobic digestate	109.75	a
Paper mill sludge	106.00	a
Control	103.75	a
Ascophyllum nodosum extract	100.50	a

Table 8.20.33 ANOVA: Treatment effects on soil magnesium yield (kg/ha) from the Skye Glen 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	4	7006.3	15	14472	1.8154	0.1784

Table 8.20.34 Treatment effects on soil magnesium yield (kg/ha) from the Skye Glen 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
Single app. anaerobic digestate	481.50	a
Paper mill sludge	463.50	a
Dual app. anaerobic digestate	451.25	a
Control	439.25	a
Ascophyllum nodosum extract	427.75	a

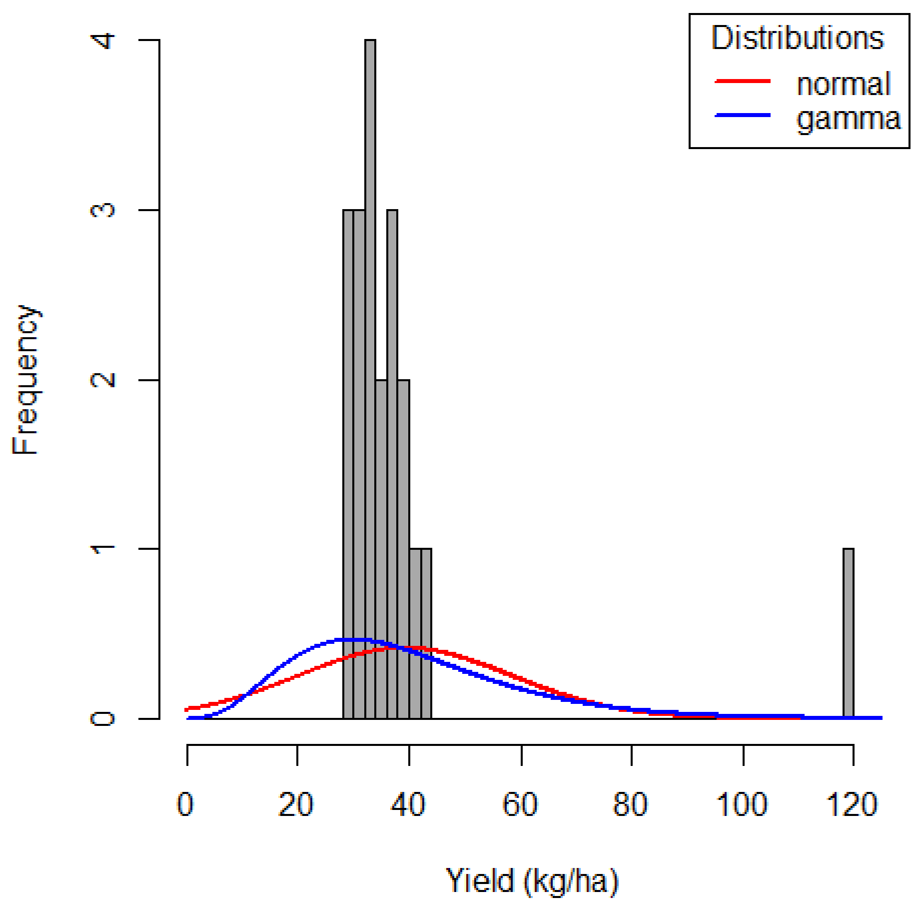

Figure 20.4 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil sodium yield (kg/ha) from the East Gore site.

Table 8.20.35 ANOVA: Treatment effects on soil sodium yield (kg/ha) from the East Gore 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	4	0.9309	15	1.4041	1.9863	0.1484

Table 8.20.36 Treatment effects on soil sodium yield (kg/ha) from the East Gore 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
Dual app. anaerobic digestate	57.25	a
Single app. anaerobic digestate	37.50	a
Paper mill sludge	35.25	a
Ascophyllum nodosum extract	33.50	a
Control	32.50	a

Table 8.20.35 ANOVA: Treatment effects on soil sodium yield (kg/ha) from the Skye Glen 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	4	0.5412	15	0.2809	7.4513	0.0016 **

Table 8.20.36 Tukey's test: Treatment effects on soil sodium yield (kg/ha) from the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), seaweed extract (SE), and two application rates of anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.1065	0.0953	1.118	0.7972
DG2 – CT	0.3872	0.0953	4.064	<0.001 ***
PS – CT	0.0268	0.0953	0.281	0.9986
SE – CT	-0.0765	0.0953	-0.803	0.9298

Table 8.20.37 Treatment effects on soil sodium yield (kg/ha) from the Skye Glen 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
Dual app. anaerobic digestate	95.00	a
Single app. anaerobic digestate	71.75	b
Paper mill sludge	66.25	b
Control	64.50	b

Ascophyllum nodosum extract	59.75	b

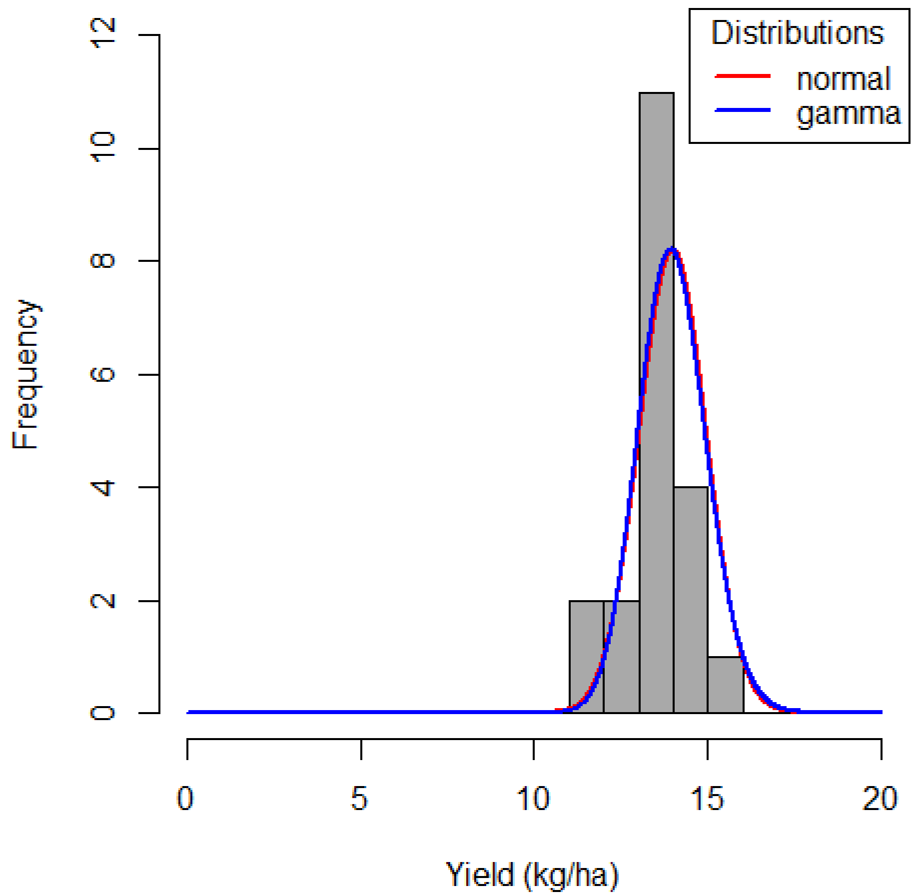

Figure 20.5 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil sulfur yield (kg/ha) from the East Gore site.

Table 8.20.38 ANOVA: Treatment effects on soil sulfur yield (kg/ha) from the East Gore 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	4	0.0278	15	0.0662	1.6179	0.2213

Table 8.20.39 Treatment effects on soil sulfur yield (kg/ha) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sulfur yield (kg/ha)	Groups
Control	14.75	a
Single app. anaerobic digestate	14.50	a

Dual app. anaerobic digestate	13.75	a
Paper mill sludge	13.50	a
Ascophyllum nodosum extract	13.50	a

Table 8.20.40 ANOVA: Treatment effects on soil sulfur yield (kg/ha) from the Skye Glen 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	4	1	15	31	0.121	0.9728

Table 8.20.41 Treatment effects on soil sulfur yield (kg/ha) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Sulfur yield (kg/ha)	Groups
Paper mill sludge	9.25	a
Ascophyllum nodosum extract	9.25	a
Dual app. anaerobic digestate	9.00	a
Control	8.75	a
Single app. anaerobic digestate	8.75	a

Table 8.20.42 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the East Gore 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	4	6404.5	15	19615	1.2244	0.3419

Table 8.20.43 Treatment effects on soil aluminum concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Single app. anaerobic digestate	1057.00	a
Ascophyllum nodosum extract	1038.50	a
Control	1032.75	a
Dual app. anaerobic digestate	1022.75	a
Paper mill sludge	1002.75	a

Table 8.20.44 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Skye Glen 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	4	15198	15	62494	0.912	0.4821

Table 8.20.45 Treatment effects on soil aluminum concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Single app. anaerobic digestate	903.25	a
Ascophyllum nodosum extract	857.50	a
Dual app. anaerobic digestate	849.50	a
Control	832.25	a
Paper mill sludge	824.50	a

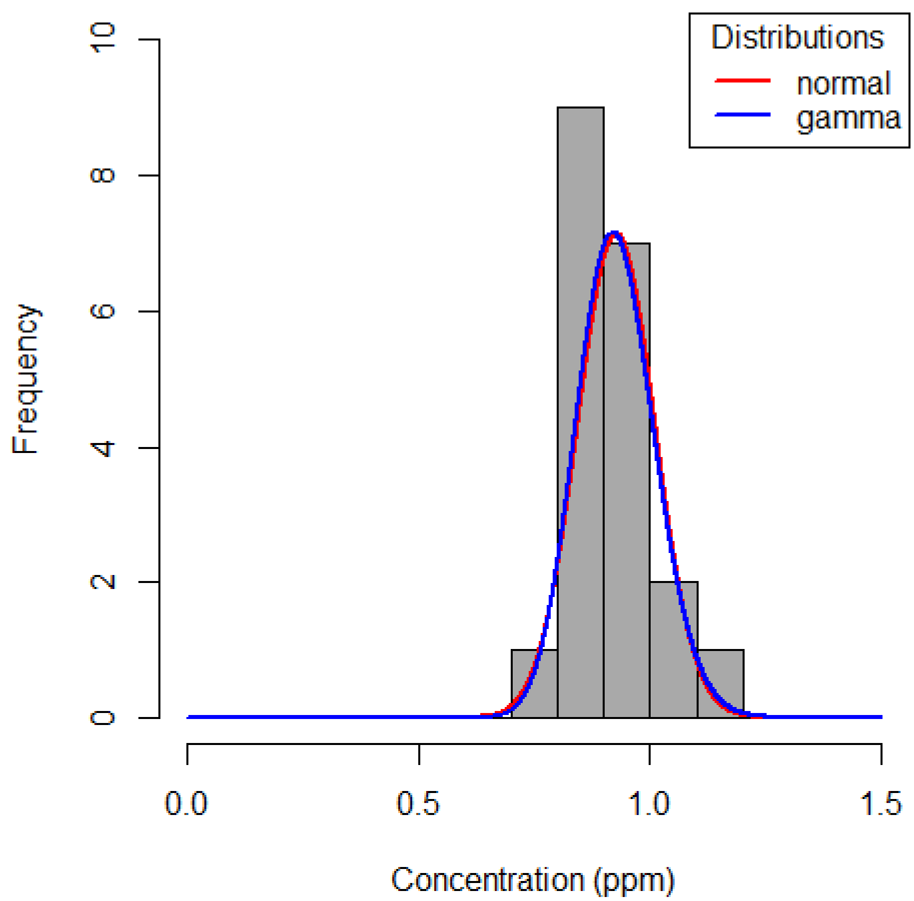

Figure 20.6 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil copper concentration (ppm) from the East Gore site.

Table 8.20.46 ANOVA: Treatment effects on soil copper concentration (ppm) from the East Gore 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	4	0.0277	15	0.1208	0.8269	0.5284

Table 8.20.47 Treatment effects on soil copper concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Single app. anaerobic digestate	0.9700	a
Control	0.9475	a
Dual app. anaerobic digestate	0.9450	a
Paper mill sludge	0.9025	a
Ascophyllum nodosum extract	0.8750	a

Table 8.20.48 ANOVA: Treatment effects on soil copper concentration (ppm) from the Skye Glen 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	4	0.0924	15	0.1380	2.5112	0.0858

Table 8.20.49 Treatment effects on soil copper concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Control	0.7525	a
Dual app. anaerobic digestate	0.7225	a
Single app. anaerobic digestate	0.6925	a
Ascophyllum nodosum extract	0.6250	a
Paper mill sludge	0.5650	a

Table 8.20.50 ANOVA: Treatment effects on soil iron concentration (ppm) from the East Gore 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	4	214.2	15	2128.0	0.3775	0.8212

Table 8.20.51 Treatment effects on soil iron concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Single app. anaerobic digestate	241.75	a

Paper mill sludge	240.25	a
Dual app. anaerobic digestate	237.50	a
Ascophyllum nodosum extract	236.75	a
Control	232.25	a

Table 8.20.52 ANOVA: Treatment effects on soil iron concentration (ppm) from the Skye Glen 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	4	2662.5	15	36715	0.2719	0.8915

Table 8.20.53 Treatment effects on soil iron concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Ascophyllum nodosum extract	264.75	a
Control	262.50	a
Single app. anaerobic digestate	260.25	a
Dual app. anaerobic digestate	242.00	a
Paper mill sludge	236.75	a

Table 8.20.54 ANOVA: Treatment effects on soil manganese concentration (ppm) from the East Gore 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	4	334	15	602	2.0806	0.1342

Table 8.20.55 Treatment effects on soil manganese concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Single app. anaerobic digestate	89.5	a
Control	84.0	a
Paper mill sludge	84.0	a
Dual app. anaerobic digestate	80.0	a
Ascophyllum nodosum extract	77.5	a

Table 8.20.54 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Skye Glen 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	4	879.3	15	10716	0.3077	0.8683

Table 8.20.55 Treatment effects on soil manganese concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Single app. anaerobic digestate	78.25	a
Paper mill sludge	72.75	a
Dual app. anaerobic digestate	70.50	a
Control	70.00	a
Ascophyllum nodosum extract	58.00	a

Table 8.20.56 ANOVA: Treatment effects on soil zinc concentration (ppm) from the East Gore 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	4	0.0163	15	0.4813	0.1266	0.9705

Table 8.20.57 Treatment effects on soil zinc concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups
Ascophyllum nodosum extract	1.0775	a
Single app. anaerobic digestate	1.0725	a
Dual app. anaerobic digestate	1.0500	a
Control	1.0200	a
Paper mill sludge	1.0050	a

Table 8.20.58 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Skye Glen 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	4	0.1264	15	0.2908	1.6302	0.2183

Table 8.20.59 Treatment effects on soil zinc concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups

Control	0.9100	a
Dual app. anaerobic digestate	0.8325	a
Single app. anaerobic digestate	0.8200	a
Ascophyllum nodosum extract	0.7775	a
Paper mill sludge	0.6675	a

8.21. Soil heavy metal concentrations (August 2020)

Table 8.21.1 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the East Gore 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	2	24351667	9	41285000	2.6543	0.1241

Table 8.21.2 Treatment effects on soil aluminum concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Dual app. anaerobic digestate	19825	a
Control	16950	a
Single app. anaerobic digestate	16675	a

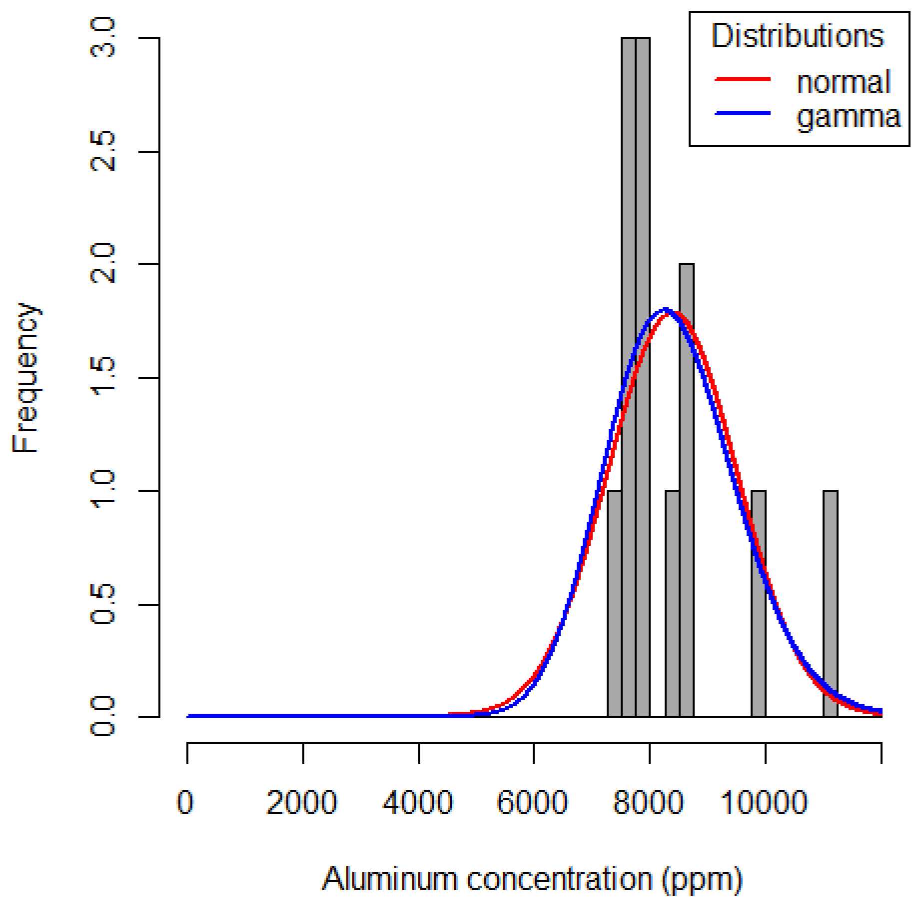

Figure 21.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil aluminum concentration (ppm) from the Skye Glen site.

Table 8.21.3 ANOVA: Treatment effects on soil aluminum concentration (ppm) from the Skye Glen 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	2	0.0380	9	0.1361	1.1801	0.3506

Table 8.21.4 Treatment effects on soil aluminum concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Aluminum conc. (ppm)	Groups
Dual app. anaerobic digestate	8952.5	a
Single app. anaerobic digestate	8425.0	a
Control	7800.0	a

Table 8.21.5 ANOVA: Treatment effects on soil arsenic concentration (ppm) from the East Gore 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	2	0.6667	9	22.250	0.1348	0.8756

Table 8.21.6 Treatment effects on soil arsenic concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc. (ppm)	Groups
Single app. anaerobic digestate	10.25	a
Control	9.75	a
Dual app. anaerobic digestate	9.75	a

Table 8.21.7 ANOVA: Treatment effects on soil arsenic concentration (ppm) from the Skye Glen 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	2	1.5	9	6.75	1	0.4053

Table 8.21.8 Treatment effects on soil arsenic concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Arsenic conc. (ppm)	Groups
Dual app. anaerobic digestate	5.75	a
Control	5.00	a
Single app. anaerobic digestate	5.00	a

Table 8.21.9 ANOVA: Treatment effects on soil barium concentration (ppm) from the East Gore 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	2	73.167	9	327.50	1.0053	0.4036

Table 8.21.10 Treatment effects on soil barium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc. (ppm)	Groups
Control	71.75	a

Single app. anaerobic digestate	67.25	a
Dual app. anaerobic digestate	66.00	a

Table 8.21.11 ANOVA: Treatment effects on soil barium concentration (ppm) from the Skye Glen 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	2	138.5	9	3585.5	0.1738	0.8432

Table 8.21.12 Treatment effects on soil barium concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Barium conc. (ppm)	Groups
Single app. anaerobic digestate	67.00	a
Dual app. anaerobic digestate	65.75	a
Control	59.25	a

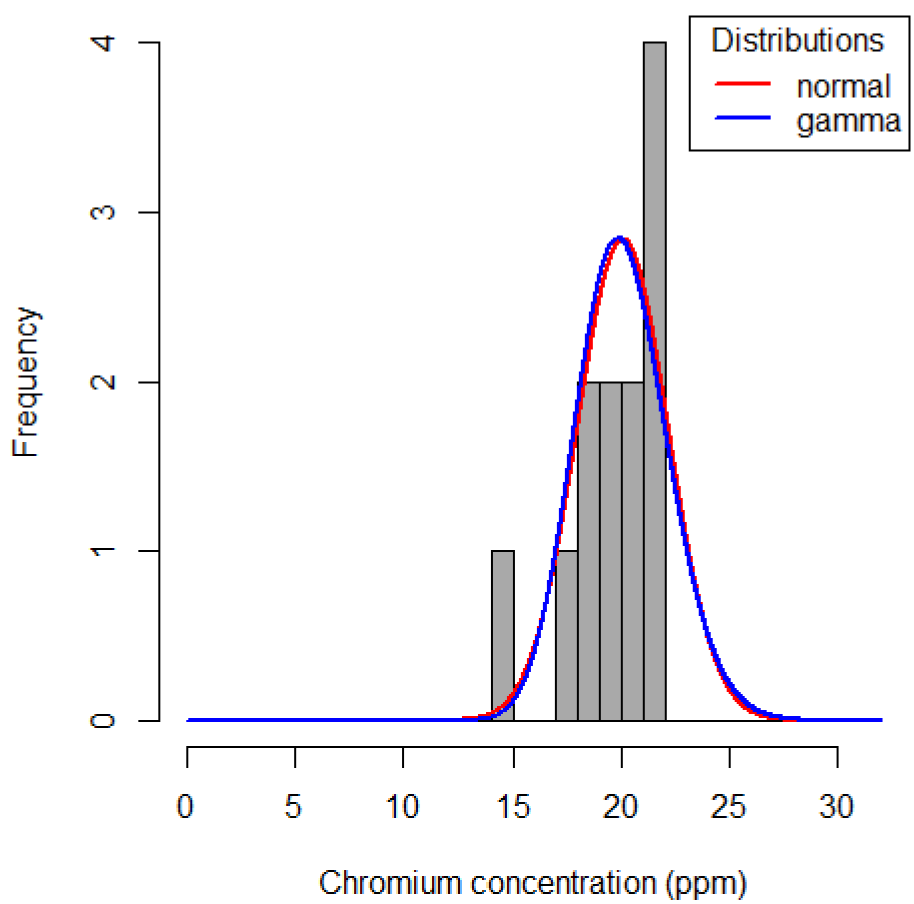

Figure 21.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil chromium concentration (ppm) from the East Gore site.

Table 8.21.13 ANOVA: Treatment effects on soil chromium concentration (ppm) from the East Gore 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	2	0.0054	9	0.1280	0.2047	0.8186

Table 8.21.14 Treatment effects on soil chromium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc. (ppm)	Groups
Control	20.50	a
Dual app. anaerobic digestate	20.25	a
Single app. anaerobic digestate	19.50	a

Table 8.21.15 ANOVA: Treatment effects on soil chromium concentration (ppm) from the Skye Glen 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	2	3.1667	9	25.750	0.5534	0.5934

Table 8.21.16 Treatment effects on soil chromium concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Chromium conc. (ppm)	Groups
Dual app. anaerobic digestate	11.25	a
Single app. anaerobic digestate	10.50	a
Control	10.00	a

Table 8.21.17 ANOVA: Treatment effects on soil cobalt concentration (ppm) from the East Gore 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	2	0.5	9	35.75	0.0629	0.9394

Table 8.21.18 Treatment effects on soil cobalt concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc. (ppm)	Groups
Dual app. anaerobic digestate	11.50	a
Control	11.25	a
Single app. anaerobic digestate	11.00	a

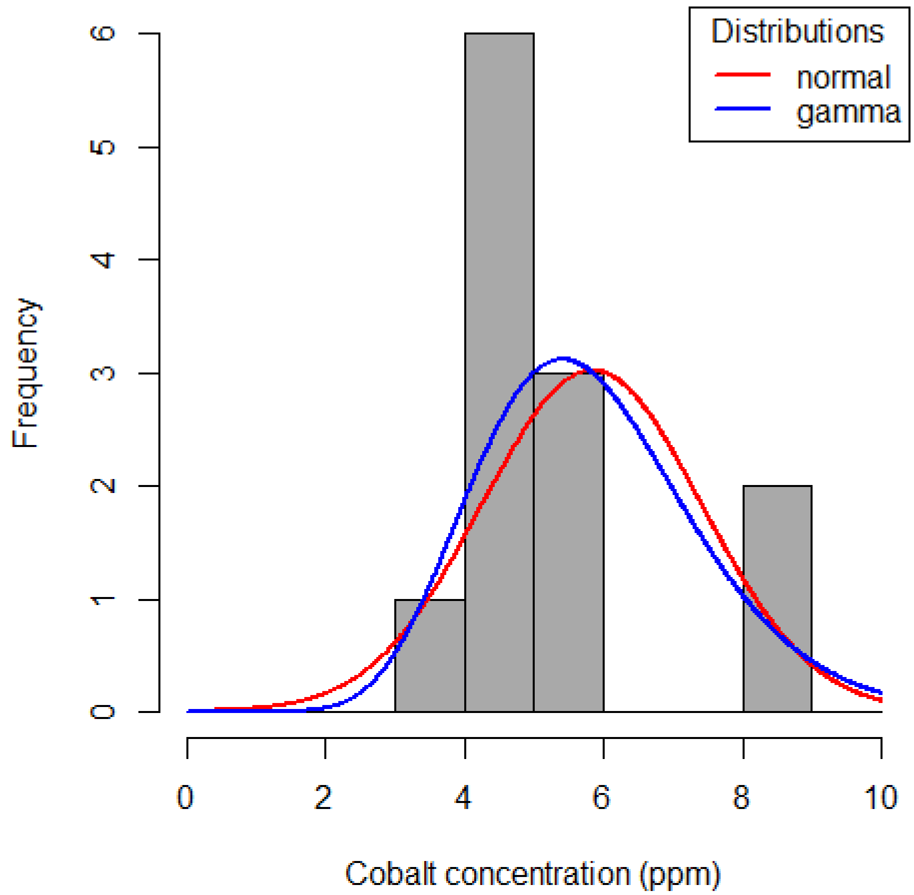

Figure 21.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil cobalt concentration (ppm) from the Skye Glen site.

Table 8.21.19 ANOVA: Treatment effects on soil cobalt concentration (ppm) from the Skye Glen 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	2	0.0656	9	0.6353	0.4269	0.6651

Table 8.21.20 Treatment effects on soil cobalt concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Cobalt conc. (ppm)	Groups
Dual app. anaerobic digestate	6.25	a
Single app. anaerobic digestate	6.00	a
Control	5.25	a

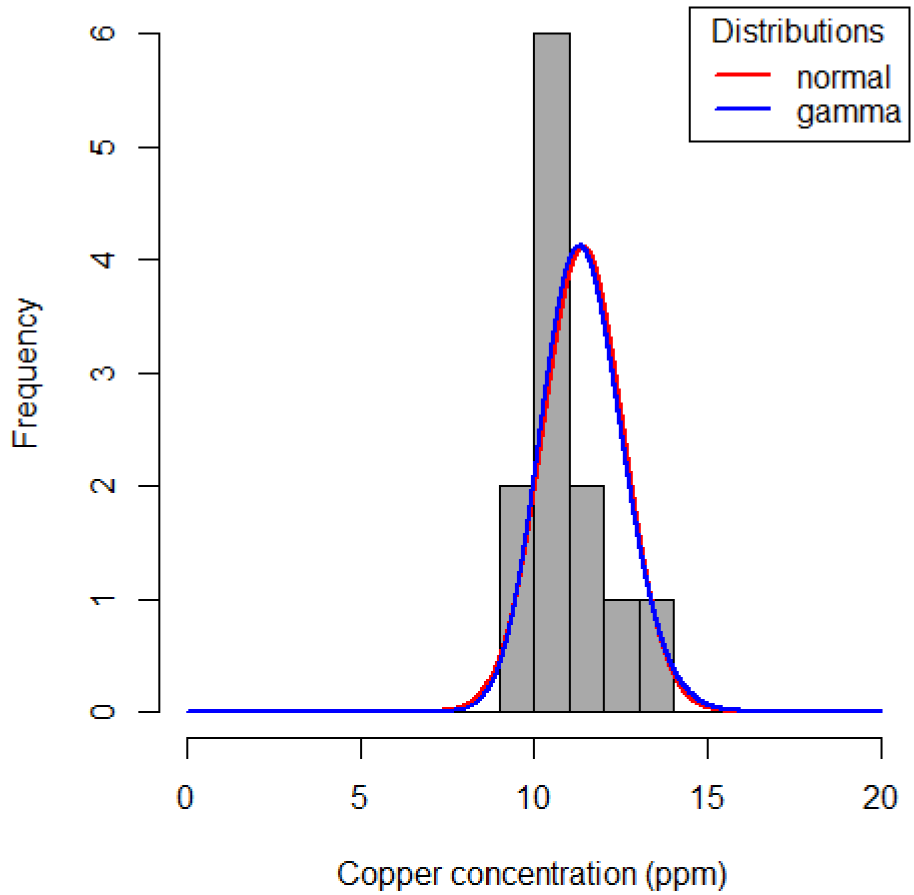

Figure 21.3 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil copper concentration (ppm) from the East Gore site.

Table 8.21.21 ANOVA: Treatment effects on soil copper concentration (ppm) from the East Gore 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	2	0.0051	9	0.1040	0.2134	0.8118

Table 8.21.22 Treatment effects on soil copper concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Dual app. anaerobic digestate	11.75	a
Control	11.25	a
Single app. anaerobic digestate	11.25	a

Table 8.21.23 ANOVA: Treatment effects on soil copper concentration (ppm) from the Skye Glen 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	2	1.1667	9	5.7500	0.913	0.4355

Table 8.21.24 Treatment effects on soil copper concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Copper conc. (ppm)	Groups
Single app. anaerobic digestate	5.00	a
Dual app. anaerobic digestate	4.50	a
Control	4.25	a

Table 8.21.25 ANOVA: Treatment effects on soil iron concentration (ppm) from the East Gore 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	2	34761667	9	61195000	2.5562	0.1321

Table 8.21.26 Treatment effects on soil iron concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Dual app. anaerobic digestate	28675	a
Single app. anaerobic digestate	25875	a
Control	24600	a

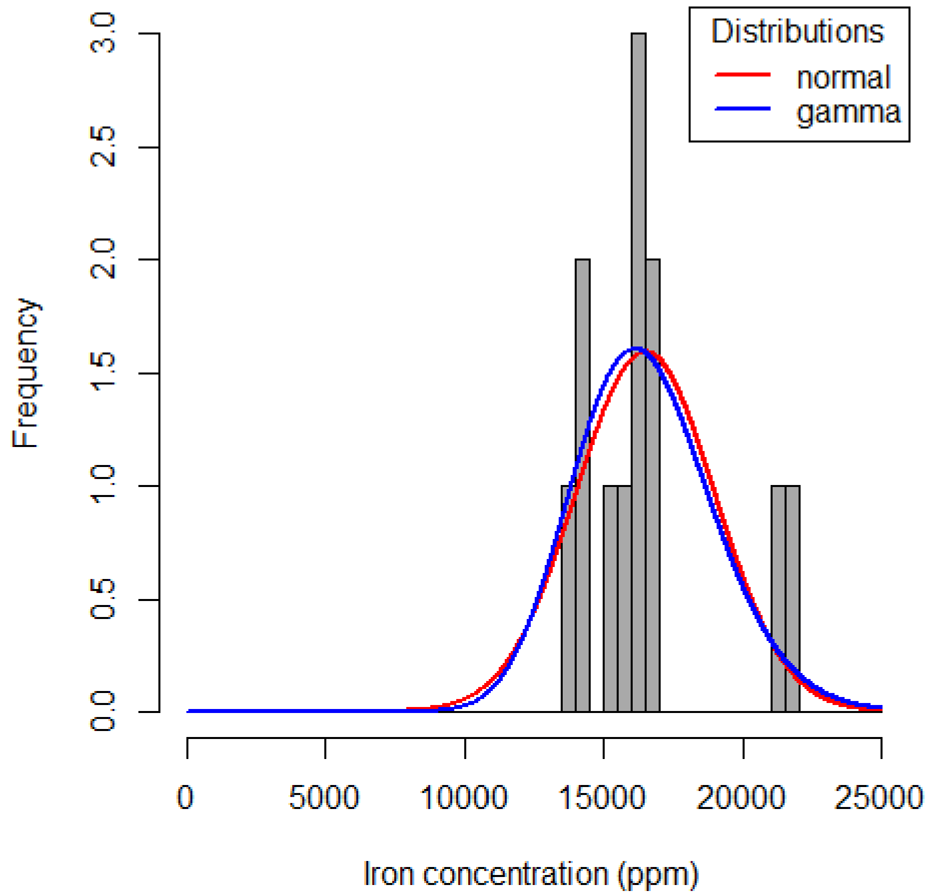

Figure 21.4 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil iron concentration (ppm) from the Skye Glen site.

Table 8.21.27 ANOVA: Treatment effects on soil iron concentration (ppm) from the Skye Glen 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	2	0.0412	9	0.1921	0.9025	0.4393

Table 8.21.28 Treatment effects on soil iron concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Dual app. anaerobic digestate	17625	a
Single app. anaerobic digestate	16625	a
Control	15275	a

Table 8.21.29 ANOVA: Treatment effects on soil lead concentration (ppm) from the East Gore 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	2	1.04	9	11.21	0.4175	0.6708

Table 8.21.30 Treatment effects on soil lead concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc. (ppm)	Groups
Single app. anaerobic digestate	15.65	a
Control	15.15	a
Dual app. anaerobic digestate	14.95	a

Table 8.21.31 ANOVA: Treatment effects on soil lead concentration (ppm) from the Skye Glen 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	2	7.4117	9	32.558	1.0244	0.3973

Table 8.21.32 Treatment effects on soil lead concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lead conc. (ppm)	Groups
Dual app. anaerobic digestate	11.025	a
Single app. anaerobic digestate	10.050	a
Control	9.100	a

Table 8.21.33 ANOVA: Treatment effects on soil lithium concentration (ppm) from the East Gore 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	2	16.667	9	386.25	0.1942	0.8269

Table 8.21.34 Treatment effects on soil lithium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc. (ppm)	Groups
Control	38.75	a
Dual app. anaerobic digestate	38.75	a

Single app. anaerobic digestate	36.25	a

Table 8.21.35 ANOVA: Treatment effects on soil lithium concentration (ppm) from the Skye Glen 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	2	19.5	9	54.75	1.6027	0.2539

Table 8.21.36 Treatment effects on soil lithium concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Lithium conc. (ppm)	Groups
Dual app. anaerobic digestate	17.50	a
Single app. anaerobic digestate	16.75	a
Control	14.50	a

Table 8.21.37 ANOVA: Treatment effects on soil manganese concentration (ppm) from the East Gore 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	2	139333	9	411972	1.5219	0.2696

Table 8.21.38 Treatment effects on soil manganese concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Dual app. anaerobic digestate	1530.00	a
Control	1312.50	a
Single app. anaerobic digestate	1291.75	a

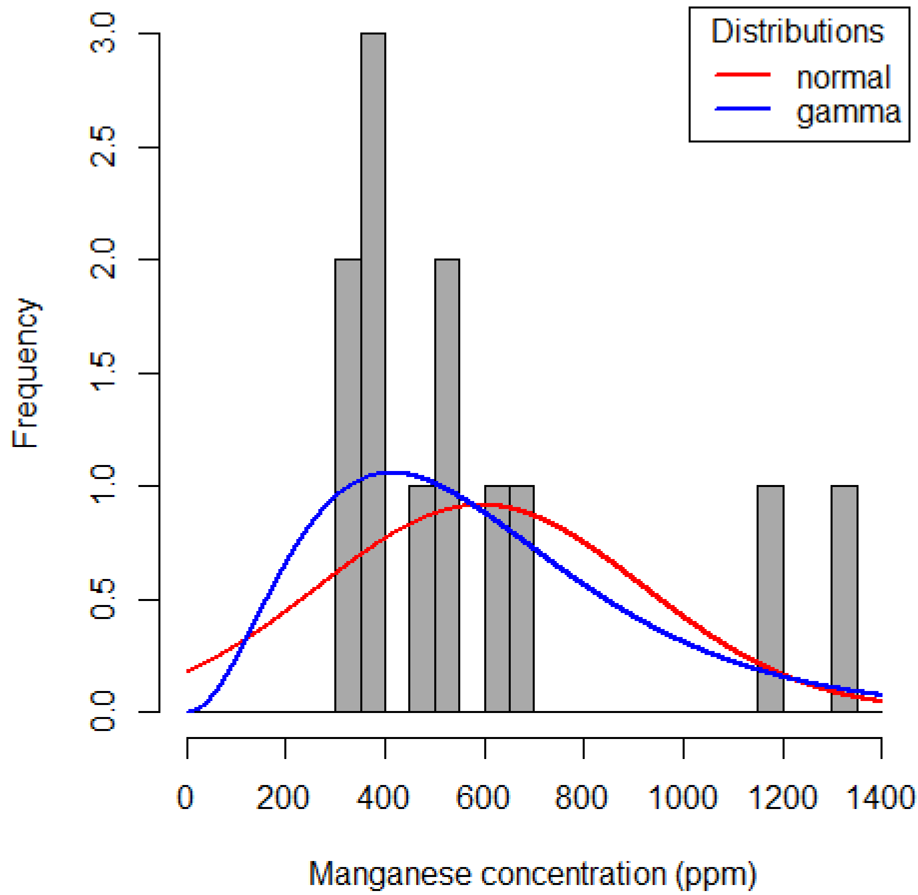

Figure 21.5 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil manganese concentration (ppm) from the Skye Glen site.

Table 8.21.39 ANOVA: Treatment effects on soil manganese concentration (ppm) from the Skye Glen 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	2	0.1113	9	2.5160	0.1709	0.8456

Table 8.21.40 Treatment effects on soil manganese concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Single app. anaerobic digestate	636.75	a
Dual app. anaerobic digestate	627.50	a

Control	514.25	a

Table 8.21.41 ANOVA: Treatment effects on soil nickel concentration (ppm) from the East Gore 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	2	2.1667	9	32.750	0.2977	0.7496

Table 8.21.42 Treatment effects on soil nickel concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc. (ppm)	Groups
Control	15.00	a
Dual app. anaerobic digestate	14.25	a
Single app. anaerobic digestate	14.00	a

Table 8.21.43 ANOVA: Treatment effects on soil nickel concentration (ppm) from the Skye Glen 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	2	5.1667	9	27.500	0.8455	0.4608

Table 8.21.44 Treatment effects on soil nickel concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nickel conc. (ppm)	Groups
Single app. anaerobic digestate	10.25	a
Dual app. anaerobic digestate	10.00	a
Control	8.75	a

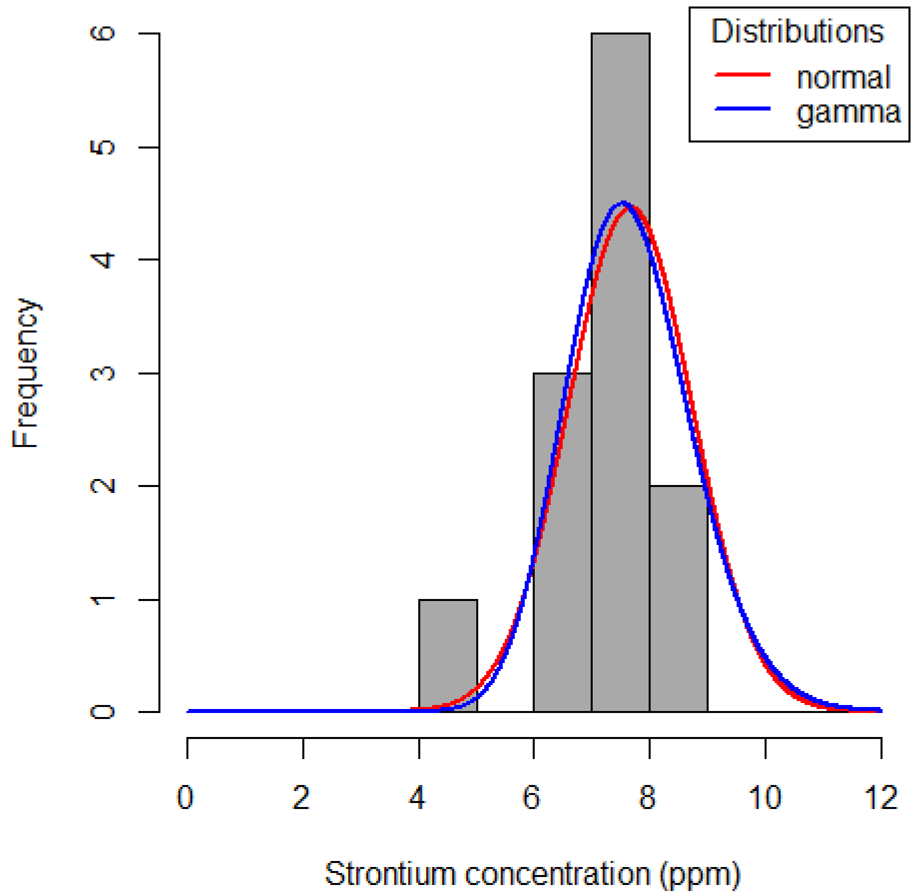

Figure 21.6 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil strontium concentration (ppm) from the East Gore site.

Table 8.21.45 ANOVA: Treatment effects on soil strontium concentration (ppm) from the East Gore 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	2	0.0201	9	0.2286	0.4398	0.6573

Table 8.21.46 Treatment effects on soil strontium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

Soil amendment	Avg. Strontium conc. (ppm)	Groups
Control	8.00	a
Dual app. anaerobic digestate	7.75	a
Single app. anaerobic digestate	7.25	a

Table 8.21.47 ANOVA: Treatment effects on soil uranium concentration (ppm) from the East Gore 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	2	0.005	9	0.175	0.1286	0.8809

Table 8.21.48 Treatment effects on soil uranium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Uranium conc. (ppm)	Groups
Single app. anaerobic digestate	1.225	a
Control	1.200	a
Dual app. anaerobic digestate	1.175	a

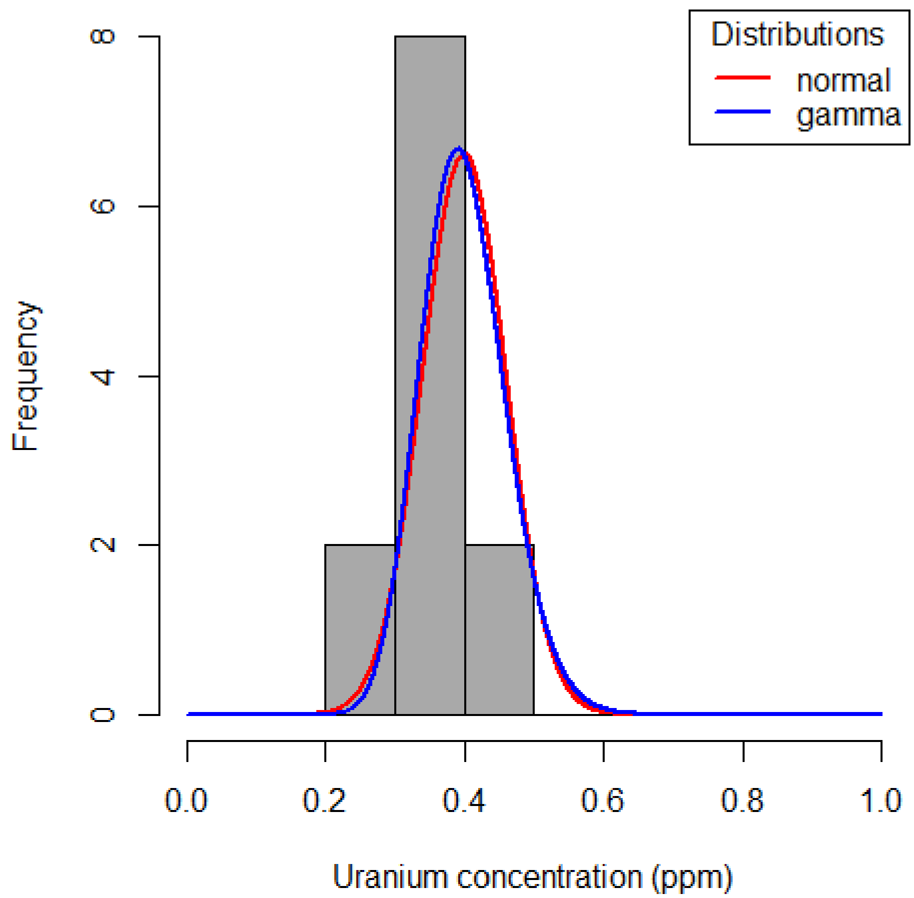

Figure 21.7 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of soil uranium concentration (ppm) from the Skye Glen site.

Table 8.21.49 ANOVA: Treatment effects on soil uranium concentration (ppm) from the Skye Glen 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	2	0.015	9	0.025	2.7	0.1206

Table 8.21.50 Treatment effects on soil uranium concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Uranium conc. (ppm)	Groups
Single app. anaerobic digestate	0.425	a
Dual app. anaerobic digestate	0.425	a
Control	0.350	a

Table 8.21.51 ANOVA: Treatment effects on soil vanadium concentration (ppm) from the East Gore 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	2	0.5	9	85.75	0.0262	0.9742

Table 8.21.52 Treatment effects on soil vanadium concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Vanadium conc. (ppm)	Groups
Dual app. anaerobic digestate	27.00	a
Control	26.75	a
Single app. anaerobic digestate	26.50	a

Table 8.21.53 ANOVA: Treatment effects on soil vanadium concentration (ppm) from the Skye Glen 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	2	10.5	9	35.75	1.3217	0.3139

Table 8.21.54 Treatment effects on soil vanadium concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Vanadium conc. (ppm)	Groups
Dual app. anaerobic digestate	20.00	a

Single app. anaerobic digestate	18.50	a
Control	17.75	a

Table 8.21.55 ANOVA: Treatment effects on soil zinc concentration (ppm) from the East Gore 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	2	8.1667	9	270.75	0.1357	0.8748

Table 8.21.56 Treatment effects on soil zinc concentration (ppm) from the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups
Dual app. anaerobic digestate	52.50	a
Control	51.75	a
Single app. anaerobic digestate	50.50	a

Table 8.21.57 ANOVA: Treatment effects on soil zinc concentration (ppm) from the Skye Glen 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	2	19.5	9	158.5	0.5536	0.5933

Table 8.21.58 Treatment effects on soil zinc concentration (ppm) from the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups
Dual app. anaerobic digestate	27.25	a
Single app. anaerobic digestate	26.50	a
Control	24.25	a

8.22. Switchgrass yield (fall 2020)

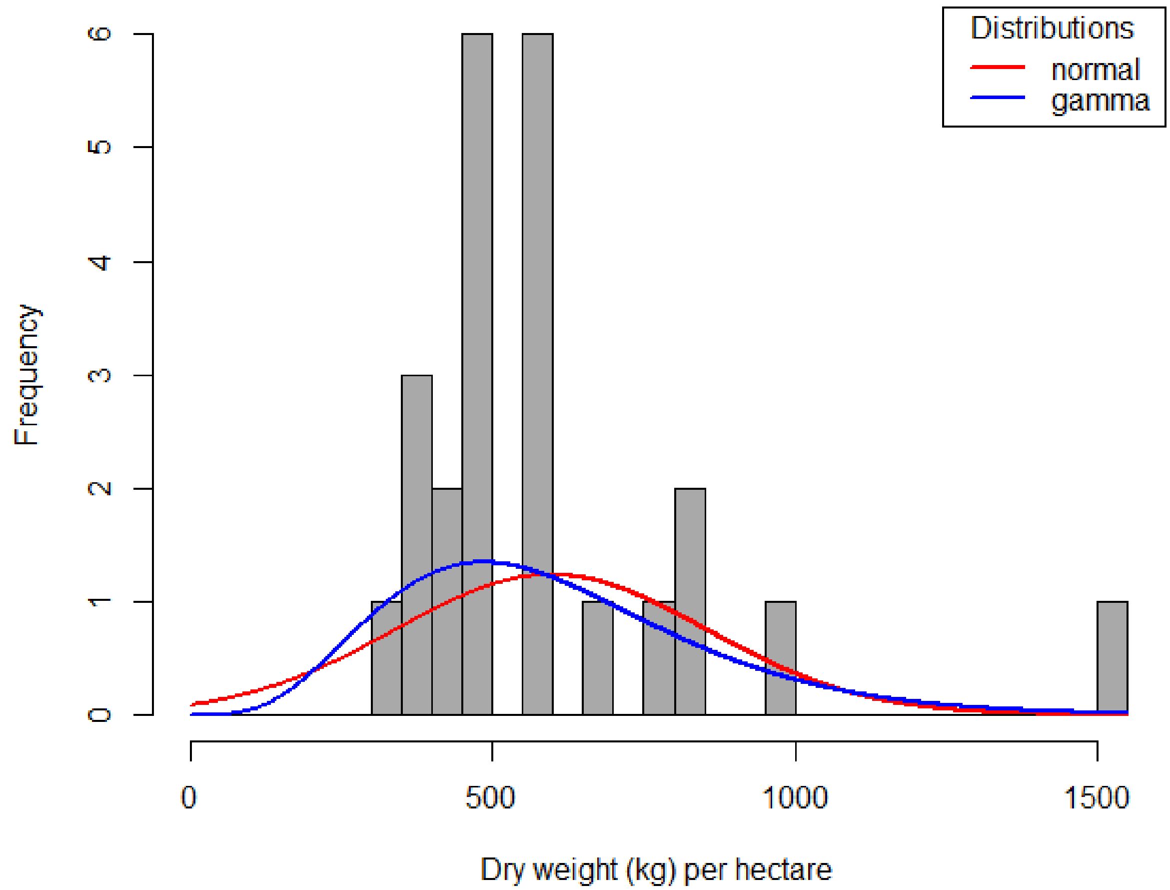

Figure 8.22.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of switchgrass yield (kg/ha) from the East Gore site.

Table 8.22.1 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the East Gore 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	1.7322	18	1.4570	4.0011	0.0129 *

Table 8.22.2 Tukey's test: Treatment effects on yield (kg/ha) for switchgrass grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.20129	0.2081	0.967	0.9283
DG2 – CT	0.58608	0.2081	2.817	0.0548
PS – CT	-0.19573	0.2081	-0.941	0.9360

SE1 – CT	-0.14912	0.2081	-0.717	0.9800
SE2 – CT	0.08913	0.2081	0.428	0.9982

Table 8.22.3 Treatment effects on yield (kg/ha) for switchgrass grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Dual app. anaerobic digestate	945.900	a
Single app. anaerobic digestate	643.775	ab
Dual app. *A. nodosum* extract	575.475	ab
Control	526.400	ab
Single app. *A. nodosum* extract	453.475	b
Paper sludge	432.825	b

Table 8.22.4 ANOVA: Treatment effects on yield (kg/ha) for switchgrass grown in the Skye Glen 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	155352	18	832955	0.671	0.65

Table 8.22.4 Treatment effects on yield (kg/ha) for switchgrass grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Dual app. *A. nodosum* extract	1154.000	a
Dual app. anaerobic digestate	1035.875	a
Single app. *A. nodosum* extract	1027.775	a
Control	979.775	a
Single app. anaerobic digestate	927.300	a
Paper sludge	912.800	a

8.23. Switchgrass moisture content (fall 2020)

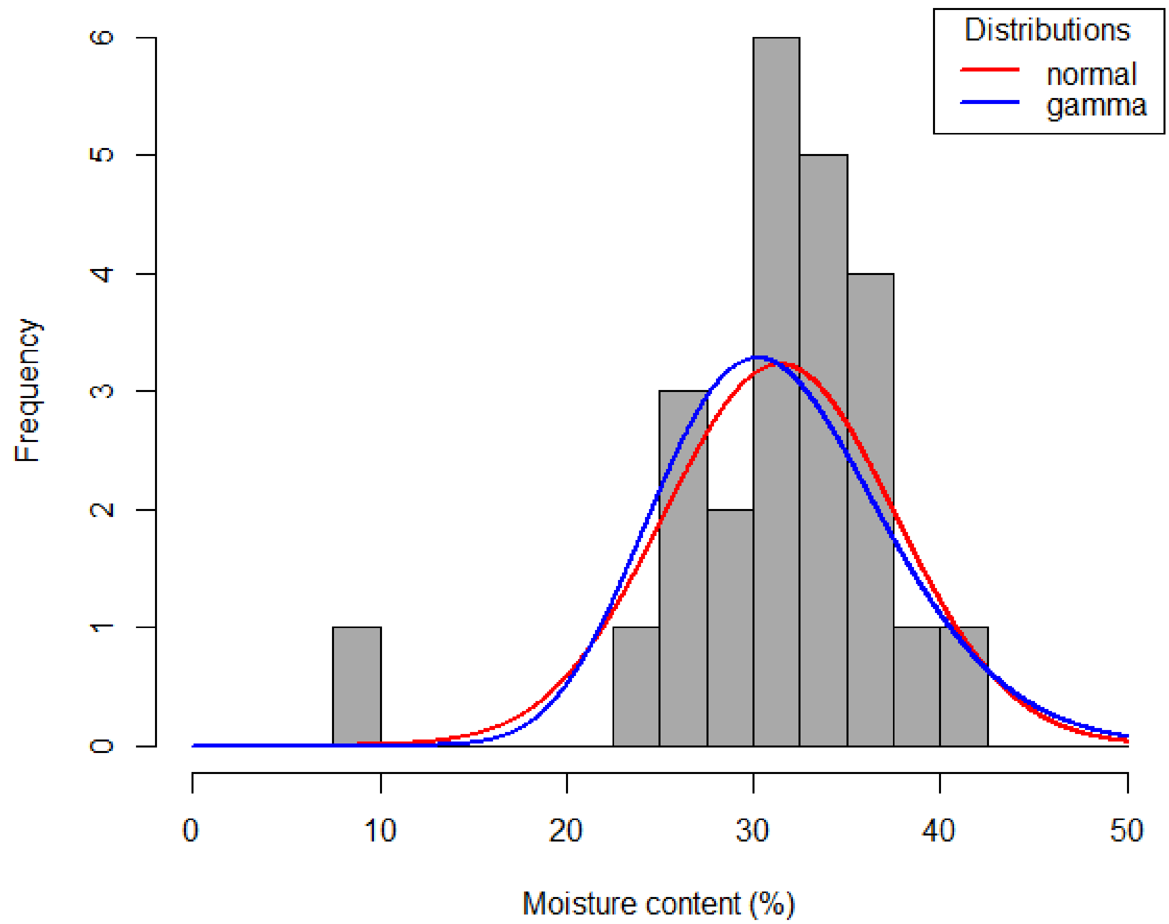

Figure 8.23.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of switchgrass moisture content (%) from the East Gore site.

Table 8.23.1 ANOVA: Treatment effects on percent moisture content for switchgrass grown in the East Gore 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	0.3352	18	1.0558	1.5728	0.218

Table 8.23.2 Treatment effects on moisture content (%) for switchgrass grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Dual app. anaerobic digestate	35.325	a
Single app. *A. nodosum* extract	34.750	a
Dual app. *A. nodosum* extract	33.850	a
Paper sludge	29.975	a

Single app. anaerobic digestate	29.600	a
Control	25.050	a

Table 8.23.3 ANOVA: Treatment effects on percent moisture content for switchgrass grown in the Skye Glen 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	108.75	18	574.24	0.6818	0.6431

Table 8.23.4 Treatment effects on moisture content (%) for switchgrass grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Paper sludge	31.175	a
Dual app. anaerobic digestate	30.375	a
Control	28.875	a
Dual app. *A. nodosum* extract	28.625	a
Single app. anaerobic digestate	27.875	a
Single app. *A. nodosum* extract	24.500	a

8.24. Miscanthus yield (fall 2020)

Table 8.24.1 ANOVA: Treatment effects on average yield (kg/ha) for Miscanthus grown in the East Gore 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	4966307	18	5652996	3.1627	0.0319 *

Table 8.24.2 Tukey's test: Treatment effects on average yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	773.35	396.27	1.952	0.3706
DG2 – CT	734.87	396.27	1.854	0.4306
PS – CT	631.05	396.27	1.592	0.6035
SE1 – CT	-350.78	396.27	-0.885	0.9502
SE2 – CT	-158.38	396.27	-0.400	0.9987

Table 8.24.3 Treatment effects on average yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. yield (kg/ha)	Groups
Single app. anaerobic digestate	1978.450	a
Dual app. anaerobic digestate	1939.975	a
Paper sludge	1836.150	a
Control	1205.100	a
Dual app. *A. nodosum* extract	1046.725	a
Single app. *A. nodosum* extract	854.325	a

Table 8.24.4 ANOVA: Treatment effects on average yield (kg/ha) for Miscanthus grown in the Skye Glen 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	48031702	18	70470696	2.454	0.0731

Table 8.24.5 Treatment effects on average dry weight (per hectare) for Miscanthus grown in the Skye Glen 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	11132.475	a
Single app. *A. nodosum* extract	10267.200	a
Dual app. anaerobic digestate	9126.425	a
Single app. anaerobic digestate	8102.700	a
Dual app. *A. nodosum* extract	7767.700	a
Control	7114.575	a

8.25. Miscanthus moisture content (fall 2020)

Table 8.25.1 ANOVA: Treatment effects on percent moisture content for Miscanthus grown in the East Gore 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	57.767	18	98.723	2.1065	0.1116

Table 8.25.2 Treatment effects on moisture content (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Dual app. anaerobic digestate	35.850	a

Single app. anaerobic digestate	35.375	a
Paper sludge	33.850	a
Control	33.475	a
Single app. *A. nodosum* extract	31.875	a
Dual app. *A. nodosum* extract	31.800	a

Table 8.25.3 ANOVA: Treatment effects on percent moisture content for Miscanthus grown in the Skye Glen 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	362.97	18	456.85	2.8602	0.0452 *

Table 8.25.4 Tukey's test: Treatment effects on percent moisture content for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-4.850	3.562	-1.361	0.7501
DG2 – CT	-3.700	3.562	-1.039	0.9050
PS – CT	-1.400	3.562	-0.393	0.9988
SE1 – CT	-10.800	3.562	-3.032	0.0293 *
SE2 – CT	0.875	3.562	0.246	0.9999

Table 8.25.5 Treatment effects on moisture content (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Moisture content (%)	Groups
Dual app. *A. nodosum* extract	41.450	a
Control	40.575	a
Paper sludge	39.175	ab
Dual app. anaerobic digestate	36.875	ab
Single app. anaerobic digestate	35.725	ab
Single app. *A. nodosum* extract	29.775	b

8.26. Miscanthus tissue nutrient concentrations (fall 2020)

Table 8.26.1. Chemical analysis of Miscanthus biomass grown in the East Gore site (2020).

	Mean nutrient concentration ± standard error							
Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)

Control	0.7 ± 0.03	0.6 ± 0.03	0.2 ± 0.01	0.1 ± 0.02	0.2 ± 0.02	24.65 ± 1.54	79.7 ± 12.42	29.0 ± 0.30
Anaerobic digestate 1	0.8 ± 0.06	0.5 ± 0.02	0.2 ± 0.01	0.1 ± 0.02	0.2 ± 0.02	22.68 ± 1.69	65.0 ± 18.71	33.7 ± 3.92
Anaerobic digestate 2	0.8 ± 0.07	0.5 ± 0.02	0.2 ± 0.01	0.1 ± 0.02	0.2 ± 0.02	24.54 ± 0.68	63.1 ± 12.81	26.3 ± 1.07
Paper mill sludge	0.6 ± 0.05	0.5 ± 0.06	0.1 ± 3e-3	0.1 ± 0.03	0.2 ± 0.02	20.11 ± 1.69	106.2 ± 30.13	29.7 ± 2.60
A. nodosum extract 1	0.8 ± 0.07	0.5 ± 0.02	0.2 ± 0.01	0.1 ± 0.02	0.2 ± 0.1	26.04 ± 2.57	66.1 ± 7.40	32.0 ± 2.20
A. nodosum extract 2	0.9 ± 0.06	0.6 ± 0.03	0.2 ± 0.02	0.1 ± 0.02	0.3 ± 0.02	28.97 ± 2.53	79.4 ± 5.44	34.3 ± 4.18

Table 8.26.2. Chemical analysis of Miscanthus biomass grown in the Skye Glen site (2020).

	Mean nutrient concentration ± standard error								
Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P (%)	Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Control	0.4 ± 0.02	0.2 ± 0.01	0.3 ± 0.08	0.1 ± 0.01	0.1 ± 0.01	0.02 ± 0.004	19.0 ± 1.96	112.2 ± 21.10	24.3 ± 1.58
Anaerobic digestate 1	0.4 ± 0.10	0.2 ± 0.04	0.4 ± 0.13	0.1 ± 0.01	0.1 ± 0.02	0.02 ± 0.008	18.5 ± 2.69	119.7 ± 14.23	26.6 ± 5.01
Anaerobic digestate 2	0.4 ± 0.02	0.2 ± 0.01	0.4 ± 0.03	0.1 ± 0.01	0.1 ± 0.01	0.02 ± 0.002	16.6 ± 1.27	90.8 ± 8.23	19.9 ± 2.52
Paper mill sludge	0.4 ± 0.02	0.2 ± 0.01	0.3 ± 0.02	0.1 ± 1e-3	0.1 ± 0.01	0.03 ± 0.004	19.0 ± 3.43	124.7 ± 25.05	20.6 ± 3.15
A. nodosum extract 1	0.4 ± 0.04	0.2 ± 0.01	0.3 ± 0.03	0.1 ± 4e-3	0.1 ± 0.01	0.02 ± 3e-4	18.1 ± 1.38	128.7 ± 36.24	22.7 ± 2.00
A. nodosum extract 2	0.6 ± 0.08	0.3 ± 0.04	0.4 ± 0.03	0.1 ± 0.03	0.1 ± 0.02	0.03 ± 0.001	28.6 ± 1.30	124.1 ± 19.87	24.7 ± 2.00

Table 8.26.3 ANOVA: Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the East Gore 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	0.1292	12	0.1195	2.5961	0.0816

Table 8.26.4 Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Dual app. *A. nodosum* extract	0.8767	a
Dual app. anaerobic digestate	0.7967	a
Single app. *A. nodosum* extract	0.7700	a

Single app. anaerobic digestate	0.7667	a
Control	0.6700	a
Paper mill sludge	0.6167	a

Table 8.26.5 ANOVA: Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Skye Glen 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	0.0948	12	0.1128	2.018	0.1481

Table 8.26.6 Treatment effects on average nitrogen concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Nitrogen conc. (%)	Groups
Dual app. *A. nodosum* extract	0.5867	a
Single app. anaerobic digestate	0.4400	a
Single app. *A. nodosum* extract	0.4200	a
Control	0.4133	a
Paper mill sludge	0.4000	a
Dual app. anaerobic digestate	0.3533	a

Table 8.26.7 ANOVA: Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the East Gore 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	0.0109	12	0.0134	1.9526	0.1588

Table 8.26.8 Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus conc. (%)	Groups
Dual app. *A. nodosum* extract	0.2723	a
Single app. *A. nodosum* extract	0.2433	a
Single app. anaerobic digestate	0.2423	a
Control	0.2280	a
Dual app. anaerobic digestate	0.2127	a
Paper mill sludge	0.1947	a

Table 8.26.9 ANOVA: Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the Skye Glen 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	0.0092	12	0.0065	3.3572	0.0397 *

Table 8.26.10 Tukey's test: Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.0060	0.0191	0.315	0.9996
DG2 – CT	-0.0100	0.0191	-0.524	0.9952
PS – CT	-0.0107	0.0191	-0.559	0.9935
SE1 – CT	0.0173	0.0191	0.909	0.9443
SE2 – CT	0.0553	0.0191	2.902	0.0432 *

Table 8.26.11 Treatment effects on average phosphorus concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus conc. (%)	Groups
Dual app. *A. nodosum* extract	0.1423	a
Single app. *A. nodosum* extract	0.1043	ab
Single app. anaerobic digestate	0.0930	ab
Control	0.0870	b
Dual app. anaerobic digestate	0.0770	b
Paper mill sludge	0.0763	b

Table 8.26.12 ANOVA: Treatment effects on average potassium concentration (%) for Miscanthus grown in the East Gore 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	0.0054	12	0.0066	1.965	0.1567

Table 8.26.13 Treatment effects on average potassium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potassium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.1820	a
Single app. anaerobic digestate	0.1777	a
Single app. *A. nodosum* extract	0.1573	a
Control	0.1547	a
Dual app. anaerobic digestate	0.1517	a

Paper mill sludge	0.1297	a

Table 8.26.14 ANOVA: Treatment effects on average potassium concentration (%) for Miscanthus grown in the Skye Glen 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	0.0166	12	0.1584	0.2514	0.9311

Table 8.26.15 Treatment effects on average potassium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Potassium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.3817	a
Single app. anaerobic digestate	0.3700	a
Dual app. anaerobic digestate	0.3577	a
Single app. *A. nodosum* extract	0.3183	a
Control	0.3077	a
Paper mill sludge	0.3073	a

Table 8.26.16 ANOVA: Treatment effects on average calcium concentration (%) for Miscanthus grown in the East Gore 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	0.0123	12	0.0388	0.7593	0.5958

Table 8.26.17 Treatment effects on average calcium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.5880	a
Control	0.5827	a
Single app. anaerobic digestate	0.5383	a
Single app. *A. nodosum* extract	0.5357	a
Paper mill sludge	0.5327	a
Dual app. anaerobic digestate	0.5193	a

Table 8.26.18 ANOVA: Treatment effects on average calcium concentration (%) for Miscanthus grown in the Skye Glen 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	0.0276	12	0.0206	3.2114	0.0454 *

Table 8.26.19 Tukey's test: Treatment effects on average calcium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-0.0113	0.0339	-0.335	0.9995
DG2 – CT	-0.0453	0.0339	-1.339	0.7635
PS – CT	-0.0067	0.0339	-0.197	1.0000
SE1 – CT	0.0007	0.0339	0.020	1.0000
SE2 – CT	0.0840	0.0339	2.480	0.1301

Table 8.26.20 Treatment effects on average calcium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Calcium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.3263	a
Single app. *A. nodosum* extract	0.2430	ab
Control	0.2423	ab
Paper mill sludge	0.2357	ab
Single app. anaerobic digestate	0.2310	ab
Dual app. anaerobic digestate	0.1970	b

Table 8.26.21 ANOVA: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the East Gore 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	0.0010	12	0.0162	0.1456	0.9776

Table 8.26.22 Treatment effects on average magnesium concentration (%) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.1417	a
Control	0.1380	a
Dual app. anaerobic digestate	0.1290	a
Single app. *A. nodosum* extract	0.1283	a
Single app. anaerobic digestate	0.1230	a
Paper mill sludge	0.1213	a

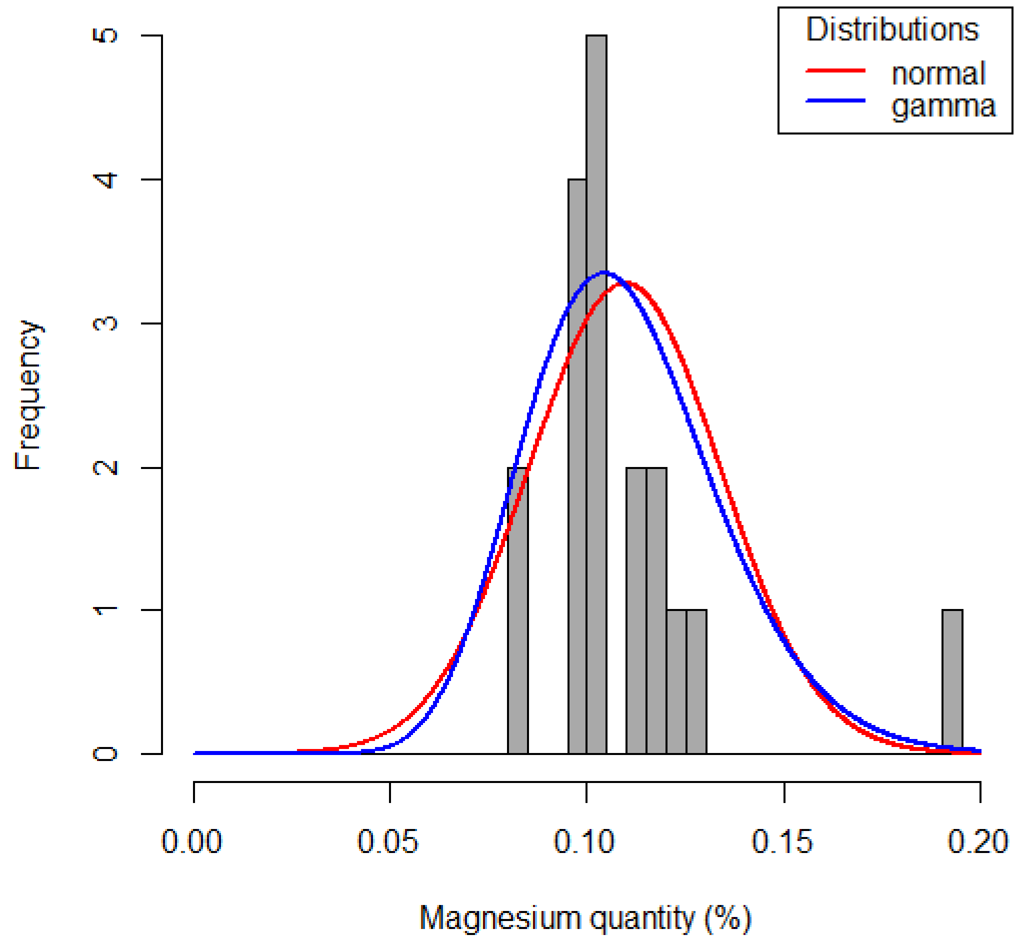

Figure 8.26.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus magnesium concentration (%) from the Skye Glen site.

Table 8.26.23 ANOVA: Treatment effects on average magnesium concentration (%) for Miscanthus grown in the Skye Glen 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	0.2641	12	0.4069	1.529	0.2528

Table 8.26.24 Treatment effects on average magnesium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Magnesium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.1373	a
Control	0.1137	a

Single app. anaerobic digestate	0.1070	a
Single app. *A. nodosum* extract	0.1067	a
Paper mill sludge	0.0977	a
Dual app. anaerobic digestate	0.0957	a

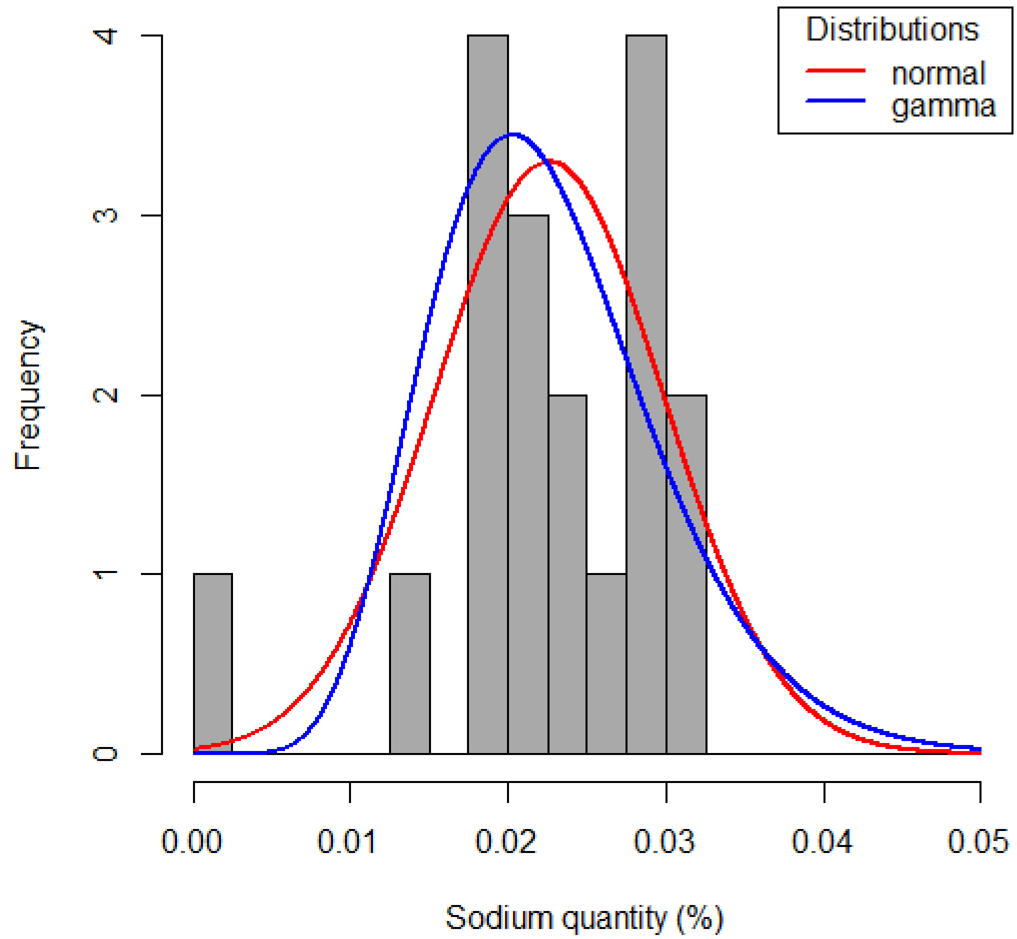

Figure 8.26.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus sodium concentration (%) from the Skye Glen site.

Table 8.26.25 ANOVA: Treatment effects on average sodium concentration (%) for Miscanthus grown in the Skye Glen 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	0.6565	12	4.4488	0.8254	0.5551

Table 8.26.26 Treatment effects on average sodium concentration (%) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Sodium conc. (%)	Groups
Dual app. *A. nodosum* extract	0.0293	a
Paper mill sludge	0.0250	a
Dual app. anaerobic digestate	0.0237	a
Single app. *A. nodosum* extract	0.0217	a
Control	0.0203	a
Single app. anaerobic digestate	0.0157	a

Table 8.26.27 ANOVA: Treatment effects on average iron concentration (ppm) for Miscanthus grown in the East Gore 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	134.71	12	129.24	2.5016	0.0897

Table 8.26.28 Treatment effects on average iron concentration (ppm) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Dual app. *A. nodosum* extract	28.9667	a
Single app. *A. nodosum* extract	26.0367	a
Control	24.6467	a
Dual app. anaerobic digestate	24.5367	a
Single app. anaerobic digestate	22.6767	a
Paper mill sludge	20.1133	a

Table 8.26.29 ANOVA: Treatment effects on average iron concentration (ppm) for Miscanthus grown in the Skye Glen 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	281.41	12	168.54	4.0074	0.0227 *

Table 8.26.30 Tukey's test: Treatment effects on average iron concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments included a no-additives control (CT), paper mill sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-0.5167	3.0599	-0.169	1.0000

DG2 – CT	-2.4267	3.0599	-0.793	0.9688
PS – CT	0.0167	3.0599	0.005	1.0000
SE1 – CT	-0.9767	3.0599	-0.319	0.9996
SE2 – CT	9.5967	3.0599	3.136	0.0211 *

Table 8.26.31 Treatment effects on average iron concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Iron conc. (ppm)	Groups
Dual app. *A. nodosum* extract	28.6267	a
Paper mill sludge	19.0467	b
Control	19.0300	b
Single app. anaerobic digestate	18.5133	b
Single app. *A. nodosum* extract	18.0533	b
Dual app. anaerobic digestate	16.6033	b

Table 8.26.32 ANOVA: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the East Gore 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	3951.6	12	9963.4	0.9519	0.4834

Table 8.26.33 Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Paper mill sludge	106.1767	a
Control	79.6833	a
Dual app. *A. nodosum* extract	79.3767	a
Single app. *A. nodosum* extract	66.1300	a
Single app. anaerobic digestate	65.0367	a
Dual app. anaerobic digestate	63.1133	a

Table 8.26.34 ANOVA: Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the Skye Glen 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			

Table 8.26.35 Treatment effects on average manganese concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Manganese conc. (ppm)	Groups
Single app. *A. nodosum* extract	128.7267	a
Paper mill sludge	124.7367	a
Dual app. *A. nodosum* extract	124.1367	a
Single app. anaerobic digestate	119.6733	a
Control	112.1500	a
Dual app. anaerobic digestate	90.8300	a

Table 8.26.36 ANOVA: Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the East Gore 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	139.19	12	274.02	1.2191	0.3582

Table 8.26.37 Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups
Dual app. *A. nodosum* extract	34.2567	a
Single app. anaerobic digestate	33.7000	a
Single app. *A. nodosum* extract	32.0467	a
Paper mill sludge	29.6500	a
Control	29.0400	a
Dual app. anaerobic digestate	26.3200	a

Table 8.26.38 ANOVA: Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the Skye Glen 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	96.794	12	311.18	0.7465	0.6039

Table 8.26.39 Treatment effects on average zinc concentration (ppm) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Zinc conc. (ppm)	Groups
Single app. anaerobic digestate	26.5700	a
Dual app. *A. nodosum* extract	24.6833	a
Control	24.2733	a

Single app. *A. nodosum* extract	22.7100	a
Paper mill sludge	20.6000	a
Dual app. anaerobic digestate	19.9467	a

8.27. Miscanthus nutrient yield (fall 2020)

Table 8.27.1 ANOVA: Treatment effects on average nitrogen yield (kg/ha) for Miscanthus grown in the East Gore 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	203.88	12	139.39	3.5102	0.0347 *

Table 8.27.2 Tukey's test: Treatment effects on average nitrogen yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	6.062	2.783	2.178	0.2476
DG2 – CT	5.156	2.783	1.853	0.4316
PS – CT	4.199	2.783	1.509	0.6584
SE1 – CT	-3.260	2.783	-1.171	0.8506
SE2 – CT	-0.234	2.783	-0.084	1.0000

Table 8.27.3 Treatment effects on average nitrogen yield (kg/ha) for Miscanthus grown in the East Gore 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
Single app. anaerobic digestate	15.6543	a
Dual app. anaerobic digestate	14.7483	a
Paper sludge	13.7913	ab
Control	9.5920	ab
Dual app. *A. nodosum* extract	9.3580	ab
Single app. *A. nodosum* extract	6.3320	b

Table 8.27.4 ANOVA: Treatment effects on average nitrogen yield (kg/ha) for Miscanthus grown in the Skye Glen 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	668.84	12	1086.4	1.4775	0.2678

Table 8.27.5 Treatment effects on average nitrogen yield (kg/ha) for Miscanthus grown in the Skye Glen 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	45.729	a
Single app. *A. nodosum* extract	44.721	a
Dual app. *A. nodosum* extract	41.859	a
Single app. anaerobic digestate	35.547	a
Dual app. anaerobic digestate	31.482	a
Control	30.567	a

Table 8.27.6 ANOVA: Treatment effects on average phosphorus yield (kg/ha) for Miscanthus grown in the East Gore 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	15.824	12	21.461	1.7696	0.1937

Table 8.27.7 Treatment effects on average phosphorus yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus yield (kg/ha)	Groups
Single app. anaerobic digestate	4.9457	a
Paper sludge	4.3923	a
Dual app. anaerobic digestate	4.0190	a
Control	3.2553	a
Dual app. *A. nodosum* extract	3.0897	a
Single app. *A. nodosum* extract	2.0877	a

Table 8.27.8 ANOVA: Treatment effects on average phosphorus yield (kg/ha) for Miscanthus grown in the Skye Glen 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	49.95	12	67.098	1.7867	0.1901

Table 8.27.9 Treatment effects on average phosphorus yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. Phosphorus yield (kg/ha)	Groups
Single app. *A. nodosum* extract	11.0907	a
Dual app. *A. nodosum* extract	10.0733	a
Paper sludge	8.5780	a

Single app. anaerobic digestate	8.0117	a
Dual app. anaerobic digestate	6.9227	a
Control	6.3250	a

Table 8.27.10 ANOVA: Treatment effects on average potassium yield (kg/ha) for Miscanthus grown in the East Gore 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	10.19	12	9.5059	2.5727	0.0835

Table 8.27.11 Treatment effects on average potassium yield (kg/ha) for Miscanthus grown in the East Gore 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
Single app. anaerobic digestate	3.6377	a
Dual app. anaerobic digestate	2.9273	a
Paper sludge	2.8963	a
Control	2.2097	a
Dual app. *A. nodosum* extract	1.9980	a
Single app. *A. nodosum* extract	1.3057	a

Table 8.27.12 ANOVA: Treatment effects on average potassium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	311.32	12	1348.0	0.5543	0.7329

Table 8.27.13 Treatment effects on average potassium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	34.7537	a
Single app. *A. nodosum* extract	33.7470	a
Dual app. anaerobic digestate	31.8573	a
Single app. anaerobic digestate	31.4793	a
Dual app. *A. nodosum* extract	26.8830	a
Control	22.7780	a

Table 8.27.14 ANOVA: Treatment effects on average calcium yield (kg/ha) for Miscanthus grown in the East Gore 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	118.42	12	111.86	2.5408	0.0862

Table 8.27.15 Treatment effects on average calcium yield (kg/ha) for Miscanthus grown in the East Gore 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
Single app. anaerobic digestate	15.6543	a
Dual app. anaerobic digestate	14.7483	a
Paper sludge	13.7913	a
Control	9.5920	a
Dual app. *A. nodosum* extract	9.3580	a
Single app. *A. nodosum* extract	6.3320	a

Table 8.27.16 ANOVA: Treatment effects on average calcium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	240.25	12	257.28	2.2412	0.117

Table 8.27.17 Treatment effects on average calcium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	45.729	a
Single app. *A. nodosum* extract	44.721	a
Dual app. *A. nodosum* extract	41.859	a
Single app. anaerobic digestate	35.547	a
Dual app. anaerobic digestate	31.482	a
Control	30.567	a

Table 8.27.18 ANOVA: Treatment effects on average magnesium yield (kg/ha) for Miscanthus grown in the East Gore 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	5.2224	12	10.466	1.1975	0.367

Table 8.27.19 Treatment effects on average magnesium yield (kg/ha) for Miscanthus grown in the East Gore 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	2.7693	a
Single app. anaerobic digestate	2.4317	a
Dual app. anaerobic digestate	2.4163	a
Control	1.9667	a
Dual app. *A. nodosum* extract	1.6963	a
Single app. *A. nodosum* extract	1.1477	a

Table 8.27.20 ANOVA: Treatment effects on average magnesium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	22.068	12	44.922	1.179	0.3748

Table 8.27.21 Treatment effects on average magnesium yield (kg/ha) for Miscanthus grown in the Skye Glen 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
Single app. *A. nodosum* extract	11.2940	a
Paper sludge	11.0927	a
Dual app. *A. nodosum* extract	9.2910	a
Single app. anaerobic digestate	8.9863	a
Dual app. anaerobic digestate	8.7733	a
Control	8.5387	a

Table 8.27.22 ANOVA: Treatment effects on average sodium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	4.951	12	6.7213	1.7679	0.194

Table 8.27.23 Treatment effects on average sodium yield (kg/ha) for Miscanthus grown in the Skye Glen 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	2.8057	a
Single app. *A. nodosum* extract	2.2970	a
Dual app. *A. nodosum* extract	2.1723	a
Dual app. anaerobic digestate	2.0957	a
Control	1.5730	a
Single app. anaerobic digestate	1.1670	a

Table 8.27.24 ANOVA: Treatment effects on average iron yield (kg/ha) for Miscanthus grown in the East Gore 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	0.0015	12	0.0013	2.9282	0.0591

Table 8.27.25 Treatment effects on average iron yield (kg/ha) for Miscanthus grown in the East Gore 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
Dual app. anaerobic digestate	0.0460	a
Single app. anaerobic digestate	0.0457	a
Paper sludge	0.0453	a
Control	0.0353	a
Dual app. *A. nodosum* extract	0.0307	a
Single app. *A. nodosum* extract	0.0213	a

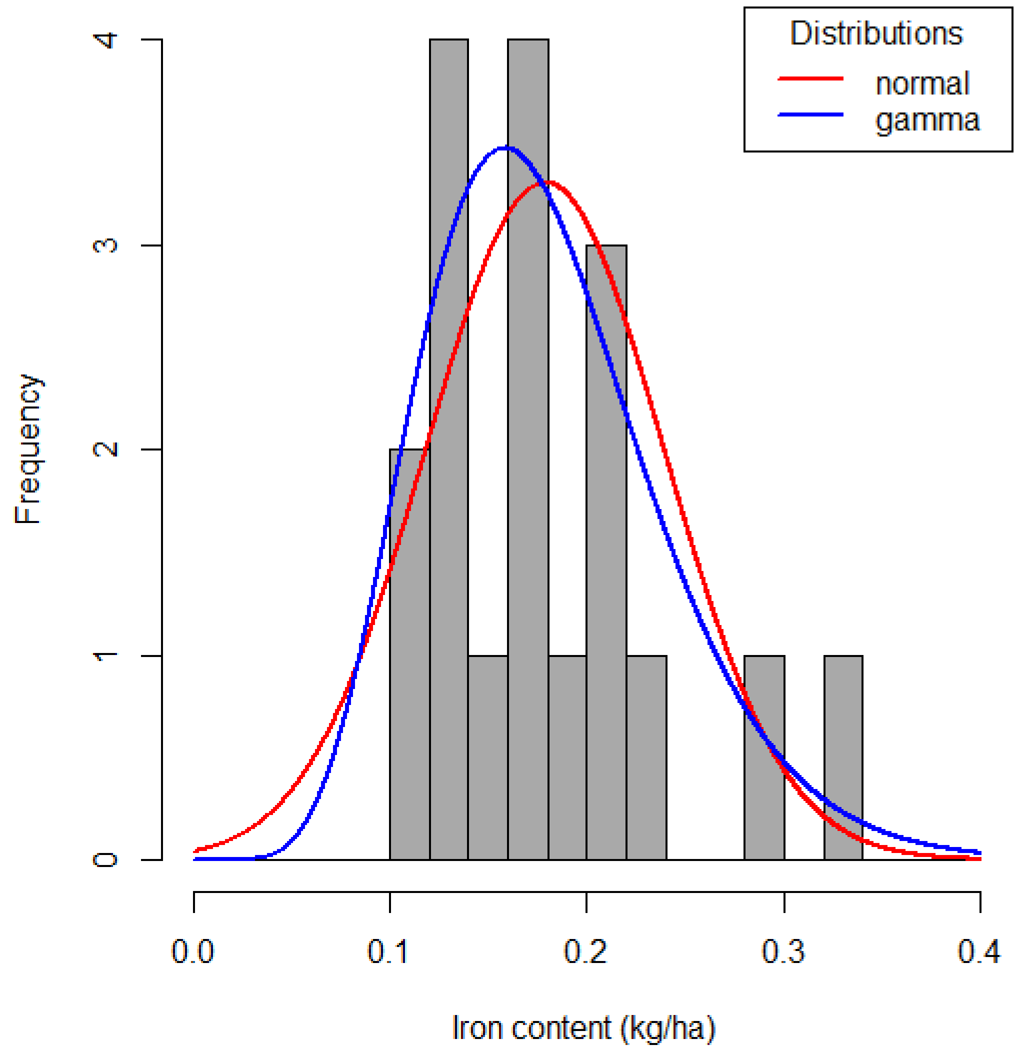

Figure 8.27.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus iron yield (kg/ha) from the Skye Glen site.

Table 8.27.26 ANOVA: Treatment effects on average iron yield (kg/ha) for Miscanthus grown in the Skye Glen 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	0.5202	12	1.2177	0.9988	0.4588

Table 8.27.27 Treatment effects on average calcium yield (kg/ha) for Miscanthus grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other ($\alpha = 0.05$).

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

Paper sludge	0.2210	a
Dual app. *A. nodosum* extract	0.2093	a
Single app. *A. nodosum* extract	0.1920	a
Single app. anaerobic digestate	0.1577	a
Dual app. anaerobic digestate	0.1540	a
Control	0.1393	a

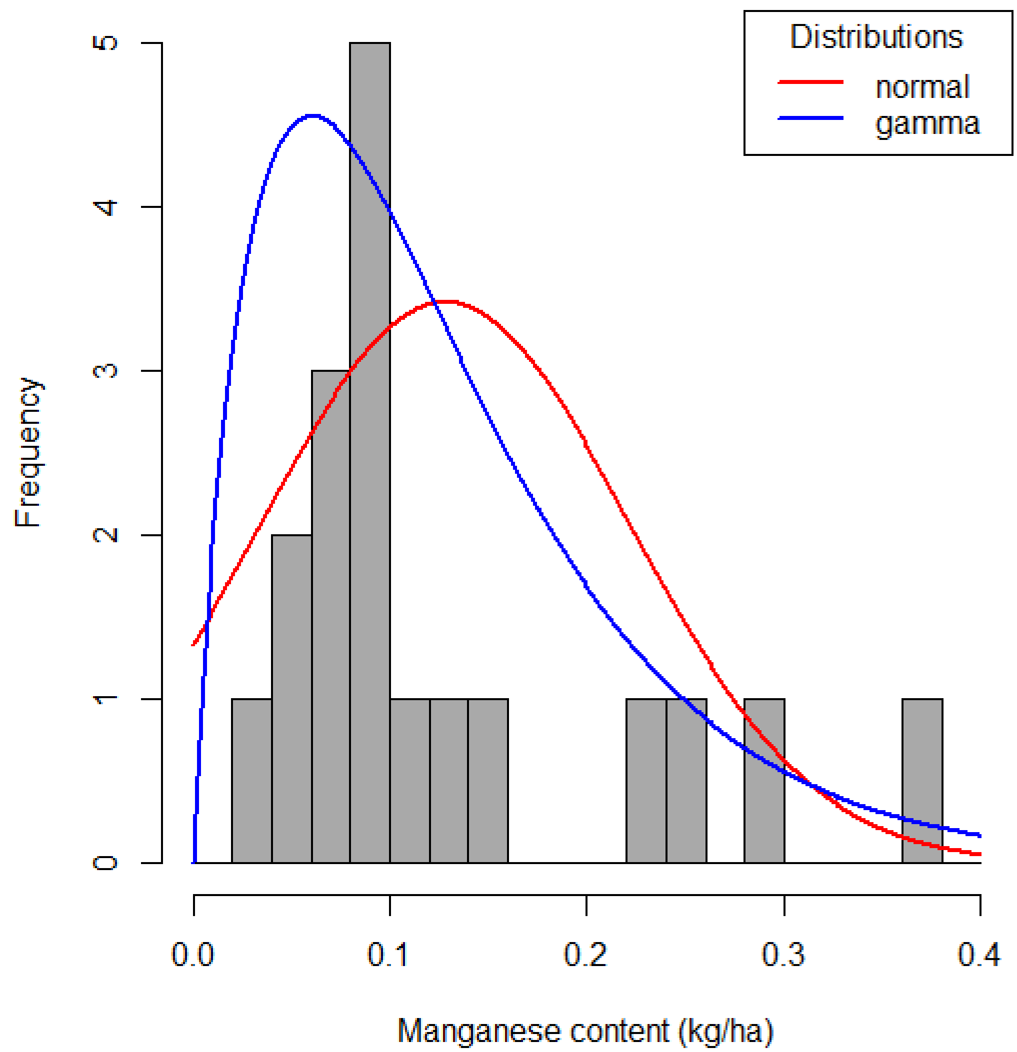

Figure 8.27.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of Miscanthus manganese yield (kg/ha) from the East Gore site.

Table 8.27.28 ANOVA: Treatment effects on average manganese yield (kg/ha) for Miscanthus grown in the East Gore 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	3.8269	12	3.6226	2.5945	0.0817

Table 8.27.29 Treatment effects on average manganese yield (kg/ha) for Miscanthus grown in the East Gore 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	0.2477	a
Single app. anaerobic digestate	0.1383	a
Dual app. anaerobic digestate	0.1283	a
Control	0.1137	a
Dual app. *A. nodosum* extract	0.0873	a
Single app. *A. nodosum* extract	0.0537	a

Table 8.27.30 ANOVA: Treatment effects on average manganese yield (kg/ha) for Miscanthus grown in the Skye Glen 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	0.9643	12	2.8363	0.816	0.5608

Table 8.27.31 Treatment effects on average manganese yield (kg/ha) for Miscanthus grown in the Skye Glen 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	1.4217	a
Single app. *A. nodosum* extract	1.3490	a
Single app. anaerobic digestate	1.0923	a
Dual app. *A. nodosum* extract	0.9653	a
Control	0.8407	a
Dual app. anaerobic digestate	0.8313	a

Table 8.27.32 ANOVA: Treatment effects on average zinc yield (kg/ha) for Miscanthus grown in the East Gore 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	0.00396	12	0.0024	3.9037	0.0247 *

Table 8.27.33 Tukey's test: Treatment effects on average zinc yield (kg/ha) for Miscanthus grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and

anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.0260	0.0116	2.235	0.2215
DG2 – CT	0.0087	0.0116	0.745	0.9762
PS – CT	0.0240	0.0116	2.063	0.3067
SE1 – CT	-0.0150	0.0116	-1.290	0.7910
SE2 – CT	-0.0047	0.0116	-0.401	0.9987

Table 8.27.34 Treatment effects on average zinc yield (kg/ha) for Miscanthus grown in the East Gore 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
Single app. anaerobic digestate	0.0677	a
Paper sludge	0.0657	a
Dual app. anaerobic digestate	0.0503	ab
Control	0.0417	ab
Dual app. *A. nodosum* extract	0.0370	ab
Single app. *A. nodosum* extract	0.0267	b

Table 8.27.35 ANOVA: Treatment effects on average zinc yield (kg/ha) for Miscanthus grown in the Skye Glen 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	0.0130	12	0.0272	1.1444	0.3897

Table 8.27.36 Treatment effects on average zinc yield (kg/ha) for Miscanthus grown in the Skye Glen 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
Single app. *A. nodosum* extract	0.2410	a
Paper sludge	0.2300	a
Single app. anaerobic digestate	0.2193	a
Control	0.1807	a
Dual app. *A. nodosum* extract	0.1797	a
Dual app. anaerobic digestate	0.1740	a

8.28. Poplar average stem length (fall 2020)

Table 8.28.1 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	976.36	18	712.43	4.9336	0.0051 **

Table 8.28.2 Tukey's test: Treatment effects on average stem length (cm) for poplar grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	5.150	4.449	1.158	0.8569
DG2 – CT	5.650	4.449	1.270	0.8014
PS – CT	17.075	4.449	3.838	0.0018 **
SE1 – CT	-2.425	4.449	-0.545	0.9943
SE2 – CT	0.475	4.449	0.107	1.0000

Table 8.28.3 Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	40.150	a
Dual app. anaerobic digestate	28.725	ab
Single app. anaerobic digestate	28.225	ab
Dual app. *A. nodosum* extract	23.550	b
Control	23.075	b
Single app. *A. nodosum* extract	20.650	b

Table 8.28.4 ANOVA: Treatment effects on average stem length (cm) for poplar grown in the Skye Glen 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	1571	18	4362	1.297	0.309

Table 8.28.5 Treatment effects on average stem length (cm) for poplar grown in the East Gore 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	100.550	a
Dual app. *A. nodosum* extract	87.975	a
Dual app. anaerobic digestate	85.975	a
Single app. anaerobic digestate	80.000	a
Single app. *A. nodosum* extract	79.675	a

Control	75.625	a

8.29. Poplar total stem length (fall 2020)

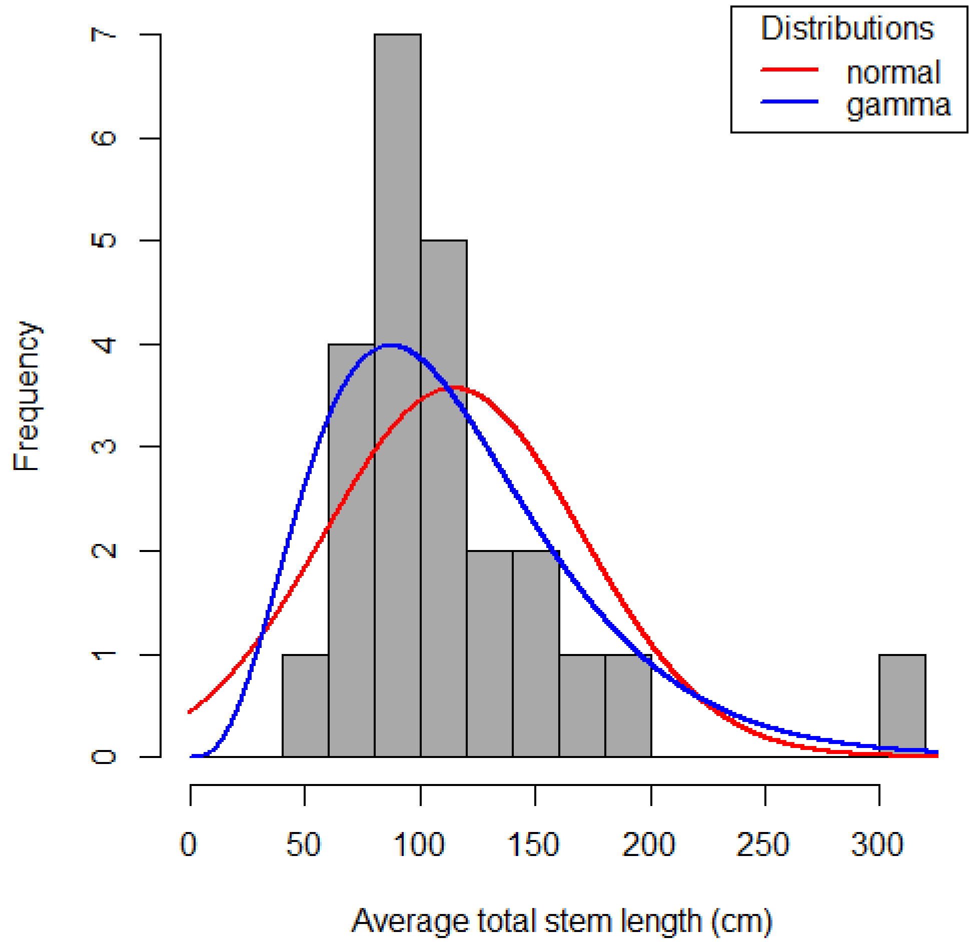

Figure 8.29.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar total stem length (cm) from the East Gore site.

Table 8.29.1 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the East Gore 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	2.8891	18	1.2646	7.6833	0.0005 ***

Table 8.29.2 Tukey's test: Treatment effects on total stem length (cm) for poplar grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate

(DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.2223	0.1939	1.146	0.8620
DG2 – CT	0.2863	0.1939	1.476	0.6795
PS – CT	0.8231	0.1939	4.245	<0.001 ***
SE1 – CT	-0.2594	0.1939	-1.338	0.7638
SE2 – CT	0.0410	0.1939	0.211	0.9999

Table 8.29.3 Treatment effects on total stem length (cm) for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	204.075	a
Dual app. anaerobic digestate	119.300	ab
Single app. anaerobic digestate	111.900	b
Dual app. *A. nodosum* extract	93.350	b
Control	89.600	b
Single app. *A. nodosum* extract	69.125	b

Table 8.29.4 ANOVA: Treatment effects on total stem length (cm) for poplar grown in the Skye Glen 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	1206	18	2223	1.953	0.135

Table 8.29.5 Treatment effects on total stem length (cm) for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	579.350	a
Dual app. *A. nodosum* extract	540.450	a
Single app. *A. nodosum* extract	459.600	a
Control	441.375	a
Single app. anaerobic digestate	405.875	a
Dual app. anaerobic digestate	379.375	a

8.30. Poplar stem diameter (fall 2020)

Table 8.30.1 ANOVA: Treatment effects on stem diameter (mm) for poplar grown in the East Gore 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	5.1083	18	3.6700	5.0109	0.0047 **

Table 8.30.2 Tukey's test: Treatment effects on stem diameter (mm) for poplar grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-6e-16	0.3193	0.000	1.0000
DG2 – CT	0.05	0.3193	0.157	1.0000
PS – CT	1.15	0.3193	3.602	0.0043 **
SE1 – CT	-0.25	0.3193	-0.783	0.9705
SE2 – CT	-0.1	0.3193	-0.313	0.9996

Table 8.30.3 Treatment effects on stem diameter (mm) for poplar grown in the East Gore 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	4.10	a
Dual app. anaerobic digestate	3.00	b
Control	2.95	b
Single app. anaerobic digestate	2.95	b
Dual app. *A. nodosum* extract	2.85	b
Single app. *A. nodosum* extract	2.70	b

Table 8.30.4 ANOVA: Treatment effects on stem diameter (mm) for poplar grown in the Skye Glen 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	4.69	18	20.37	0.829	0.546

Table 8.30.5 Treatment effects on stem diameter (mm) for poplar grown in the Skye Glen 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	7.125	a
Dual app. anaerobic digestate	6.725	a
Dual app. *A. nodosum* extract	6.500	a
Single app. anaerobic digestate	6.175	a
Single app. *A. nodosum* extract	6.100	a

Control	5.775	a

8.31. Poplar stem volume estimate (fall 2020)

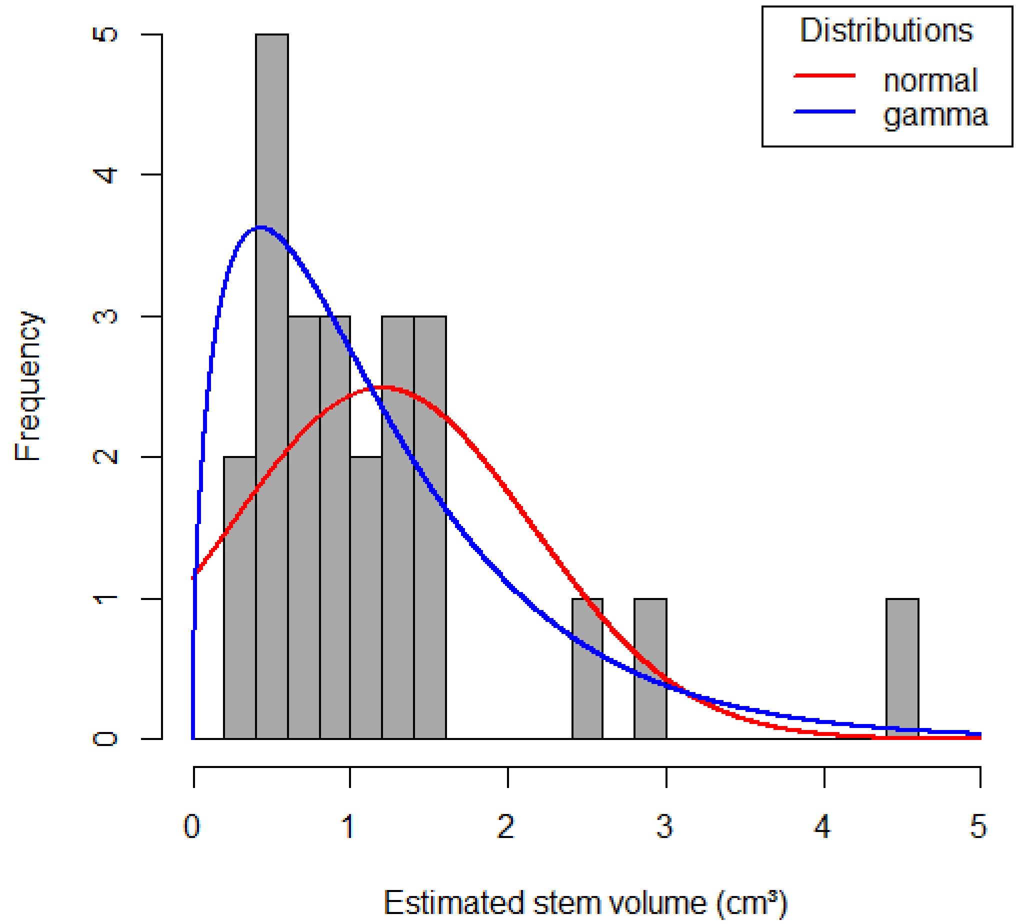

Figure 8.31.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar estimated stem volume (cm^3) from the East Gore site.

Table 8.31.1 ANOVA: Treatment effects on estimated stem volume for poplar grown in the East Gore 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	6.3698	18	4.7067	5.185	0.0040 **

Table 8.31.2 Tukey's test: Treatment effects on estimated stem volume for poplar grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate

(DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.1168	0.3505	0.333	0.9995
DG2 – CT	0.1658	0.3505	0.473	0.9971
PS – CT	1.1552	0.3505	3.296	0.0125 *
SE1 – CT	-0.3348	0.3505	-0.955	0.9319
SE2 – CT	-0.0976	0.3505	-0.278	0.9998

Table 8.31.3 Treatment effects on estimated stem volume (cm^3) for poplar grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. stem volume (cm^3)	Groups
Paper sludge	2.8175	a
Dual app. anaerobic digestate	1.0475	ab
Single app. anaerobic digestate	0.9975	b
Control	0.8875	b
Dual app. *A. nodosum* extract	0.8050	b
Single app. *A. nodosum* extract	0.6350	b

Table 8.31.4 ANOVA: Treatment effects on estimated stem volume for poplar grown in the Skye Glen 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	256.79	18	876.62	1.0545	0.4171

Table 8.31.5 Treatment effects on estimated stem volume (cm^3) for poplar grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. stem volume (cm^3)	Groups
Paper sludge	20.7425	a
Dual app. anaerobic digestate	16.4175	a
Dual app. *A. nodosum* extract	15.3725	a
Single app. anaerobic digestate	12.9375	a
Single app. *A. nodosum* extract	12.1500	a
Control	10.8675	a

8.32. Willow average stem length (fall 2020)

Table 8.32.1 ANOVA: Treatment effects on average stem length (cm) for willow grown in the East Gore 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	744.26	18	828.02	3.2359	0.0294 *

Table 8.32.2 Tukey's test: Treatment effects on average stem length (cm) for willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	1.300	4.796	0.271	0.9998
DG2 – CT	4.550	4.796	0.949	0.9337
PS – CT	16.475	4.796	3.435	0.0079 **
SE1 – CT	2.475	4.796	0.516	0.9956
SE2 – CT	1.650	4.796	0.344	0.9994

Table 8.32.3 Treatment effects on average stem length (cm) for willow grown in the East Gore 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	37.225	a
Dual app. anaerobic digestate	25.300	ab
Single app. *A. nodosum* extract	23.225	ab
Dual app. *A. nodosum* extract	22.400	ab
Single app. anaerobic digestate	22.050	ab
Control	20.750	b

Table 8.32.4 ANOVA: Treatment effects on average stem length (cm) for willow grown in the Skye Glen 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	2016.1	18	1575.6	4.6064	0.0070 **

Table 8.32.5 Tukey's test: Treatment effects on average stem length (cm) for willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-8.025	6.616	-1.213	0.8308
DG2 – CT	-3.000	6.616	-0.453	0.9976
PS – CT	1.575	6.616	0.238	0.9999

SE1 – CT	-22.400	6.616	-3.386	0.0092 **
SE2 – CT	-18.825	6.616	-2.845	0.0506

Table 8.32.6 Treatment effects on average stem length (cm) for willow grown in the Skye Glen 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	124.075	a
Control	122.500	a
Dual app. anaerobic digestate	119.500	ab
Single app. anaerobic digestate	114.475	ab
Dual app. *A. nodosum* extract	103.675	ab
Single app. *A. nodosum* extract	100.100	b

8.33. Willow total stem length (fall 2020)

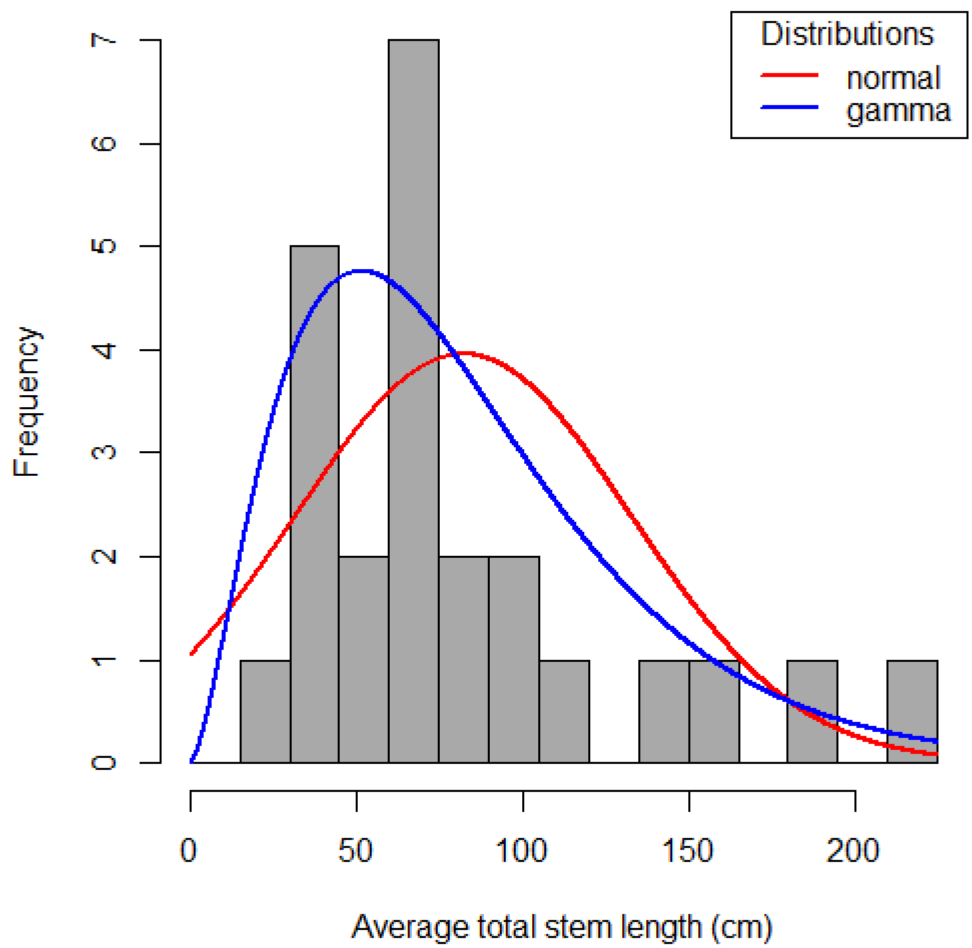

Figure 8.33.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow total stem length (cm) from the East Gore site.

Table 8.33.1 ANOVA: Treatment effects on total stem length (cm) for willow grown in the East Gore 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	4.8468	18	2.5128	6.9626	0.0009 ***

Table 8.33.2 Tukey's test: Treatment effects on total stem length (cm) for willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.0989	0.2638	0.375	0.9990
DG2 – CT	0.1959	0.2638	0.742	0.9766
PS – CT	1.0502	0.2638	3.981	0.0010 **
SE1 – CT	-0.1121	0.2638	-0.425	0.9983
SE2 – CT	-0.1859	0.2638	-0.704	0.9815

Table 8.33.3 Treatment effects on total stem length (cm) for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	178.650	a
Dual app. anaerobic digestate	76.025	b
Single app. anaerobic digestate	69.000	b
Control	62.500	b
Single app. *A. nodosum* extract	55.875	b
Dual app. *A. nodosum* extract	51.900	b

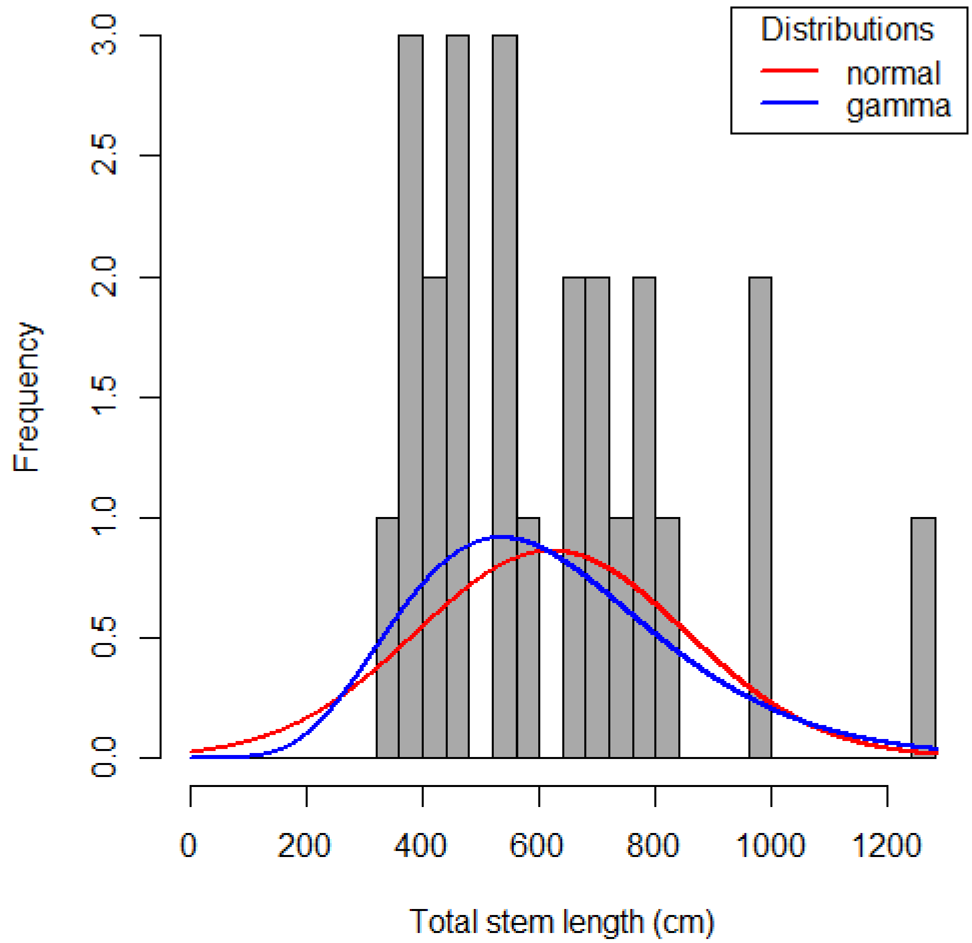

Figure 8.33.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow total stem length (cm) from the Skye Glen site.

Table 8.33.4 ANOVA: Treatment effects on total stem length (cm) for willow grown in the Skye Glen 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	1.9798	18	0.96509	7.3374	0.0007 ***

Table 8.33.5 Tukey's test: Treatment effects on total stem length (cm) for willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-0.1436	0.1643	-0.874	0.9527

DG2 – CT	-0.1408	0.1643	-0.857	0.9564
PS – CT	0.3886	0.1643	2.366	0.1684
SE1 – CT	-0.4683	0.1643	-2.851	0.0498 *
SE2 – CT	-0.3950	0.1643	-2.404	0.1546

Table 8.33.6 Treatment effects on total stem length (cm) for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. total stem length (cm)	Groups
Paper sludge	997.900	a
Control	676.550	ab
Dual app. anaerobic digestate	587.675	bc
Single app. anaerobic digestate	586.050	bc
Dual app. *A. nodosum* extract	455.800	bc
Single app. *A. nodosum* extract	423.550	c

8.34. Willow stem diameter (fall 2020)

Table 8.34.1 ANOVA: Treatment effects on stem diameter (mm) for willow grown in the East Gore 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	2.8721	18	2.9775	3.4725	0.0226 *

Table 8.34.2 Tukey's test: Treatment effects on stem diameter (mm) for willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.200	0.2876	0.695	0.9825
DG2 – CT	0.400	0.2876	1.391	0.7326
PS – CT	1.075	0.2876	3.738	0.0026 **
SE1 – CT	0.200	0.2876	0.695	0.9825
SE2 – CT	0.200	0.2876	0.695	0.9825

Table 8.34.3 Treatment effects on stem diameter (mm) for willow grown in the East Gore 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	3.225	a
Dual app. anaerobic digestate	2.550	ab
Single app. anaerobic digestate	2.350	ab

Single app. *A. nodosum* extract	2.350	ab
Dual app. *A. nodosum* extract	2.350	ab
Control	2.150	b

Table 8.34.4 ANOVA: Treatment effects on stem diameter (mm) for willow grown in the Skye Glen 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	4.0271	18	3.6325	3.9911	0.0130 *

Table 8.34.5 Tukey's test: Treatment effects on stem diameter (mm) for willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-0.0750	0.3176	-0.236	0.9999
DG2 – CT	0.2000	0.3176	0.630	0.9889
PS – CT	0.3750	0.3176	1.181	0.8463
SE1 – CT	-0.7250	0.3176	-2.282	0.2012
SE2 – CT	-0.6500	0.3176	-2.046	0.3160

Table 8.34.4 Treatment effects on stem diameter (mm) for willow grown in the Skye Glen 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	7.300	a
Dual app. anaerobic digestate	7.125	ab
Control	6.925	ac
Single app. anaerobic digestate	6.850	ac
Dual app. *A. nodosum* extract	6.275	bc
Single app. *A. nodosum* extract	6.200	c

8.35. Willow stem volume estimate (fall 2020)

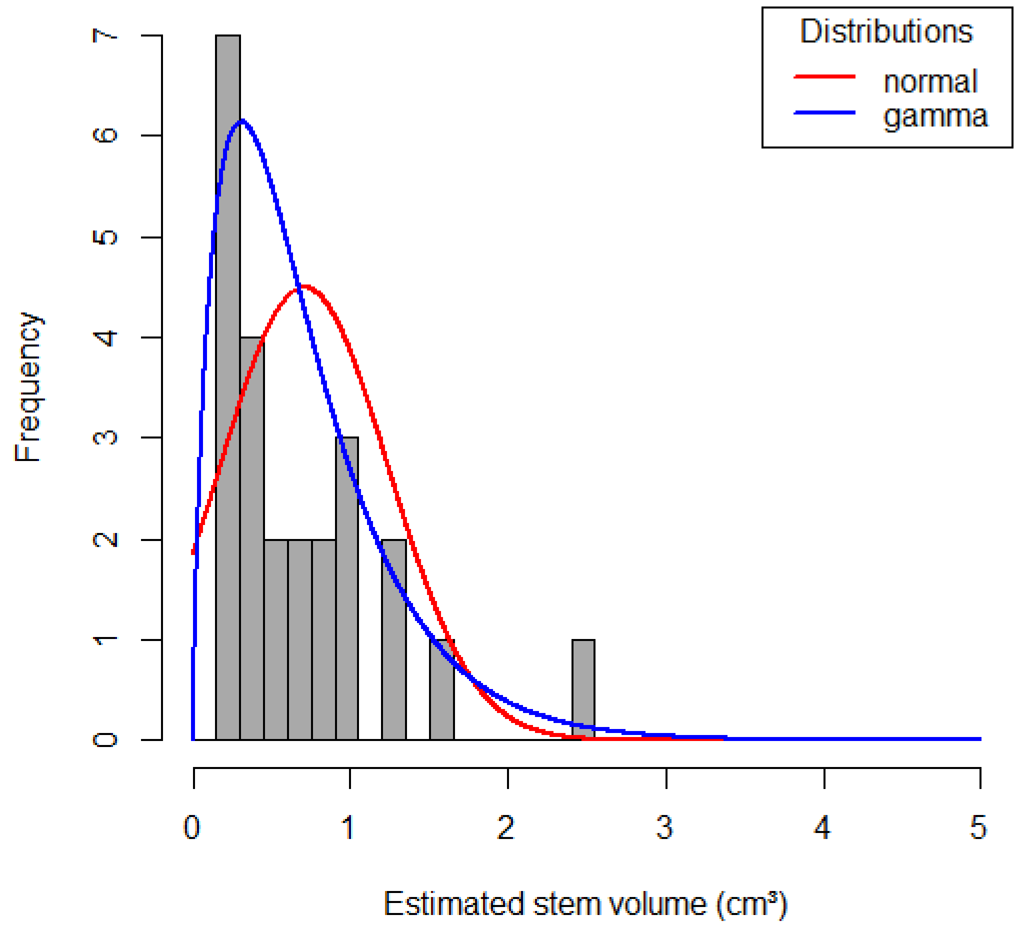

Figure 8.35.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of willow estimated stem volume (cm^3) from the East Gore site.

Table 8.35.1 ANOVA: Treatment effects on estimated stem volume for willow grown in the East Gore 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	5.121	18	6.1288	2.9791	0.0394 *

Table 8.35.2 Tukey's test: Treatment effects on estimated stem volume for willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	0.2267	0.4146	0.547	0.9942

DG2 – CT	0.5013	0.4146	1.209	0.8326
PS – CT	1.3010	0.4146	3.139	0.0211 *
SE1 – CT	0.2267	0.4146	0.547	0.9942
SE2 – CT	0.2076	0.4146	0.501	0.9962

Table 8.35.3 Treatment effects on estimated stem volume (cm^3) for willow grown in the East Gore site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. stem volume (cm^3)	Groups
Paper sludge	1.5525	a
Dual app. anaerobic digestate	0.6975	ab
Single app. anaerobic digestate	0.5300	ab
Single app. *A. nodosum* extract	0.5300	ab
Dual app. *A. nodosum* extract	0.5200	ab
Control	0.4225	b

Table 8.35.4 Treatment effects on estimated stem volume for willow grown in the Skye Glen 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	388.64	18	344.36	4.0629	0.0121 *

Table 8.35.5 Tukey's test: Treatment effects on estimated stem volume for willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of liquid *A. nodosum* extract (SE1/SE2) and anaerobic digestate (DG1/DG2). Asterisks were a measure of significance, with three asterisks indicating that the p-value is considerably lower than the alpha (0.05).

	Estimate	Standard error	Z-value	P-value
DG1 – CT	-2.1750	3.0928	-0.703	0.9816
DG2 – CT	0.5425	3.0928	0.175	1.0000
PS – CT	2.9950	3.0928	0.968	0.9280
SE1 – CT	-8.0825	3.0928	-2.613	0.0939
SE2 – CT	-7.0225	3.0928	-2.271	0.2061

Table 8.35.6 Treatment effects on estimated stem volume (cm^3) for willow grown in the Skye Glen site. Treatments labelled with the same letter were not significantly different from each other (α = 0.05).

Soil amendment	Avg. stem volume (cm^3)	Groups
Paper sludge	26.2700	a
Dual app. anaerobic digestate	23.8175	ab
Control	23.2750	ab
Single app. anaerobic digestate	21.1000	ab

Dual app. *A. nodosum* extract	16.2525	b
Single app. *A. nodosum* extract	15.1925	b

8.36. Survival rate, woody crops (2019)

Table 8.36.1 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the East Gore 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	0.0041	0.0041	0.875	0.359
Treatment	3	0.0240	0.0080	1.731	0.187
Crop:Treatment	3	0.0061	0.0020	0.438	0.728

Table 8.36.2 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Skye Glen 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	0.0648	0.0648	9.296	0.0055 **
Treatment	3	0.0214	0.0071	1.025	0.3993
Crop:Treatment	3	0.0287	0.0096	1.371	0.2755

8.37. Yield, woody crops (2019)

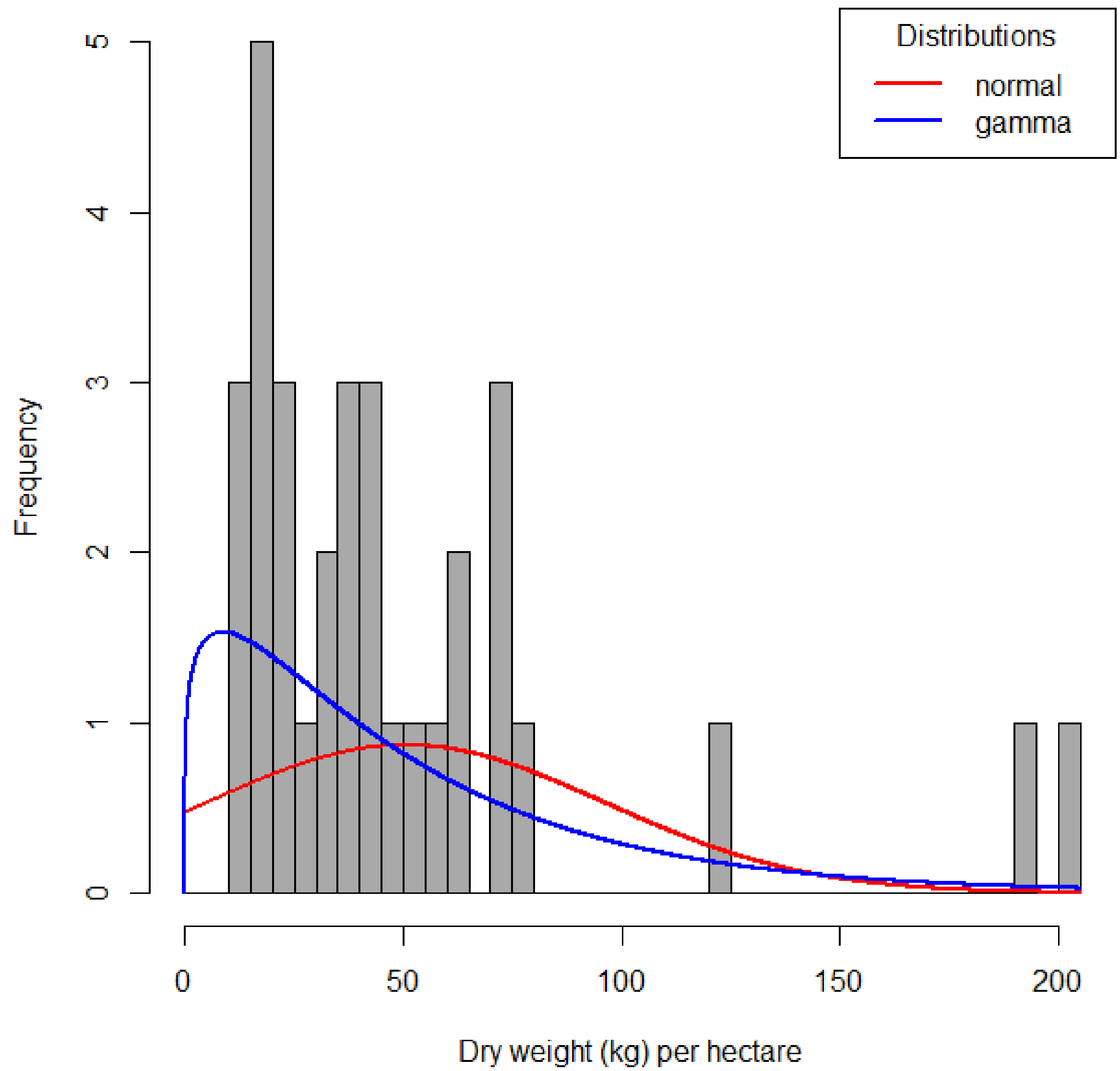

Figure 8.37.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow yield (kg/ha) from the East Gore site.

Table 8.37.1 Two-way ANOVA: Crop, treatment, and interaction effects on yield (kg/ha) for woody crops (poplar, willow) grown in the East Gore 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	3051	3051	1.968	0.1735
Treatment	3	19776	6592	4.252	0.0152 *
Crop:Treatment	3	5503	1834	1.183	0.3370

Table 8.37.2 Tukey's test: Treatment effects on yield (kg/ha) for poplar and willow grown in the East Gore 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	0.7225	-53.5862	55.0312	1.0000
PS – CT	61.2413	6.9326	115.5499	0.0230 *
SE – CT	21.6800	-32.6287	75.9887	0.6922

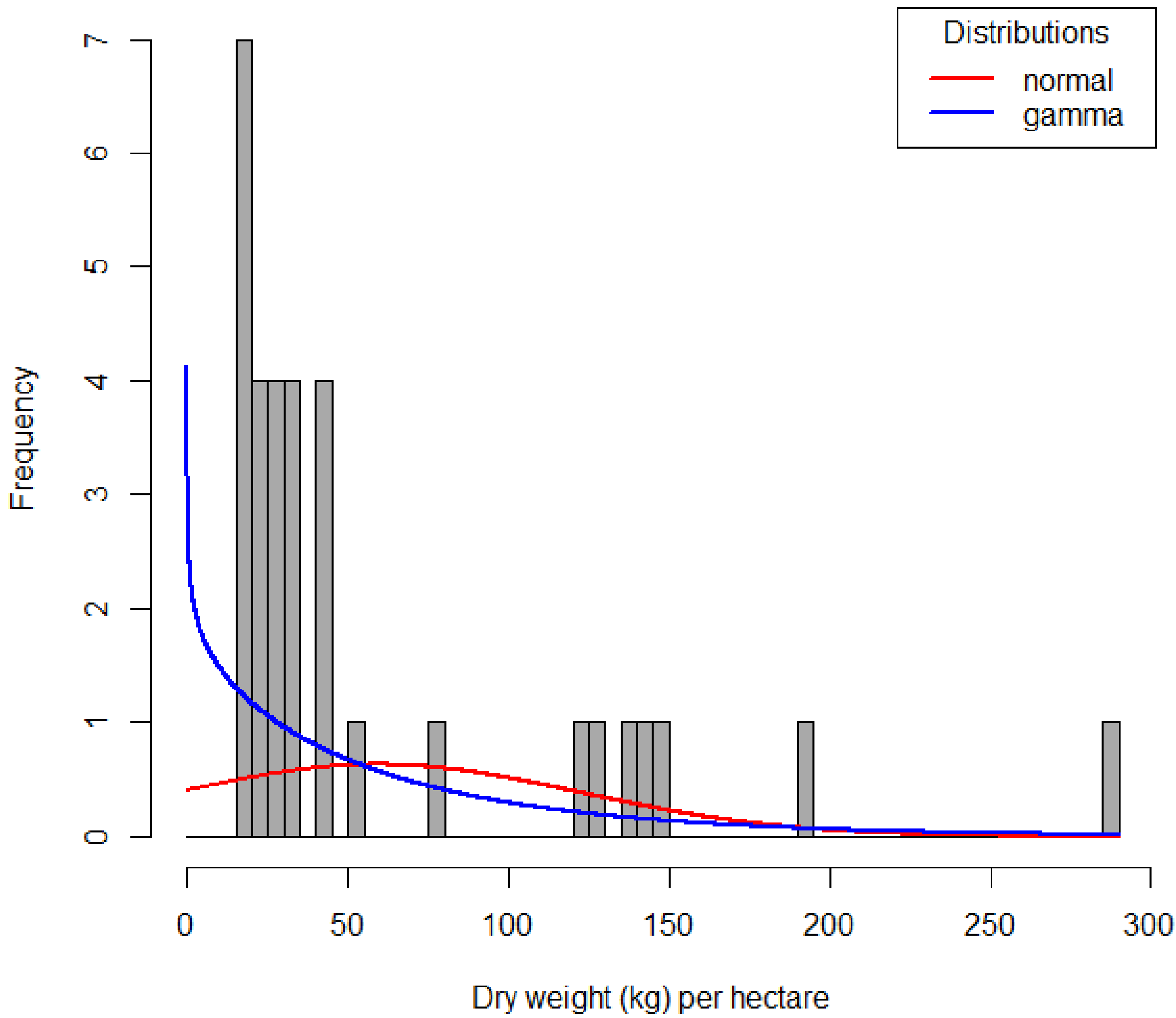

Figure 8.37.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow dry weight (kg) per hectare from the Skye Glen site.

Table 8.37.3 Two-way ANOVA: Crop, treatment, and interaction effects on yield (kg/ha) for woody crops (poplar, willow) grown in the Skye Glen 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	692	692	0.834	0.3702
Treatment	3	96023	32008	38.599	2e-9 ***
Crop:Treatment	3	8124	2708	3.266	0.0388 *

Table 8.37.4 Tukey's test: Treatment effects on yield (kg/ha) for poplar and willow grown in the Skye Glen 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	1.2788	-38.4405	40.9980	0.9997
PS – CT	127.3638	87.6445	167.0830	< 0.0000 ***
SE – CT	1.3113	-38.4080	41.0305	0.9997

Table 8.37.5 Tukey's test: Treatment and crop effects on yield (kg/ha) for poplar (PO) and willow (WW) grown in the Skye Glen 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
PO CT – WW CT	-0.4575	-67.8955	66.9805	1.0000
PO DG – WW DG	-13.1900	-80.6280	54.2480	0.9976
PO PS – WW PS	63.7700	-3.6680	131.2080	0.0732
PO SE – WW SE	-12.9300	-80.3680	54.5080	0.9979

8.38. Survival rate 2020, woody crops

Table 8.38.1 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the East Gore 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	0.1200	0.1201	12.735	0.0016 **
Treatment	3	0.0928	0.0309	3.280	0.0383 *
Crop:Treatment	3	0.0285	0.0095	1.009	0.4061

Table 8.38.2 Tukey's test: Treatment effects on survival rate for poplar and willow grown in the East Gore 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	0.0463	-0.0877	0.1802	0.7770
PS – CT	0.1488	0.0148	0.2827	0.0256 *
SE – CT	0.0625	-0.0714	0.1964	0.5795

Table 8.38.3 Two-way ANOVA: Crop, treatment, and interaction effects on survival rate for woody crops (poplar, willow) grown in the Skye Glen 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	0.1140	0.1140	13.820	0.0011 **
Treatment	3	0.0242	0.0081	0.977	0.4199
Crop:Treatment	3	0.0053	0.0018	0.213	0.8867

8.39. Stem count, woody crops (August 2020)

Table 8.39.1 Two-way ANOVA: Crop, treatment, and interaction effects on stem counts for woody crops (poplar, willow) grown in the East Gore 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	0.070	0.070	0.064	0.8027
Treatment	3	10.653	3.551	3.224	0.0404 *
Crop:Treatment	3	1.688	0.563	0.511	0.6785

Table 8.39.2 Tukey's test: Treatment effects on stem counts for poplar and willow grown in the East Gore 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	0.3125	-1.1350	1.7600	0.9324
PS – CT	1.3625	-0.0850	2.8100	0.0702
SE – CT	-0.0875	-1.5350	1.3600	0.9983

Table 8.39.3 Two-way ANOVA: Crop, treatment, and interaction effects on stem counts for woody crops (poplar, willow) grown in the Skye Glen 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	33.21	33.21	24.571	5e-5 ***
Treatment	3	12.25	4.08	3.022	0.0494
Crop:Treatment	3	29.94	9.98	7.384	0.0011 **

Table 8.39.4 Tukey's test: Treatment and crop effects on stem counts for poplar (PO) and willow (WW) grown in the Skye Glen 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
PO CT – WW CT	2.15	-0.5726	4.8727	0.1988
PO DG – WW DG	1.50	-1.2227	4.2227	0.6107
PO PS – WW PS	4.95	2.2273	7.6727	0.0001 ***
PO SE – WW SE	-0.45	-3.1727	2.2727	0.9992

8.40. Average stem length, woody crops (August 2020)

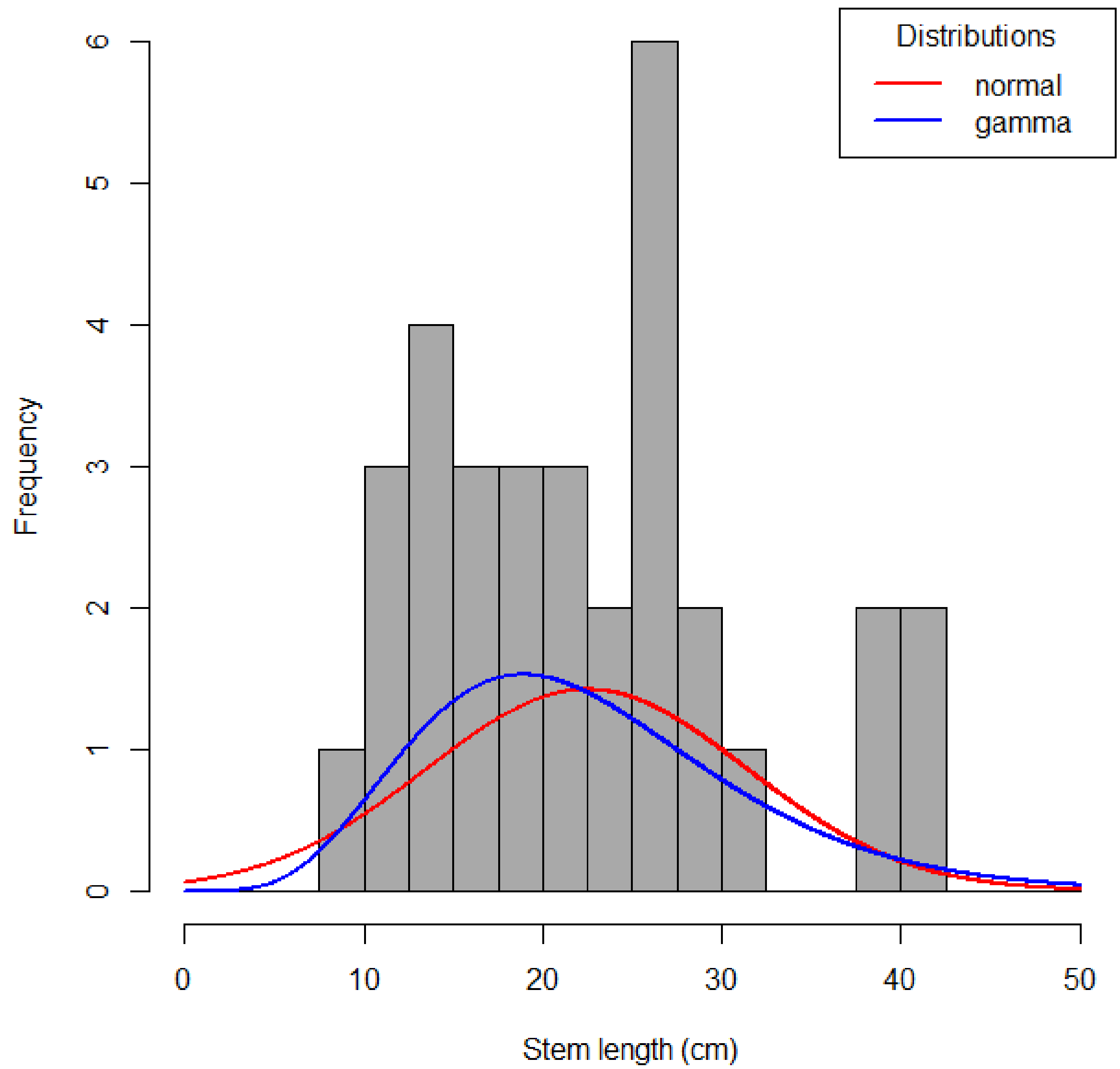

Figure 8.40.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow average stem length (cm) from the East Gore site.

Table 8.40.1 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the East Gore 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	326.8	326.8	8.214	0.0085 **

Treatment	3	1172.8	390.9	9.826	0.0002 ***
Crop:Treatment	3	35.2	11.7	0.295	0.8285

Table 8.40.2 Tukey's test: Treatment effects on average stem length (cm) for poplar and willow grown in the East Gore 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	4.7582	-3.9420	13.4584	0.4481
PS – CT	14.8941	6.1939	23.5942	0.0005 ***
SE – CT	0.1358	-8.5644	8.8360	1.0000

Table 8.40.3 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the Skye Glen 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	218	217.9	1.409	0.2469
Treatment	3	2019	673.1	4.352	0.0139 *
Crop:Treatment	3	630	209.9	1.357	0.2797

Table 8.40.4 Tukey's test: Treatment effects on average stem length (cm) for poplar and willow grown in the Skye Glen 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	7.4875	-9.6664	24.6414	0.6303
PS – CT	21.5375	4.3836	38.6914	0.0101 *
SE – CT	5.4625	-11.6914	22.6164	0.8159

8.41. Total stem length, woody crops (August 2020)

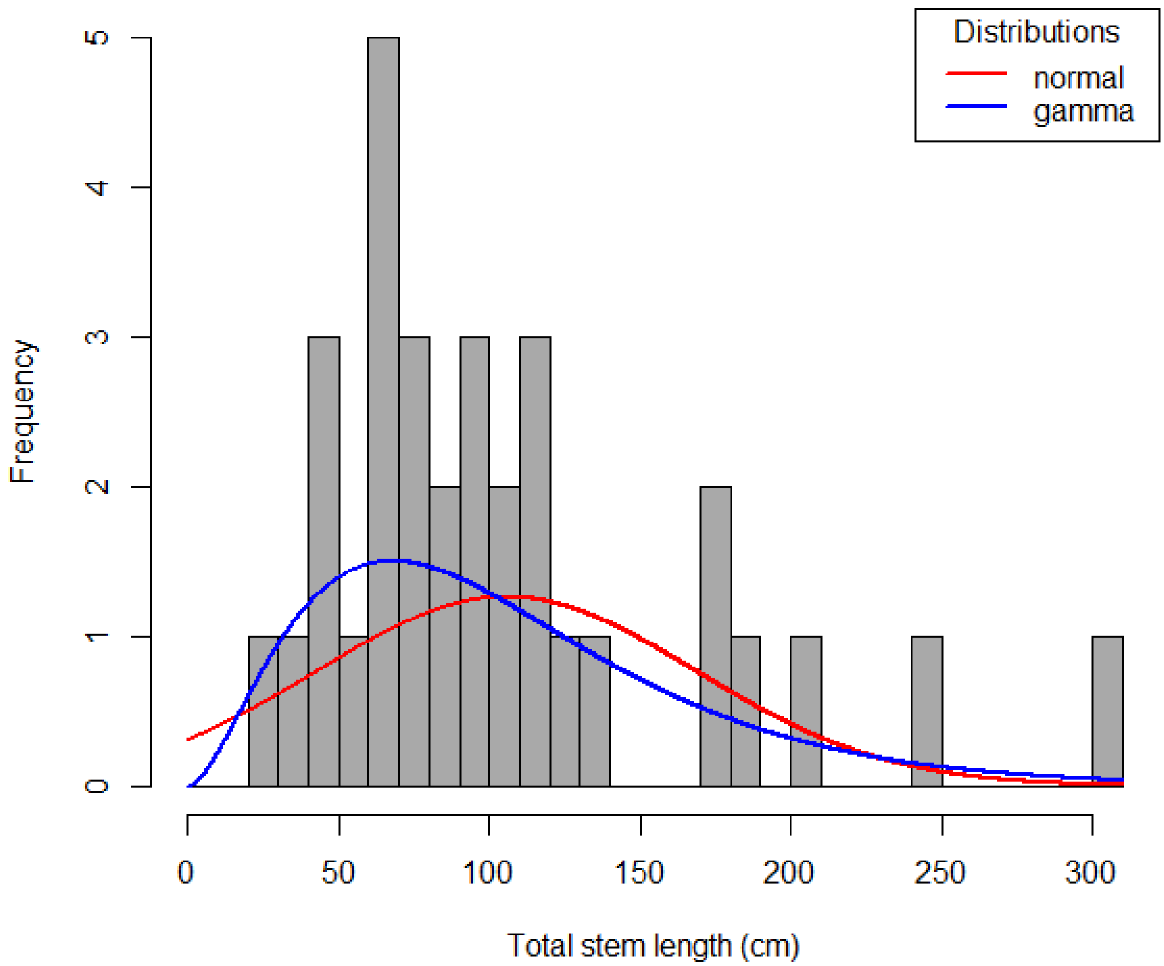

Figure 8.41.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow total stem length (cm) from the East Gore site.

Table 8.41.1 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the East Gore 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	5523	5523	2.279	0.1442
Treatment	3	58466	19489	8.040	0.0007 ***
Crop:Treatment	3	1599	533	0.220	0.8816

Table 8.41.2 Tukey's test: Treatment effects on total stem length (cm) for poplar and willow grown in the East Gore 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	31.2625	-36.6451	99.1701	0.5901
PS – CT	103.5875	35.6799	171.4951	0.0017 **
SE – CT	-2.1250	-70.0326	65.7826	0.9998

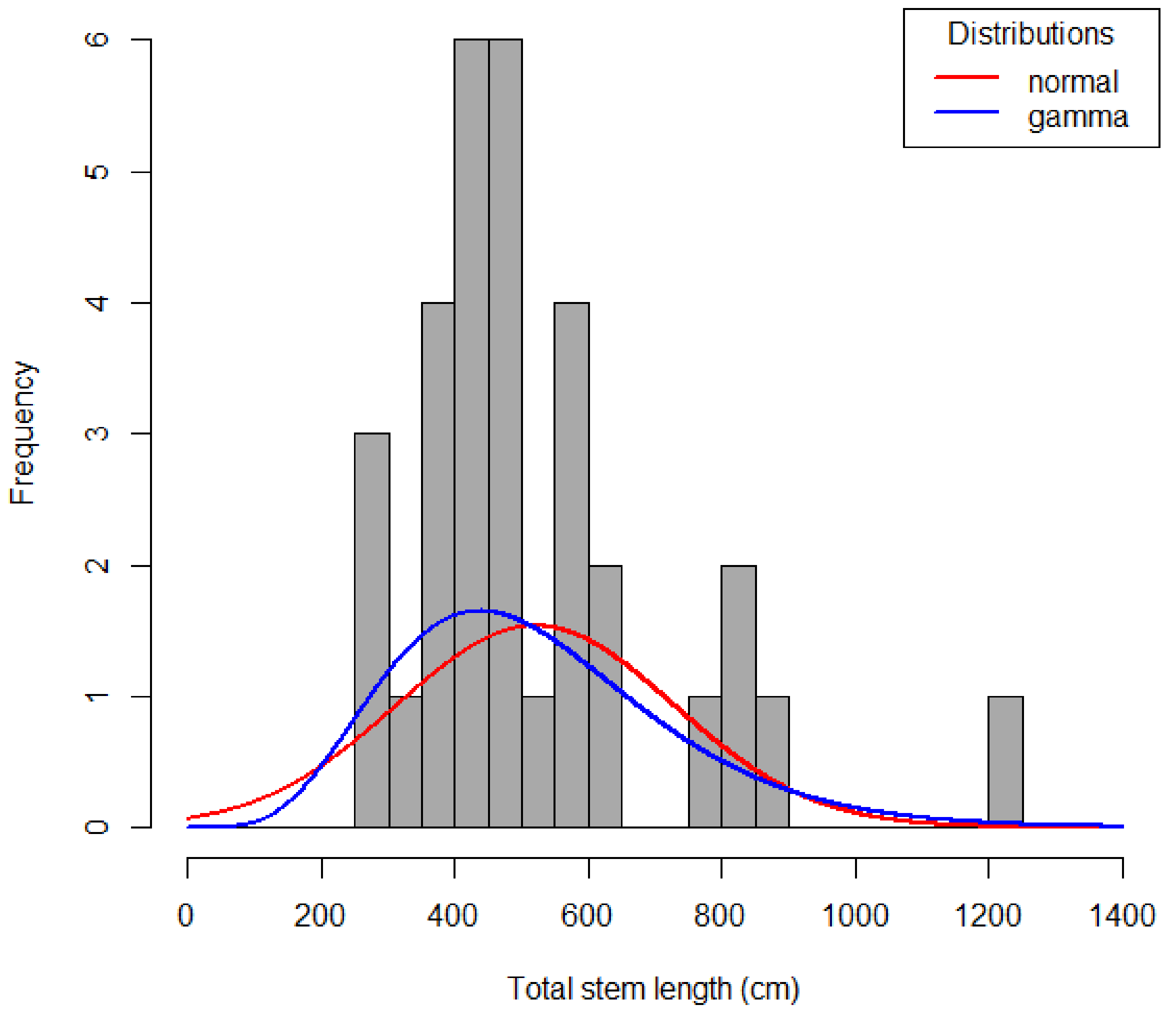

Figure 8.41.2 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow total stem length (cm) from the Skye Glen site.

Table 8.41.3 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the Skye Glen 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	399059	399059	41.961	2e-6 ***
Treatment	3	310904	103635	10.897	0.0002 ***
Crop:Treatment	3	278668	92889	9.767	0.0003 ***

Table 8.41.4 Tukey's test: Treatment effects on total stem length (cm) for poplar and willow grown in the Skye Glen 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	2.1375	-133.7732	138.0482	1.0000
PS – CT	223.2000	87.2893	359.1107	0.0009 ***
SE – CT	-14.0750	-149.9857	121.8357	0.9914

Table 8.41.5 Tukey's test: Treatment and crop effects on total stem length (cm) for poplar (PO) and willow (WW) grown in the Skye Glen 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
PO CT – WW CT	243.125	11.8321	474.4179	0.0349 *
PO DG – WW DG	216.300	-14.9929	447.5929	0.0778
PO PS – WW PS	480.425	249.1321	711.7179	2e-5 ***
PO SE – WW SE	-46.475	-277.7679	184.8179	0.9969

8.42. Average stem length, woody crops (fall 2020)

Table 8.42.1 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the East Gore 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	60.1	60.1	1.829	0.1854
Treatment	5	1637.1	327.4	9.971	7e-6 ***
Crop:Treatment	5	83.5	16.7	0.508	0.7678

Table 8.42.2 Tukey's test: Treatment effects on average stem length (cm) for poplar and willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	3.2250	-5.4383	11.8883	0.8672
DG2 – CT	5.1000	-3.5633	13.7633	0.4918
PS – CT	16.7750	8.1117	25.4383	< 0.0000 ***
SE1 – CT	0.0250	-8.6383	8.6883	1.0000
SE2 – CT	1.0625	-7.6008	9.7258	0.9990

Table 8.42.3 Two-way ANOVA: Crop, treatment, and interaction effects on average stem length (cm) for woody crops (poplar, willow) grown in the Skye Glen 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	10153	10153	102.166	1e-11 ***
Treatment	5	2287	457	4.602	0.0027 **
Crop:Treatment	5	1301	260	2.618	0.0423 *

Table 8.42.4 Tukey's test: Treatment effects on average stem length (cm) for poplar and willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	-1.8250	-16.8955	13.2455	0.9991
DG2 – CT	3.6750	-11.3955	18.7455	0.9757
PS – CT	13.2500	-1.8205	28.3205	0.1115
SE1 – CT	-9.1750	-24.2455	5.8955	0.4549
SE2 – CT	-3.2375	-18.3080	11.8330	0.9861

Table 8.42.5 Tukey's test: Treatment and crop effects on average stem length (cm) for poplar (PO) and willow (WW) grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
PO CT – WW CT	46.875	22.1253	71.6247	9e-6 ***
PO DG1 – WW DG1	34.475	9.7253	59.2247	0.0013 **
PO DG2 – WW DG2	33.525	8.7753	58.2747	0.0019 **

PO PS – WW PS	23.525	-1.2247	48.2747	0.0747
PO SE1 – WW SE1	20.425	-4.3247	45.1747	0.1880
PO SE2 – WW SE2	15.700	-9.0497	40.4497	0.5431

43. Total stem length, woody crops (fall 2020)

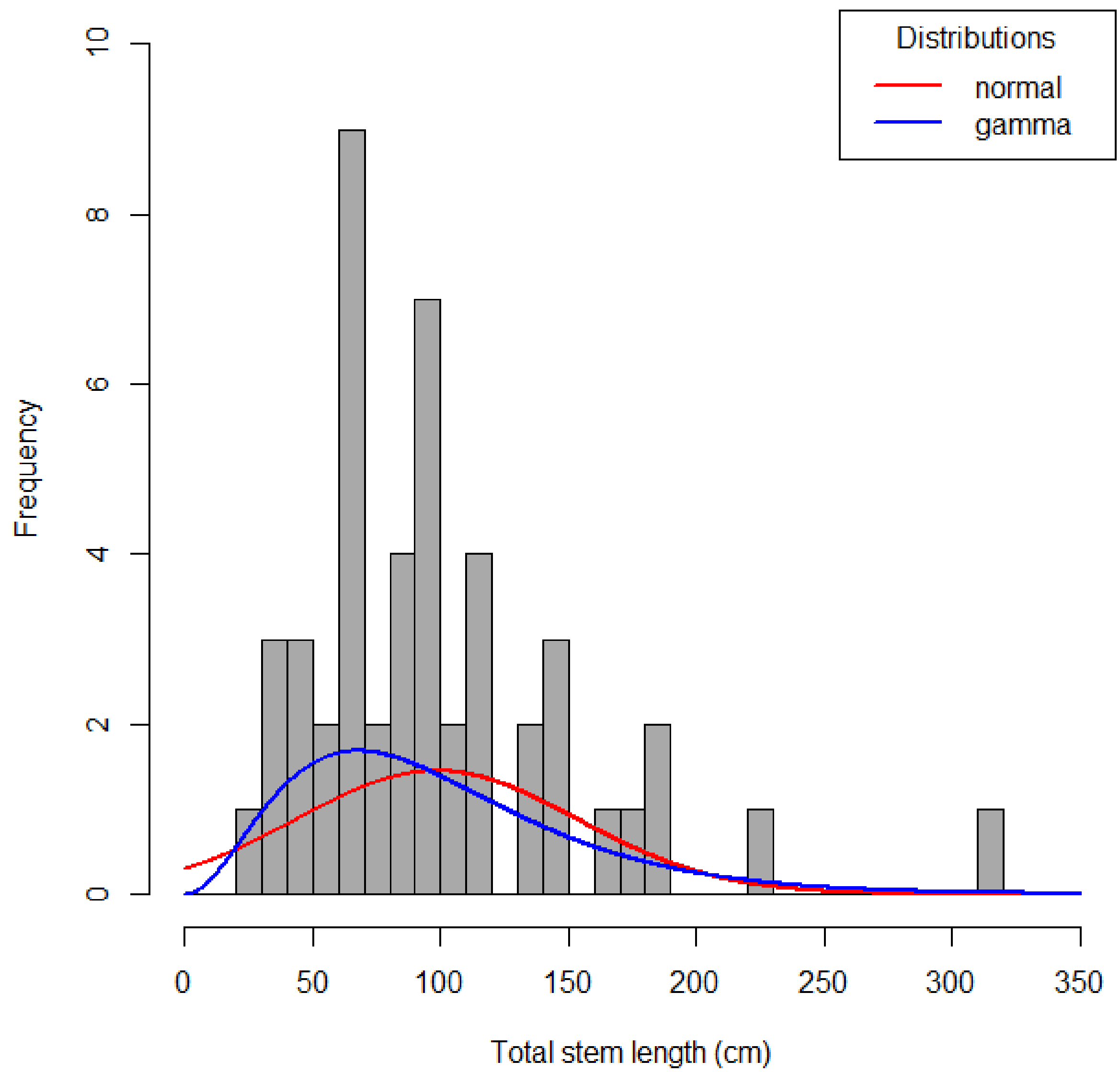

Figure 8.43.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of poplar and willow total stem length (cm) from the East Gore site.

Table 8.43.1 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the East Gore 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	12468	12468	11.383	0.0018 **
Treatment	5	89268	17854	16.300	2e-8 ***
Crop:Treatment	5	1507	301	0.275	0.9237

Table 8.43.2 Tukey's test: Treatment effects on total stem length (cm) for poplar and willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	14.4000	-35.3850	64.1850	0.9512
DG2 – CT	21.6125	-28.1725	71.3975	0.7798
PS – CT	115.3125	65.5275	165.0975	5e-7 ***
SE1 – CT	-13.5500	-63.3350	36.2350	0.9621
SE2 – CT	-3.4250	-53.2100	46.3600	0.9999

Table 8.43.3 Two-way ANOVA: Crop, treatment, and interaction effects on total stem length (cm) for woody crops (poplar, willow) grown in the Skye Glen 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	283054	283054	23.397	3e-5 ***
Treatment	5	628994	125799	10.399	5e-6 ***
Crop:Treatment	5	346563	69313	5.729	0.0007 ***

Table 8.43.4 Tukey's test: Treatment effects on total stem length (cm) for poplar and willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	-63.0000	-229.2788	103.2788	0.8586
DG2 – CT	-75.4375	-241.7163	90.8413	0.7431
PS – CT	229.6625	63.3837	395.9413	0.0026 **
SE1 – CT	-117.3875	-283.6663	48.8913	0.2952
SE2 – CT	-60.8375	-227.1163	105.4413	0.8753

Table 8.43.5 Tukey's test: Treatment and crop effects on total stem length (cm) for poplar (PO) and willow (WW) grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
PO CT – WW CT	235.175	-37.8971	508.2471	0.1465
PO DG1 – WW DG1	180.175	-92.8971	453.2471	0.4854
PO DG2 – WW DG2	208.300	-64.7721	481.3721	0.2803
PO PS – WW PS	418.550	145.4779	691.6221	0.0003 ***
PO SE1 – WW SE1	-36.050	-309.1221	237.0221	1.000
PO SE2 – WW SE2	-84.650	-357.7221	188.4221	0.9932

8.44. Stem diameter, woody crops (fall 2020)

Table 8.44.1 Two-way ANOVA: Crop, treatment, and interaction effects on stem diameter (mm) for woody crops (poplar, willow) grown in the East Gore 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	4.260	4.260	30.396	4e-6 ***
Treatment	5	7.559	1.512	10.787	3e-6 ***
Crop:Treatment	5	0.421	0.084	0.601	0.6996

Table 8.44.2 Tukey's test: Treatment effects on stem diameter (mm) for poplar and willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	0.1000	-0.4660	0.6660	0.9943
DG2 – CT	0.2250	-0.3410	0.7910	0.8327
PS – CT	1.1125	0.5465	1.6785	< 0.0000 ***
SE1 – CT	-0.0250	-0.5910	0.5410	1.0000
SE2 – CT	0.0500	-0.5160	0.6160	0.9998

Table 8.44.3 Two-way ANOVA: Crop, treatment, and interaction effects on stem diameter (mm) for woody crops (poplar, willow) grown in the Skye Glen 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	1.725	1.7252	3.728	0.0621
Treatment	5	6.384	1.2767	2.759	0.0344 *
Crop:Treatment	5	2.334	0.4667	1.008	0.4283

Table 8.44.4 Tukey's test: Treatment effects on stem diameter (mm) for poplar and willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	0.1625	-0.8659	1.1909	0.9966
DG2 – CT	0.5750	-0.4534	1.6034	0.5474
PS – CT	0.8625	-0.1659	1.8909	0.1430
SE1 – CT	-0.2000	-1.2284	0.8284	0.9912
SE2 – CT	0.0375	-0.9909	1.0659	0.9999

8.45. Estimated stem volume, woody crops (fall 2020)

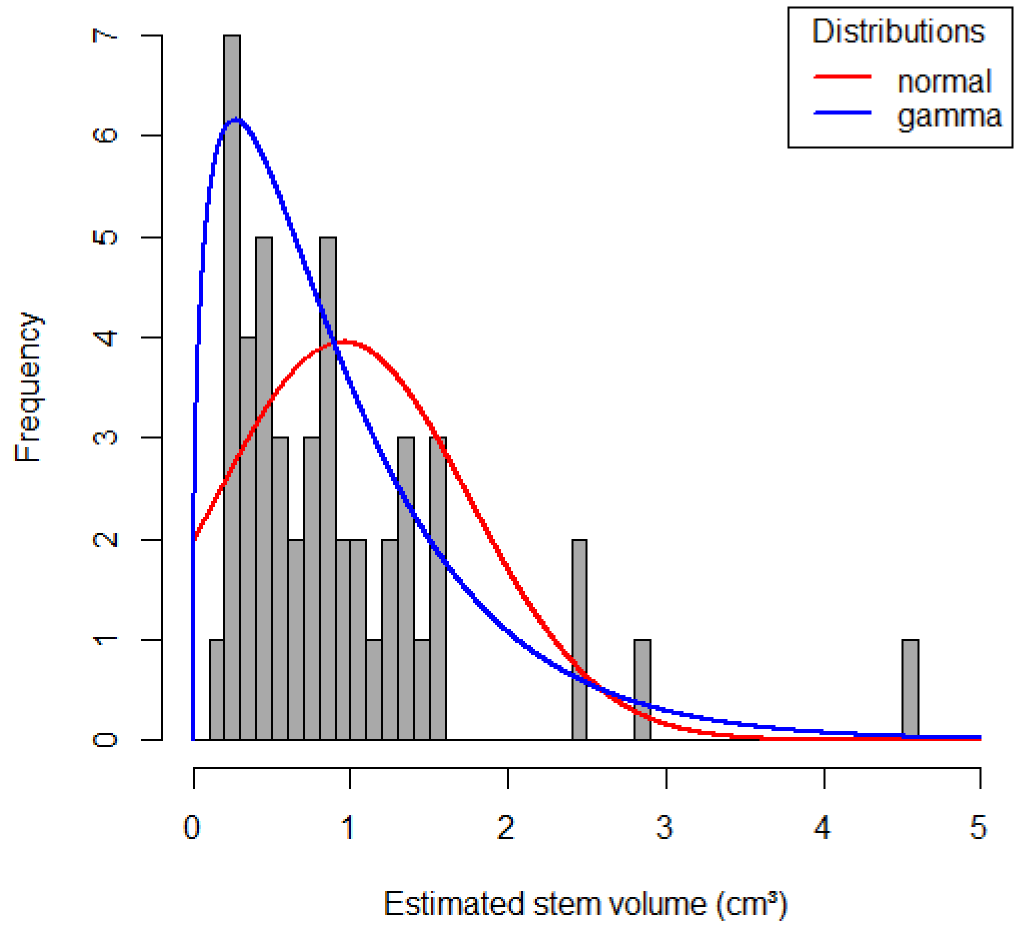

Figure 8.45.1 Probability plots for the normal (ANOVA; red) and gamma (GLM; blue) distributions on a histogram of estimated poplar and willow stem volume (cm^3) from the East Gore site.

Table 8.45.1 Two-way ANOVA: Crop, treatment, and interaction effects on estimated stem volume for woody crops (poplar, willow) grown in the East Gore 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	2.876	2.8763	9.249	0.0044 **
Treatment	5	14.965	2.9929	9.624	7e-6 ***
Crop:Treatment	5	1.623	0.3246	1.044	0.4072

Table 8.45.2 Tukey's test: Treatment effects on estimated stem volume for poplar and willow grown in the East Gore site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A.*

nodosum extract (SE1/2). 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
DG1 – CT	0.1088	-0.7301	0.9476	0.9987
DG2 – CT	0.2175	-0.6214	1.0564	0.9692
PS – CT	1.5300	0.6911	2.3689	5e-5 ***
SE1 – CT	-0.0725	-0.9114	0.7664	0.9998
SE2 – CT	0.0075	-0.8314	0.8464	1.0000

Table 8.45.3 Two-way ANOVA: Crop, treatment, and interaction effects on estimated stem volume for woody crops (poplar, willow) grown in the Skye Glen 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	466.8	466.8	13.762	0.0007 ***
Treatment	5	480.4	96.1	2.833	0.0293 *
Crop:Treatment	5	165.1	33.0	0.973	0.4471

Table 8.45.4 Tukey's test: Treatment effects on estimated stem volume for poplar and willow grown in the Skye Glen site. Treatments included a no-additives control (CT), paper sludge (PS), and two application rates of anaerobic digestate (DG1/2) and liquid *A. nodosum* extract (SE1/2). 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
DG1 – CT	-0.0525	-8.8131	8.7081	1.0000
DG2 – CT	3.0463	-5.7144	11.8069	0.8989
PS – CT	6.4350	-2.3256	15.1956	0.2583
SE1 – CT	-3.4000	-12.1606	5.3606	0.8490
SE2 – CT	-1.2588	-10.0194	7.5019	0.9979

9.0 DATABASE

9.1 Raw data

Biomass yield (2019)

Site	Crop	Treatment	Replicate	Dry weight (kg/ha)
East Gore	Switchgrass	Control	1	160.1
			2	128.9
			3	168.4

			4	227.9
		Anaerobic digestate	1	170.0
			2	176.2
			3	281.9
			4	178.8
		Paper mill sludge	1	132.2
			2	88.5
			3	144.8
			4	186.8
		A. nodosum extract	1	101.3
			2	76.7
			3	112.8
			4	144.5
	Miscanthus	Control	1	262.4
			2	242.6
			3	255.4
			4	189.0
		Anaerobic digestate	1	292.0
			2	261.4
			3	309.0
			4	359.4
		Paper mill sludge	1	377.2
			2	602.7
			3	453.4
			4	271.8
		A. nodosum extract	1	160.4
			2	165.6
			3	217.3
			4	319.0
	Poplar	Control	1	62.3
			2	35.2
			3	34.6
			4	36.3
		Anaerobic digestate	1	59.8
			2	35.2
			3	34.4
			4	43.7
		Paper mill sludge	1	194.4
			2	121.2
			3	75.0
			4	71.9

		A. nodosum extract	1	48.6
			2	40.9
			3	26.2
			4	44.3
	Willow	Control	1	21.7
			2	20.1
			3	12.5
			4	13.9
		Anaerobic digestate	1	23.4
			2	10.7
			3	19.4
			4	15.8
		Paper mill sludge	1	71.9
			2	64.1
			3	54.5
			4	73.5
		A. nodosum extract	1	15.6
			2	15.1
			3	201.6
			4	17.8
Skye Glen	Switchgrass	Control	1	469.6
			2	483.1
			3	267.3
			4	397.7
		Anaerobic digestate	1	512.5
			2	339.0
			3	317.9
			4	361.8
		Paper mill sludge	1	885.2
			2	756.8
			3	845.3
			4	629.6
		A. nodosum extract	1	508.7
			2	542.7
			3	309.3
			4	370.5
	Miscanthus	Control	1	226.0
			2	163.3
			3	361.5
			4	182.1
		Anaerobic digestate	1	299.3

			2	179.3
			3	331.4
			4	234.8
		Paper mill sludge	1	644.2
			2	576.8
			3	427.8
			4	296.0
		A. nodosum extract	1	381.0
			2	286.9
			3	450.2
			4	284.4
	Poplar	Control	1	42.8
			2	20.5
			3	19.4
			4	25.3
		Anaerobic digestate	1	41.0
			2	25.3
			3	30.1
			4	42.2
		Paper mill sludge	1	128.8
			2	144.7
			3	78.3
			4	137.3
		A. nodosum extract	1	54.0
			2	30.0
			3	21.8
			4	32.5
	Willow	Control	1	23.2
			2	25.6
			3	16.1
			4	41.3
		Anaerobic digestate	1	30.2
			2	16.7
			3	19.2
			4	19.8
		Paper mill sludge	1	285.3
			2	146.1
			3	122.1
			4	190.7
		A. nodosum extract	1	19.6
			2	16.9

			3	21.9
			4	28.1

Miscanthus tissue nutrient concentrations (2019)
All nutrients listed are in % concentrations, excluding iron, manganese, and zinc (ppm).

Site	Replicate	Treatment	N	Ca	K	Mg	P	Na	Fe	Mn	Zn
East Gore	1	Control	1.19	0.506	0.462	0.235	0.286	0.024	41.67	81.78	22.08
	2	CT	1.41	0.649	0.532	0.261	0.428	0.02	68.24	102.03	24.83
	3	CT	1.26	0.622	0.403	0.249	0.36	0.022	49.96	101.18	21.04
	4	CT	1	0.479	0.513	0.187	0.233	0.031	44.59	90.76	23.14
	1	DG	1.44	0.496	0.595	0.267	0.33	0.03	45.72	47.54	21.43
	2	DG	1.47	0.475	0.909	0.213	0.332	0.032	48.69	70.4	21.72
	3	DG	1.22	0.515	0.722	0.227	0.252	0.035	44.3	77.95	20.09
	4	DG	1.36	0.448	0.822	0.229	0.213	0.035	53.9	84.52	24.12
	1	PS	1.47	0.577	0.354	0.357	0.269	0.021	49.82	156.36	16.67
	2	PS	1.35	0.555	0.199	0.344	0.251	0.019	44.12	196.02	19.78
	3	PS	1.33	0.556	0.206	0.361	0.233	0.017	42.59	169.84	18.47
	4	PS	1.3	0.518	0.376	0.244	0.141	0.035	44.18	273.93	18.47
	1	SE	1.1	0.538	0.38	0.236	0.246	0.028	42.62	113.27	20
	2	SE	1.54	0.57	0.607	0.287	0.458	0.019	46.11	83.77	21.88
	3	SE	1.23	0.552	0.482	0.234	0.381	0.022	43.91	75.32	23.17
	4	SE	1.22	0.514	0.447	0.275	0.193	0.021	43.43	82.42	22.08
Skye Glen	1	CT	2.4	0.4	1.312	0.348	0.239	0.063	415.82	92.91	25.31
	2	CT	2.45	0.424	1.491	0.311	0.26	0.086	356.33	84.8	20.65
	3	CT	2.25	0.357	1.327	0.284	0.211	0.069	702.92	109.6	21.93
	4	CT	2.34	0.334	1.119	0.265	0.217	0.066	591.97	98.98	18.25
	1	DG	2.49	0.388	1.432	0.377	0.267	0.061	335.85	94.46	21.78
	2	DG	2.81	0.394	1.534	0.306	0.29	0.068	347.6	65.96	21.7
	3	DG	2.33	0.33	1.512	0.267	0.235	0.073	273.32	118.98	21.39
	4	DG	2.67	0.385	1.388	0.326	0.265	0.083	481.47	132.31	24.64
	1	PS	2.53	0.442	1.291	0.39	0.258	0.056	379.66	148.76	25.01
	2	PS	2.32	0.43	1.108	0.354	0.228	0.07	1302.13	211.49	22.55

	3	PS	2.59	0.441	1.216	0.413	0.267	0.064	275.66	233.41	22.6
	4	PS	2.29	0.43	1.046	0.428	0.242	0.05	269.79	275.08	24.1
	1	SE	2.66	0.437	1.402	0.351	0.273	0.067	357.67	110.14	25.13
	2	SE	2.53	0.465	1.494	0.342	0.271	0.064	431.86	112.68	24.93
	3	SE	2.61	0.371	1.525	0.298	0.258	0.077	414.03	91.01	22.71
	4	SE	2.37	0.353	1.207	0.306	0.237	0.06	1353.14	120.86	27.74

Miscanthus nutrient yield (2019)
All nutrients listed are in kg/ha.

Site	Replicate	Treatment	N	Ca	K	Mg	P	Na	Fe	Mn	Zn
East Gore	1	CT	3.122	1.327	1.212	0.617	0.75	0.063	0.011	0.021	0.006
	2	CT	3.42	1.574	1.29	0.633	1.038	0.049	0.017	0.025	0.006
	3	CT	3.218	1.588	1.029	0.636	0.919	0.056	0.013	0.026	0.005
	4	CT	1.89	0.905	0.97	0.353	0.44	0.059	0.008	0.017	0.004
	1	DG	4.299	1.481	1.777	0.797	0.985	0.09	0.014	0.014	0.006
	2	DG	3.886	1.256	2.403	0.563	0.878	0.085	0.013	0.019	0.006
	3	DG	3.854	1.627	2.281	0.717	0.796	0.111	0.014	0.025	0.006
	4	DG	4.887	1.61	2.954	0.823	0.765	0.126	0.019	0.03	0.009
	1	PS	5.543	2.176	1.335	1.346	1.014	0.079	0.019	0.059	0.006
	2	PS	8.137	3.345	1.2	2.074	1.513	0.115	0.027	0.118	0.012
	3	PS	6.168	2.578	0.955	1.674	1.08	0.079	0.02	0.079	0.009
	4	PS	3.615	1.441	1.046	0.679	0.392	0.097	0.012	0.076	0.005
	1	SE	1.784	0.873	0.616	0.383	0.399	0.045	0.007	0.018	0.003
	2	SE	2.55	0.944	1.005	0.475	0.758	0.031	0.008	0.014	0.004
	3	SE	2.673	1.2	1.048	0.509	0.828	0.048	0.01	0.016	0.005
	4	SE	3.892	1.64	1.426	0.877	0.616	0.067	0.014	0.026	0.007
Skye Glen	1	CT	11.437	1.906	6.252	1.658	1.139	0.3	0.198	0.044	0.012
	2	CT	12.039	2.084	7.327	1.528	1.278	0.423	0.175	0.042	0.01
	3	CT	17.172	2.725	10.128	2.167	1.61	0.527	0.536	0.084	0.017

	4	CT	7.724	1.102	3.694	0.875	0.716	0.218	0.195	0.033	0.006
	1	DG	17.491	2.726	10.059	2.648	1.876	0.428	0.236	0.066	0.015
	2	DG	12.177	1.707	6.648	1.326	1.257	0.295	0.151	0.029	0.009
	3	DG	14.637	2.073	9.498	1.677	1.476	0.459	0.172	0.075	0.013
	4	DG	11.943	1.722	6.209	1.458	1.185	0.371	0.215	0.059	0.011
	1	PS	37.331	6.522	19.049	5.755	3.807	0.826	0.56	0.22	0.037
	2	PS	23.464	4.349	11.206	3.58	2.306	0.708	1.317	0.214	0.023
	3	PS	23.083	3.93	10.837	3.681	2.38	0.57	0.246	0.208	0.02
	4	PS	16.266	3.054	7.43	3.04	1.719	0.355	0.192	0.195	0.017
	1	SE	15.824	2.6	8.34	2.088	1.624	0.399	0.213	0.066	0.015
	2	SE	16.736	3.076	9.883	2.262	1.793	0.423	0.286	0.075	0.016
	3	SE	20.818	2.959	12.164	2.377	2.058	0.614	0.33	0.073	0.018
	4	SE	12.163	1.812	6.195	1.57	1.216	0.308	0.694	0.062	0.014

Woody crop survival rate (2019)

Site	Replicate	Crop	Treatment	Survival rate
East Gore	1	Poplar	Control	0.92
	2			0.95
	3			0.92
	4			0.83
	1		Anaerobic digestate	1
	2			0.86
	3			0.89
	4			0.83
	1		Paper mill sludge	0.95
	2			0.94
	3			0.94
	4			0.92
	1		*A. nodosum* extract	0.94
	2			1
	3			0.86
	4			0.95
	1	Willow	Control	0.91
	2			0.86
	3			0.88
	4			0.94
	1		Anaerobic digestate	0.91
	2			0.66
	3			0.89
	4			0.91
	1		Paper mill sludge	0.97
	2			0.91
	3			0.98
	4			0.95
	1		*A. nodosum* extract	0.78
	2			0.88
	3			0.91
	4			1
Skye Glen	1	Poplar	Control	0.6
	2			0.66
	3			0.72
	4			0.83
	1		Anaerobic digestate	0.68
	2			0.57
	3			0.97

	4			0.78
	1		Paper mill sludge	0.83
	2			0.85
	3			0.83
	4			0.83
	1		*A. nodosum* extract	0.85
	2			0.75
	3			0.75
	4			0.82
Skye Glen	1	Willow	Control	0.98
	2			0.86
	3			0.85
	4			0.88
	1		Anaerobic digestate	0.75
	2			0.91
	3			0.78
	4			0.89
	1		Paper mill sludge	0.94
	2			0.85
	3			0.82
	4			0.91
	1		*A. nodosum* extract	0.88
	2			0.85
	3			0.78
	4			0.83

Post winter survival rate (2020)

Site	Replicate	Crop	Treatment	Survival rate
East Gore	1	Miscanthus	Control	1
	2			1
	3			1
	4			1
	1		Anaerobic digestate	0.98
	2			0.99
	3			0.98
	4			1
	1		Paper mill sludge	1
	2			1
	3			0.98
	4			0.98
	1		*A. nodosum* extract	0.99

	2			1
	3			1
	4			1
	1	Poplar	Control	0.95
	2			0.83
	3			0.82
	4			0.8
	1		Anaerobic digestate	0.97
	2			0.78
	3			0.92
	4			0.86
	1		Paper mill sludge	1
	2			0.98
	3			0.83
	4			0.91
	1		*A. nodosum* extract	0.94
	2			0.98
	3			0.78
	4			0.98
	1	Willow	Control	0.51
	2			0.69
	3			0.78
	4			0.78
	1		Anaerobic digestate	0.71
	2			0.8
	3			0.66
	4			0.83
	1		Paper mill sludge	0.88
	2			0.91
	3			0.95
	4			0.89
	1		*A. nodosum* extract	0.52
	2			0.75
	3			0.82
	4			0.89
Skye Glen	1	Poplar	Control	0.8
	2			0.66
	3			0.65
	4			0.77
	1		Anaerobic digestate	0.82
	2			0.55

	3			0.85
	4			0.74
	1		Paper mill sludge	0.6
	2			0.88
	3			0.74
	4			0.8
	1		*A. nodosum* extract	0.54
	2			0.62
	3			0.74
	4			0.74
	1	Willow	Control	0.88
	2			0.85
	3			0.74
	4			0.89
	1		Anaerobic digestate	0.83
	2			0.89
	3			0.72
	4			0.85
	1		Paper mill sludge	0.94
	2			0.85
	3			0.82
	4			0.89
	1		*A. nodosum* extract	0.92
	2			0.8
	3			0.74
	4			0.8

Poplar leaf count (August 2020)

Site	Replicate	Treatment	Leaf count
East Gore	1	Control	79.5
	2		49.2
	3		36.3
	4		34.9
	1	Anaerobic digestate	74.3
	2		69.4
	3		37.8
	4		35
	1	Paper mill sludge	135
	2		81.3
	3		59.6
	4		48.9

	1	*A. nodosum* extract	63.6
	2		51.9
	3		34.3
	4		37.1
Skye Glen	1	Control	93.8
	2		134.9
	3		77.7
	4		75
	1	Anaerobic digestate	81.2
	2		77.3
	3		67.9
	4		103.1
	1	Paper mill sludge	130.2
	2		108.6
	3		102.4
	4		91
	1	*A. nodosum* extract	125
	2		114.5
	3		106.4
	4		113.7

Poplar leaf area (August 2020)

Site	Replicate	Treatment	Leaf area (cm^2)
East Gore	1	Control	14.2
	2		6.8
	3		15.6
	4		12.1
	1	Anaerobic digestate	10.8
	2		12.2
	3		16.0
	4		12.0
	1	*A. nodosum* extract	12.9
	2		11.2
	3		13.5
	4		9.6
	1	Paper mill sludge	23.6
	2		15.8
	3		20.5
	4		16.7
Skye Glen	1	Control	52.9
	2		45.7

	3		41.2
	4		40
	1	Anaerobic digestate	56.1
	2		38.3
	3		33
	4		47
	1	*A. nodosum* extract	54.7
	2		38.3
	3		33.4
	4		45.1
	1	Paper mill sludge	63.9
	2		59.8
	3		42.7
	4		56.3

Poplar stem count (August 2020)

Site	Replicate	Treatment	Stem count
East Gore	1	Control	5.2
	2		4.4
	3		3.8
	4		4.2
	1	Anaerobic digestate	4.4
	2		4.7
	3		3.9
	4		4.1
	1	Paper mill sludge	7.8
	2		4.8
	3		4.3
	4		3.9
	1	*A. nodosum* extract	4.6
	2		4.7
	3		3.4
	4		4.1
Skye Glen	1	Control	4.9
	2		5.3
	3		3.9
	4		4.6
	1	Anaerobic digestate	4.5
	2		4.3
	3		5.3
	4		4.2

	1	Paper mill sludge	5.5
	2		3.9
	3		4.5
	4		3.6
	1	*A. nodosum* extract	5.6
	2		7.2
	3		4.6
	4		4.9

Poplar average stem length (August 2020)

Site	Replicate	Treatment	Average stem length (cm)
East Gore	1	Control	25.2
	2		14.4
	3		23.5
	4		16.1
	1	Anaerobic digestate	26.9
	2		22.0
	3		25.6
	4		24.0
	1	Paper mill sludge	38.6
	2		39.5
	3		40.6
	4		30.6
	1	*A. nodosum* extract	21.8
	2		16.1
	3		26.4
	4		19.1
Skye Glen	1	Control	83.3
	2		82.4
	3		66.8
	4		60.8
	1	Anaerobic digestate	91.9
	2		78.5
	3		54.0
	4		97.5
	1	Paper mill sludge	102.7
	2		121.5
	3		79.5
	4		113.0
	1	*A. nodosum* extract	101.1
	2		69.2

	3		77.5
	4		99.3

Poplar total stem length (August 2020)

Site	Replicate	Treatment	Total stem length (cm)
East Gore	1	Control	131.1
	2		63.5
	3		89.2
	4		67.8
	1	Anaerobic digestate	118.5
	2		103.5
	3		99.7
	4		98.3
	1	Paper mill sludge	301
	2		189.5
	3		174.5
	4		119.2
	1	*A. nodosum* extract	100.5
	2		75.5
	3		89.8
	4		78.5
Skye Glen	1	Control	408.1
	2		436.6
	3		260.6
	4		279.5
	1	Anaerobic digestate	413.7
	2		337.6
	3		286.2
	4		409.5
	1	Paper mill sludge	564.6
	2		473.7
	3		357.9
	4		406.8
	1	*A. nodosum* extract	565.9
	2		498.4
	3		356.7
	4		486.7

Willow leaf count (per tallest stem; August 2020)

Site	Replicate	Treatment	Stem count

East Gore	1	Control	25.5
	2		17.9
	3		16
	4		25.9
	1	Anaerobic digestate	26.8
	2		14.4
	3		20.5
	4		35.3
	1	Paper mill sludge	37.9
	2		25.8
	3		29.8
	4		27.1
	1	*A. nodosum* extract	22.8
	2		18.5
	3		17.5
	4		19.2
Skye Glen	1	Control	63.7
	2		60.8
	3		62.4
	4		70.7
	1	Anaerobic digestate	60.7
	2		65.5
	3		64.7
	4		71.1
	1	Paper mill sludge	73.1
	2		61.3
	3		61
	4		74
	1	*A. nodosum* extract	53.4
	2		46.3
	3		62.6
	4		59.8

Willow leaf area (per tallest stem; August 2020)

Site	Replicate	Treatment	Leaf area (cm^2)
Skye Glen	1	Control	13.3
	2		13.5
	3		12.5
	4		11.2
	1	Anaerobic digestate	11.7
	2		11.8

	3		12.2
	4		10.5
	1	*A. nodosum* extract	11.8
	2		7.3
	3		10.7
	4		9
	1	Paper mill sludge	21.5
	2		19.5
	3		11.5
	4		20.5

Willow stem count (August 2020)

Site	Replicate	Treatment	Stem count
East Gore	1	Control	3.3
	2		3.5
	3		4.1
	4		4.1
	1	Anaerobic digestate	4.8
	2		2.9
	3		4.3
	4		6
	1	Paper mill sludge	7.4
	2		6.6
	3		4.8
	4		3.9
	1	*A. nodosum* extract	4.7
	2		3.1
	3		3.6
	4		3.7
Skye Glen	1	Control	7.5
	2		7.4
	3		5.1
	4		7.3
	1	Anaerobic digestate	5.9
	2		8.7
	3		4.6
	4		5.1
	1	Paper mill sludge	11.5
	2		9.4
	3		8.7
	4		7.7

	1	*A. nodosum* extract	3.9
	2		6.2
	3		5.1
	4		5.3

Willow average stem length (August 2020)

Site	Replicate	Treatment	Stem length (cm)
East Gore	1	Control	12.9
	2		18.6
	3		12.3
	4		17.0
	1	Anaerobic digestate	19.0
	2		8.6
	3		11.1
	4		41.0
	1	Paper mill sludge	28.2
	2		26.7
	3		26.8
	4		28.3
	1	*A. nodosum* extract	12.9
	2		11.5
	3		12.6
	4		20.7
Skye Glen	1	Control	85.4
	2		86.2
	3		95.3
	4		81.2
	1	Anaerobic digestate	96.8
	2		95.8
	3		90.3
	4		96.5
	1	Paper mill sludge	107.9
	2		93.7
	3		97.6
	4		97.8
	1	*A. nodosum* extract	90.8
	2		80.8
	3		74.3
	4		92.1

Willow total stem length (August 2020)

Site	Replicate	Treatment	Total stem length (cm)
East Gore	1	Control	42.5
	2		65
	3		50.6
	4		69.8
	1	Anaerobic digestate	91
	2		25
	3		47.6
	4		246
	1	Paper mill sludge	209
	2		176
	3		128.5
	4		110.5
	1	*A. nodosum* extract	60.5
	2		35.5
	3		45.5
	4		76.7
Skye Glen	1	Control	640.3
	2		638
	3		486
	4		593
	1	Anaerobic digestate	571.1
	2		833.2
	3		415.5
	4		492.4
	1	Paper mill sludge	1241.2
	2		881
	3		849.5
	4		753
	1	*A. nodosum* extract	354
	2		500.8
	3		379
	4		488

Miscanthus tiller count (August 2020)

Site	Replicate	Treatment	Tiller count
East Gore	1	Control	8
	2		11.3
	3		11.8
	4		5.5

	1	Anaerobic digestate	10.7
	2		9.1
	3		12.5
	4		14.3
	1	Paper mill sludge	11.3
	2		16.9
	3		14
	4		8.9
	1	*A. nodosum* extract	6.4
	2		8
	3		9.4
	4		10.1
Skye Glen	1	Control	18.1
	2		14.5
	3		22.7
	4		17.2
	1	Anaerobic digestate	19.7
	2		12.7
	3		19
	4		17.8
	1	Paper mill sludge	20.6
	2		18.9
	3		22.9
	4		21.9
	1	*A. nodosum* extract	16.2
	2		17.5
	3		22.9
	4		18.5

Miscanthus leaf length (August 2020)

Site	Replicate	Treatment	Leaf length (cm)
East Gore	1	Control	109.1
	2		112.4
	3		115.1
	4		80.6
	1	Anaerobic digestate	140.6
	2		116.6
	3		131.8
	4		123.4
	1	Paper mill sludge	132.7
	2		129.2

	3		132.3
	4		107.8
	1	*A. nodosum* extract	100.5
	2		96.2
	3		124.2
	4		100.8
Skye Glen	1	Control	196.2
	2		162
	3		205
	4		186.3
	1	Anaerobic digestate	208.5
	2		193
	3		205.5
	4		228.5
	1	Paper mill sludge	243
	2		203.5
	3		227
	4		229.3
	1	*A. nodosum* extract	211.6
	2		201.5
	3		216
	4		211.6

Miscanthus leaf area (per tallest stem; August 2020)

Site	Replicate	Treatment	Leaf area (cm^2)
East Gore	1	Control	57.7
	2		58.4
	3		58.1
	4		43.7
	1	Anaerobic digestate	75.4
	2		62.7
	3		67.4
	4		64.3
	1	*A. nodosum* extract	53.0
	2		48.5
	3		63.3
	4		56.5
	1	Paper mill sludge	70.9
	2		61.9
	3		66.6
	4		54.0

Skye Glen	1	Control	94.0
	2		92.0
	3		95.7
	4		87.3
	1	Anaerobic digestate	104.0
	2		106.3
	3		105.5
	4		98.3
	1	*A. nodosum* extract	108.3
	2		108.8
	3		89.7
	4		106.0
	1	Paper mill sludge	103.5
	2		114.9
	3		102.9
	4		116.4

Miscanthus total leaf area (per tallest stem; August 2020)

Site	Replicate	Treatment	Total leaf area (cm^2)
East Gore	1	Control	352.1
	2		315.6
	3		447.5
	4		214.2
	1	Anaerobic digestate	482.5
	2		388.5
	3		491.8
	4		334.2
	1	*A. nodosum* extract	323.1
	2		286.0
	3		449.4
	4		305.2
	1	Paper mill sludge	397.1
	2		408.4
	3		493.1
	4		275.4
Skye Glen	1	Control	705.2
	2		727.1
	3		650.5
	4		663.6
	1	Anaerobic digestate	811.4
	2		871.6

	3		864.8
	4		737.2
	1	*A. nodosum* extract	812.2
	2		880.9
	3		780.5
	4		784.2
	1	Paper mill sludge	817.8
	2		930.6
	3		853.9
	4		873.2

Soil compositional analysis (August 2020)
Organic matter, nitrogen = % concentration
Phosphate, potash, calcium, magnesium, sodium, sulfur = kg/ha
Aluminum, copper, iron, manganese, zinc = ppm

Site	Rep	Treatment	pH	Buffer pH	OM	N	P2O5	K2O	Ca	Mg	Na	S	Al	Cu	Fe	Mn	Zn
East Gore	1	CT	6.5	7.73	6.7	0.33	200	143	3293	122	40	14	995	0.92	246	83	0.95
	2	CT	6.54	7.79	6.1	0.28	214	114	3246	92	29	15	1054	1.08	224	87	1.19
	3	CT	6.53	7.71	6.3	0.32	199	129	3287	97	30	16	1060	0.89	229	89	0.95
	4	CT	6.45	7.76	6	0.32	184	113	3270	104	31	14	1022	0.9	230	77	0.99
	1	PS	6.48	7.72	6.6	0.34	205	150	3254	111	43	14	945	0.85	248	79	0.91
	2	PS	6.49	7.76	6.1	0.31	217	116	3287	106	31	14	1061	1	218	85	1.2
	3	PS	6.49	7.73	6.5	0.32	211	125	3078	105	33	12	997	0.87	262	89	0.96
	4	PS	6.47	7.71	6.1	0.33	175	135	3065	102	34	14	1008	0.89	233	83	0.95
	1	SE	6.45	7.71	6.5	0.32	155	108	2817	104	33	13	987	0.79	242	65	0.79
	2	SE	6.44	7.76	6.4	0.31	177	110	3109	97	30	14	1079	0.93	238	88	1.4
	3	SE	6.59	7.72	6.2	0.34	216	118	3283	102	39	13	1024	0.9	234	79	1.2
	4	SE	6.38	7.72	6	0.3	160	117	3142	99	32	14	1064	0.88	233	78	0.92
	1	DG1	6.55	7.8	6.6	0.33	202	155	3261	121	42	14	1030	0.99	263	89	0.99
	2	DG1	6.53	7.73	6.5	0.34	239	138	3473	113	34	15	1091	1.07	237	95	1.34
	3	DG1	6.44	7.79	6.2	0.3	200	147	3435	112	36	14	1038	0.91	228	93	0.9
	4	DG1	6.38	7.66	6.5	0.31	178	128	2953	93	38	15	1069	0.91	239	81	1.06
	1	DG2	6.67	7.78	6.4	0.32	205	191	3055	122	119	14	987	1.12	238	75	1.08
	2	DG2	6.39	7.76	6.6	0.34	246	129	3068	106	37	14	1045	0.93	233	85	1.22
	3	DG2	6.65	7.78	6.2	0.32	208	129	3427	112	37	12	1011	0.88	236	84	0.9
	4	DG2	6.15	7.67	6	0.31	162	131	2735	102	36	15	1048	0.85	243	76	1
Skye Glen	1	CT	5.66	7.7	2.8	0.14	43	106	2152	437	72	9	929	0.71	238	63	0.7
	2	CT	5.79	7.8	2.8	0.16	38	97	2263	442	65	9	757	0.72	246	74	0.97
	3	CT	5.66	7.67	3.7	0.17	56	88	2238	448	66	10	901	0.69	252	61	1.13
	4	CT	5.8	7.88	3.4	0.17	48	99	2279	430	55	7	742	0.89	314	82	0.84

	1	PS	5.5	7.73	2.5	0.14	41	102	2138	444	75	11	840	0.57	244	61	0.64
	2	PS	5.84	7.71	3.2	0.17	41	105	2262	457	66	9	811	0.62	199	100	0.69
	3	PS	5.55	7.75	3	0.15	47	105	2189	483	64	9	798	0.42	220	53	0.63
	4	PS	5.94	7.85	2.9	0.15	42	120	2171	470	60	8	849	0.65	284	77	0.71
	1	SE	5.84	7.76	2.5	0.13	40	108	2147	428	64	11	884	0.62	258	50	0.77
	2	SE	5.63	7.78	2.8	0.16	37	112	2151	416	69	9	813	0.57	200	101	0.79
	3	SE	5.61	7.8	2.8	0.13	46	122	1766	443	56	9	934	0.58	307	34	0.83
	4	SE	5.73	7.91	2.6	0.13	37	102	1924	424	50	8	799	0.73	294	47	0.72
	1	DG1	5.71	7.73	2.7	0.15	39	111	2452	445	80	10	910	0.69	236	81	0.76
	2	DG1	5.94	7.71	2.7	0.14	35	109	2321	501	76	10	895	0.55	184	101	0.71
	3	DG1	5.55	7.79	3.5	0.17	54	149	2065	461	70	9	978	0.77	332	37	0.98
	4	DG1	6.01	7.89	2.9	0.17	42	99	2276	519	61	6	830	0.76	289	94	0.83
	1	DG2	5.92	7.77	2.4	0.12	38	132	2027	391	116	9	771	0.6	199	65	0.55
	2	DG2	5.85	7.73	3.2	0.17	52	165	2156	464	99	10	869	0.71	193	123	1.05
	3	DG2	5.87	7.81	3.2	0.15	62	143	1928	427	72	10	907	0.86	314	38	0.93
	4	DG2	5.81	7.9	2.8	0.14	50	162	2181	523	93	7	851	0.72	262	56	0.8

Soil heavy metal concentrations (August 2020)

All metals listed are in ppm.

Site	Replicate	Treatment	Al	As	Ba	Cr	Co	Cu	Fe	Pb	Li	Mn	Ni	Sr	U	V	Zn
East Gore	1	CT	17200	10	78	22	12	11	23300	15.8	42	1370	15	8	1.2	28	52
	2	CT	17800	9	66	19	10	11	26700	14.8	34	1310	15	8	1.1	24	50
	3	CT	16100	9	71	22	11	11	23800	15.2	38	1320	15	9	1.2	28	53
	4	CT	16700	11	72	19	12	12	24600	14.8	41	1250	15	7	1.3	27	52
	1	DG1	18400	9	71	21	11	11	28200	15.8	37	1310	14	8	1.2	28	49
	2	DG1	12400	10	55	15	8	10	20500	14.9	23	987	11	5	1	21	40
	3	DG1	19900	10	71	22	12	11	29700	14.9	39	1630	14	8	1.2	28	54
	4	DG1	16000	12	72	20	13	13	25100	17	46	1240	17	8	1.5	29	59
	1	DG2	19100	9	69	22	11	12	27500	15.2	41	1350	15	8	1.2	28	53

	2	DG2	20600	8	60	18	9	10	28300	13.8	33	1350	12	7	1.1	23	48
	3	DG2	21600	9	66	20	11	11	28400	13.7	37	1530	13	9	1.1	26	50
	4	DG2	18000	13	69	21	15	14	30500	17.1	44	1890	17	7	1.3	31	59
Skye Glen	1	CT	7900	5	68	11	5	5	13800	8.8	16	397	10	-	0.4	19	27
	2	CT	7880	4	50	10	6	4	16800	8.6	15	622	9	-	0.3	16	22
	3	CT	7830	6	71	11	5	5	14200	10.8	15	372	9	-	0.4	20	28
	4	CT	7590	5	48	8	5	3	16300	8.2	12	666	7	-	0.3	16	20
	1	DG1	7730	5	77	11	6	5	15200	9.1	18	540	11	-	0.4	18	27
	2	DG1	10000	6	96	12	9	5	21100	12.9	20	1320	12	-	0.5	21	32
	3	DG1	8520	4	43	8	4	5	14100	8.1	13	326	8	-	0.4	16	22
	4	DG1	7450	5	52	11	5	5	16100	10.1	16	361	10	-	0.4	19	25
	1	DG2	8290	5	64	10	5	4	16200	9.4	17	501	10	-	0.4	18	25
	2	DG2	11200	7	97	14	9	6	21700	14.4	21	1180	13	-	0.5	22	34
	3	DG2	8590	5	50	10	5	4	15800	9.9	15	345	8	-	0.4	19	25
	4	DG2	7730	6	52	11	6	4	16800	10.4	17	484	9	-	0.4	21	25

Switchgrass yield (fall 2020)

Site	Replicate	Treatment	Yield (kg/ha)
East Gore	1	Control	782.6
	2		578
	3		360
	4		385
	1	Anaerobic digestate, single application	562.9
	2		986.9
	3		589.8
	4		435.5
	1	Anaerobic digestate, dual application	849.3
	2		1536.9
	3		591.8
	4		805.6
	1	Paper mill sludge	483.7
	2		429.3
	3		345
	4		473.3
	1	*A. nodosum* extract, single application	460.1
	2		499.2
	3		360
	4		494.6
	1	*A. nodosum* extract, dual application	563.6
	2		493.3
	3		589.8
	4		655.2
Skye Glen	1	Control	835
	2		1378.9
	3		947.2
	4		758
	1	Anaerobic digestate, single application	853.7
	2		926.7
	3		1250.2
	4		678.6
	1	Anaerobic digestate, dual application	863.9
	2		1264.9
	3		1093.3
	4		921.4
	1	Paper mill sludge	662.5
	2		1038.2

	3		995.1
	4		955.4
	1	*A. nodosum* extract, single application	1066.5
	2		1052.9
	3		967.5
	4		1024.2
	1	*A. nodosum* extract, dual application	1067.6
	2		986.4
	3		1574.2
	4		987.8

Switchgrass moisture content (fall 2020)

Site	Replicate	Treatment	Moisture content (%)
East Gore	1	Control	9.5
	2		31.2
	3		26.5
	4		33
	1	Paper mill sludge	32.4
	2		35.9
	3		23.3
	4		28.3
	1	*A. nodosum* extract, single application	36.5
	2		34.7
	3		35.1
	4		32.7
	1	*A. nodosum* extract, dual application	37.4
	2		33.3
	3		32.2
	4		32.5
	1	Anaerobic digestate, single application	34.5
	2		27.4
	3		27.2
	4		29.3
	1	Anaerobic digestate, dual application	40.2
	2		38.9
	3		31.6
	4		30.6
Skye Glen	1	Control	41.4
	2		21.4
	3		24.5

	4		28.2
	1	Paper mill sludge	36.6
	2		35.7
	3		24
	4		28.4
	1	*A. nodosum* extract, single application	25.2
	2		22.6
	3		25
	4		25.2
	1	*A. nodosum* extract, dual application	30.7
	2		34.5
	3		27.1
	4		22.2
	1	Anaerobic digestate, single application	31.7
	2		28.4
	3		22.8
	4		28.6
	1	Anaerobic digestate, dual application	36.7
	2		28.3
	3		33.3
	4		23.2

Miscanthus yield (fall 2020)

Site	Replicate	Treatment	Yield (kg/ha)
East Gore	1	Control	1492.2
	2		1407
	3		1402.3
	4		518.9
	1	Anaerobic digestate, single application	2277.4
	2		1425.4
	3		2489.5
	4		1721.5
	1	Anaerobic digestate, dual application	1548.2
	2		1384.3
	3		2719.2
	4		2108.2
	1	Paper mill sludge	1894.4
	2		2523.8
	3		2280.2
	4		646.2

	1	*A. nodosum* extract, single application	494.8
	2		757.5
	3		1336.4
	4		828.6
	1	*A. nodosum* extract, dual application	745.9
	2		803.9
	3		1788.4
	4		848.7
Skye Glen	1	Control	8937.5
	2		5400
	3		8187.1
	4		5933.7
	1	Anaerobic digestate, single application	12087
	2		5597.9
	3		8902.9
	4		5823
	1	Anaerobic digestate, dual application	11918.4
	2		7465.3
	3		7884.6
	4		9237.4
	1	Paper mill sludge	12656.3
	2		10650.9
	3		10800.1
	4		10422.6
	1	*A. nodosum* extract, single application	10876.9
	2		10762
	3		10173.6
	4		9256.3
	1	*A. nodosum* extract, dual application	9780.5
	2		4507
	3		7588.4
	4		9194.9

Miscanthus moisture content (fall 2020)

Site	Replicate	Treatment	Moisture content (%)
East Gore	1	Control	35.5
	2		35.9
	3		33.8
	4		28.7
	1	Paper mill sludge	36.1

	2		35.1
	3		29.7
	4		34.5
	1	*A. nodosum* extract, single application	30.5
	2		33.3
	3		33.8
	4		29.9
	1	*A. nodosum* extract, dual application	31.8
	2		31.9
	3		32.3
	4		31.2
	1	Anaerobic digestate, single application	33.8
	2		32.8
	3		36.8
	4		38.1
	1	Anaerobic digestate, dual application	34.9
	2		35
	3		38.7
	4		34.8
Skye Glen	1	Control	39.9
	2		41.9
	3		38.7
	4		41.8
	1	Paper mill sludge	40
	2		41.3
	3		38.2
	4		37.2
	1	*A. nodosum* extract, single application	39.3
	2		26.5
	3		29.2
	4		24.1
	1	*A. nodosum* extract, dual application	35.3
	2		51.5
	3		37.7
	4		41.3
	1	Anaerobic digestate, single application	37.8
	2		42.7
	3		26.7
	4		35.7
	1	Anaerobic digestate, dual application	37.8
	2		34.1

	3		35.8
	4		39.8

Miscanthus tissue nutrient concentrations (fall 2020)

All nutrients listed are in % concentrations, excluding iron, manganese, and zinc (ppm).

Site	Replicate	Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn
East Gore	1	CT	0.62	0.18	0.127	0.533	0.097	-	21.56	57.45	29.58
	2	CT	0.69	0.254	0.17	0.65	0.168	-	26.18	81.21	28.55
	3	CT	0.7	0.25	0.167	0.565	0.149	-	26.2	100.39	28.99
	1	DG1	0.64	0.198	0.148	0.496	0.079	-	21.17	35.93	26.71
	2	DG1	0.84	0.267	0.192	0.542	0.162	-	26.04	59.23	40.28
	3	DG1	0.82	0.262	0.193	0.577	0.128	-	20.82	99.95	34.11
	1	DG2	0.7	0.184	0.13	0.492	0.103	-	24.23	42.86	24.39
	2	DG2	0.94	0.235	0.155	0.551	0.155	-	25.83	59.64	26.49
	3	DG2	0.75	0.219	0.17	0.515	0.129	-	23.55	86.84	28.08
	1	PS	0.57	0.16	0.127	0.436	0.075	-	16.86	46.61	30.27
	2	PS	0.57	0.196	0.127	0.531	0.122	-	20.98	143.84	24.87
	3	PS	0.71	0.228	0.135	0.631	0.167	-	22.5	128.08	33.81
	1	SE1	0.84	0.23	0.165	0.56	0.095	-	27.92	80.65	36
	2	SE1	0.83	0.269	0.173	0.545	0.156	-	29.24	61.35	31.76
	3	SE1	0.64	0.231	0.134	0.502	0.134	-	20.95	56.39	28.38
	1	SE2	0.95	0.233	0.153	0.529	0.105	-	33.38	89.85	29.41
	2	SE2	0.92	0.296	0.221	0.604	0.144	-	28.91	71.56	42.57
	3	SE2	0.76	0.288	0.172	0.631	0.176	-	24.61	76.72	30.79
Skye Glen	1	CT	0.4	0.071	0.169	0.236	0.124	0.019	18.2	142.89	25.15
	2	CT	0.46	0.105	0.305	0.26	0.116	0.015	22.77	121.82	26.47
	3	CT	0.38	0.085	0.449	0.231	0.101	0.027	16.12	71.74	21.2
	1	DG1	0.25	0.064	0.182	0.155	0.081	0.001	13.45	122.5	16.56
	2	DG1	0.57	0.086	0.308	0.268	0.127	0.018	19.48	93.74	31.6
	3	DG1	0.5	0.129	0.62	0.27	0.113	0.028	22.61	142.78	31.55
	1	DG2	0.31	0.073	0.315	0.177	0.102	0.02	18.83	93.49	15.05
	2	DG2	0.39	0.093	0.414	0.217	0.101	0.028	16.55	75.43	23.44

	3	DG2	0.36	0.065	0.344	0.197	0.084	0.023	14.43	103.57	21.35
	1	PS	0.44	0.062	0.279	0.219	0.096	0.019	25.86	126.4	14.3
	2	PS	0.39	0.1	0.331	0.261	0.099	0.024	16.4	80.54	24.04
	3	PS	0.37	0.067	0.312	0.227	0.098	0.032	14.88	167.27	23.46
	1	SE1	0.49	0.106	0.276	0.227	0.104	0.022	19.82	86.54	19.64
	2	SE1	0.43	0.116	0.364	0.253	0.101	0.021	19	98.78	26.46
	3	SE1	0.34	0.091	0.315	0.249	0.115	0.022	15.34	200.86	22.03
	1	SE2	0.62	0.145	0.348	0.344	0.118	0.032	30.47	159.43	26.92
	2	SE2	0.7	0.174	0.45	0.384	0.194	0.028	29.3	90.67	26.44
	3	SE2	0.44	0.108	0.347	0.251	0.1	0.028	26.11	122.31	20.69

Miscanthus nutrient yield (fall 2020)
All nutrients listed are in kg/ha.

Site	Replicate	Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn
East Gore	1	CT	9.252	2.686	1.895	7.953	1.447	-	0.032	0.086	0.044
	2	CT	9.708	3.574	2.392	9.146	2.364	-	0.037	0.114	0.04
	3	CT	9.816	3.506	2.342	7.923	2.089	-	0.037	0.141	0.041
	1	DG1	14.575	4.509	3.371	11.296	1.799	-	0.048	0.082	0.061
	2	DG1	11.974	3.806	2.737	7.726	2.309	-	0.037	0.084	0.057
	3	DG1	20.414	6.522	4.805	14.364	3.187	-	0.052	0.249	0.085
	1	DG2	10.838	2.849	2.013	7.617	1.595	-	0.038	0.066	0.038
	2	DG2	13.013	3.253	2.146	7.628	2.146	-	0.036	0.083	0.037
	3	DG2	20.394	5.955	4.623	14.004	3.508	-	0.064	0.236	0.076
	1	PS	10.798	3.031	2.406	8.26	1.421	-	0.032	0.088	0.057
	2	PS	14.386	4.947	3.205	13.402	3.079	-	0.053	0.363	0.063
	3	PS	16.19	5.199	3.078	14.388	3.808	-	0.051	0.292	0.077
	1	SE1	4.156	1.138	0.816	2.771	0.47	-	0.014	0.04	0.018
	2	SE1	6.287	2.038	1.31	4.128	1.182	-	0.022	0.046	0.024
	3	SE1	8.553	3.087	1.791	6.709	1.791	-	0.028	0.075	0.038

	1	SE2	7.086	1.738	1.141	3.946	0.783	-	0.025	0.067	0.022
	2	SE2	7.396	2.38	1.777	4.856	1.158	-	0.023	0.058	0.034
	3	SE2	13.592	5.151	3.076	11.285	3.148	-	0.044	0.137	0.055
Skye Glen	1	CT	35.75	6.346	15.104	21.093	11.083	1.698	0.163	1.277	0.225
	2	CT	24.84	5.67	16.47	14.04	6.264	0.81	0.123	0.658	0.143
	3	CT	31.111	6.959	36.76	18.912	8.269	2.211	0.132	0.587	0.174
	1	DG1	30.218	7.736	21.998	18.735	9.79	0	0.163	1.481	0.2
	2	DG1	31.908	4.814	17.242	15.002	7.109	1.008	0.109	0.525	0.177
	3	DG1	44.515	11.485	55.198	24.038	10.06	2.493	0.201	1.271	0.281
	1	DG2	36.947	8.7	37.543	21.096	12.157	2.384	0.224	1.114	0.179
	2	DG2	29.115	6.943	30.906	16.2	7.54	2.09	0.124	0.563	0.175
	3	DG2	28.384	5.125	27.123	15.533	6.623	1.813	0.114	0.817	0.168
	1	PS	55.688	7.847	35.311	27.717	12.15	2.405	0.327	1.6	0.181
	2	PS	41.539	10.651	35.254	27.799	10.544	2.556	0.175	0.858	0.256
	3	PS	39.96	7.236	33.696	24.516	10.584	3.456	0.161	1.807	0.253
	1	SE1	53.297	11.53	30.02	24.691	11.312	2.393	0.216	0.941	0.214
	2	SE1	46.276	12.484	39.174	27.228	10.87	2.26	0.204	1.063	0.285
	3	SE1	34.59	9.258	32.047	25.332	11.7	2.238	0.156	2.043	0.224
	1	SE2	60.639	14.182	34.036	33.645	11.541	3.13	0.298	1.559	0.263
	2	SE2	31.549	7.842	20.281	17.307	8.744	1.262	0.132	0.409	0.119
	3	SE2	33.389	8.196	26.332	19.047	7.588	2.125	0.198	0.928	0.157

Poplar average stem length (fall 2020)

Site	Replicate	Treatment	Stem length (cm)
East Gore	1	Control	31.5
	2		17.3
	3		27.1
	4		16.4
	1	Paper mill sludge	50.6
	2		40.1
	3		41.3
	4		28.6
	1	*A. nodosum* extract, single application	21.3
	2		15
	3		26.8
	4		19.5
	1	*A. nodosum* extract, dual application	25
	2		18.9
	3		30.6
	4		19.7
	1	Anaerobic digestate, single application	32.7
	2		25.9
	3		28.5
	4		25.8
	1	Anaerobic digestate, dual application	33.7
	2		25.8
	3		33.9
	4		21.5
Skye Glen	1	Control	90.7
	2		86.7
	3		56.7
	4		68.4
	1	Paper mill sludge	112.6
	2		109.2
	3		80.8
	4		99.6
	1	*A. nodosum* extract, single application	82.6
	2		84.8
	3		63.9
	4		87.4
	1	*A. nodosum* extract, dual application	108.4
	2		77.3
	3		75.8

	4		90.4
	1	Anaerobic digestate, single application	98.4
	2		63.8
	3		62.3
	4		95.5
	1	Anaerobic digestate, dual application	101.2
	2		82.9
	3		64.2
	4		95.6

Poplar total stem length (fall 2020)

Site	Replicate	Treatment	Total stem length (cm)
East Gore	1	Control	138.6
	2		62.2
	3		92
	4		65.6
	1	Paper mill sludge	318.7
	2		188.4
	3		177.6
	4		131.6
	1	*A. nodosum* extract, single application	74.4
	2		51
	3		88.6
	4		62.5
	1	*A. nodosum* extract, dual application	107.7
	2		81.2
	3		91.9
	4		92.6
	1	Anaerobic digestate, single application	147.2
	2		93.4
	3		114.1
	4		92.9
	1	Anaerobic digestate, dual application	144.8
	2		113.4
	3		105.2
	4		113.8
Skye Glen	1	Control	489.7
	2		597.9
	3		329.1
	4		348.8

	1	Paper mill sludge	776.7
	2		600.5
	3		412.3
	4		527.9
	1	*A. nodosum* extract, single application	404.6
	2		525.7
	3		383.6
	4		524.5
	1	*A. nodosum* extract, dual application	607.2
	2		510.1
	3		538.3
	4		506.2
	1	Anaerobic digestate, single application	501.8
	2		325.3
	3		261.7
	4		534.7
	1	Anaerobic digestate, dual application	313.8
	2		373
	3		314.4
	4		516.3

Poplar stem diameter (fall 2020)

Site	Replicate	Treatment	Stem diameter (mm)
East Gore	1	Control	3.6
	2		2.3
	3		3.3
	4		2.6
	1	Paper mill sludge	4.8
	2		4
	3		4.2
	4		3.4
	1	*A. nodosum* extract, single application	2.8
	2		2.1
	3		3.2
	4		2.7
	1	*A. nodosum* extract, dual application	3
	2		2.6
	3		3.3
	4		2.5
	1	Anaerobic digestate, single application	3.3
	2		2.9

	3		2.8
	4		2.8
	1	Anaerobic digestate, dual application	3.2
	2		2.7
	3		3.4
	4		2.7
Skye Glen	1	Control	6.8
	2		6.8
	3		4.6
	4		4.9
	1	Paper mill sludge	7.8
	2		8
	3		6.1
	4		6.6
	1	*A. nodosum* extract, single application	6.7
	2		6.6
	3		4.7
	4		6.4
	1	*A. nodosum* extract, dual application	7.8
	2		6.2
	3		5.6
	4		6.4
	1	Anaerobic digestate, single application	7.3
	2		5.7
	3		5
	4		6.7
	1	Anaerobic digestate, dual application	8.3
	2		6.6
	3		5.1
	4		6.9

Poplar estimated stem volume (fall 2020)

Site	Replicate	Treatment	Estimated stem volume (cm^3)
East Gore	1	Control	1.6
	2		0.4
	3		1.2
	4		0.4
	1	Paper mill sludge	4.6
	2		2.5
	3		2.9

	4		1.3
	1	Anaerobic digestate, single application	1.4
	2		0.9
	3		0.9
	4		0.8
	1	Anaerobic digestate, dual application	1.3
	2		0.7
	3		1.5
	4		0.6
	1	*A. nodosum* extract, single application	0.6
	2		0.3
	3		1.1
	4		0.5
	1	*A. nodosum* extract, dual application	0.9
	2		0.5
	3		1.3
	4		0.5
Skye Glen	1	Control	16.6
	2		15.8
	3		4.7
	4		6.4
	1	Paper mill sludge	27.0
	2		27.2
	3		11.7
	4		17.2
	1	Anaerobic digestate, single application	20.7
	2		8.3
	3		6.0
	4		16.8
	1	Anaerobic digestate, dual application	27.1
	2		14.0
	3		6.7
	4		17.9
	1	*A. nodosum* extract, single application	14.6
	2		14.5
	3		5.4
	4		14.1
	1	*A. nodosum* extract, dual application	25.9
	2		11.7
	3		9.3
	4		14.6

Willow average stem length (fall 2020)

Site	Replicate	Treatment	Stem length (cm)
East Gore	1	Control	24.5
	2		13.2
	3		19
	4		26.3
	1	Paper mill sludge	36.4
	2		32.5
	3		32
	4		48
	1	*A. nodosum* extract, single application	30.5
	2		16.2
	3		22.2
	4		24
	1	*A. nodosum* extract, dual application	22.9
	2		15.9
	3		18.8
	4		32
	1	Anaerobic digestate, single application	18.8
	2		20
	3		18.1
	4		31.3
	1	Anaerobic digestate, dual application	33.9
	2		17.5
	3		19.7
	4		30.1
Skye Glen	1	Control	135.7
	2		112.8
	3		123.5
	4		118
	1	Paper mill sludge	125.4
	2		116
	3		118.6
	4		136.3
	1	*A. nodosum* extract, single application	90.3
	2		96.2
	3		97.7
	4		116.2
	1	*A. nodosum* extract, dual application	112.8
	2		88.3

	3		107
	4		106.6
	1	Anaerobic digestate, single application	114.9
	2		110.6
	3		108.9
	4		123.5
	1	Anaerobic digestate, dual application	118.7
	2		112
	3		116.4
	4		130.9

Willow total stem length (fall 2020)

Site	Replicate	Treatment	Total stem length (cm)
East Gore	1	Control	49
	2		38.3
	3		62.7
	4		100
	1	Paper mill sludge	145.5
	2		188.4
	3		160.1
	4		220.6
	1	*A. nodosum* extract, single application	64
	2		25.9
	3		68.9
	4		64.7
	1	*A. nodosum* extract, dual application	36.7
	2		34.9
	3		43.2
	4		92.8
	1	Anaerobic digestate, single application	75
	2		52
	3		61.4
	4		87.6
	1	Anaerobic digestate, dual application	111.8
	2		43.7
	3		61.2
	4		87.4
Skye Glen	1	Control	719.4
	2		699.1
	3		555.9

	4		731.8
	1	Paper mill sludge	1279.1
	2		963
	3		972.7
	4		776.8
	1	*A. nodosum* extract, single application	397.5
	2		548.1
	3		341.8
	4		406.8
	1	*A. nodosum* extract, dual application	361.1
	2		565.1
	3		363.8
	4		533.2
	1	Anaerobic digestate, single application	666.3
	2		807.1
	3		413.8
	4		457
	1	Anaerobic digestate, dual application	652.6
	2		772.7
	3		454.1
	4		471.3

Willow stem diameter (fall 2020)

Site	Replicate	Treatment	Stem diameter (mm)
East Gore	1	Control	2.4
	2		1.8
	3		1.8
	4		2.6
	1	Paper mill sludge	3.4
	2		3.2
	3		2.7
	4		3.6
	1	*A. nodosum* extract, single application	2.9
	2		2.2
	3		2.1
	4		2.2
	1	*A. nodosum* extract, dual application	2.7
	2		2.1
	3		1.9
	4		2.7
	1	Anaerobic digestate, single application	2.2

	2		2.3
	3		2
	4		2.9
	1	Anaerobic digestate, dual application	3.1
	2		2.4
	3		2
	4		2.7
Skye Glen	1	Control	7.2
	2		6.6
	3		7.2
	4		6.7
	1	Paper mill sludge	7.2
	2		6.8
	3		7.1
	4		8.1
	1	*A. nodosum* extract, single application	5.8
	2		6
	3		6.1
	4		6.9
	1	*A. nodosum* extract, dual application	6.7
	2		5.4
	3		6.5
	4		6.5
	1	Anaerobic digestate, single application	6.9
	2		6.7
	3		6.6
	4		7.2
	1	Anaerobic digestate, dual application	7.4
	2		6.6
	3		7.1
	4		7.4

Willow stem volume estimate (fall 2020)

Site	Replicate	Treatment	Estimated stem volume (cm^3)
East Gore	1	Control	0.6
	2		0.2
	3		0.3
	4		0.7
	1	Paper mill sludge	1.6
	2		1.3

	3		0.9
	4		2.4
	1	Anaerobic digestate, single application	0.4
	2		0.4
	3		0.3
	4		1.1
	1	Anaerobic digestate, dual application	1.3
	2		0.4
	3		0.3
	4		0.9
	1	*A. nodosum* extract, single application	1.0
	2		0.3
	3		0.4
	4		0.5
	1	*A. nodosum* extract, dual application	0.7
	2		0.3
	3		0.3
	4		0.9
Skye Glen	1	Control	27.7
	2		19.2
	3		25.5
	4		20.8
	1	Paper mill sludge	25.5
	2		21.1
	3		23.3
	4		35.2
	1	Anaerobic digestate, single application	21.5
	2		19.3
	3		18.4
	4		25.3
	1	Anaerobic digestate, dual application	25.6
	2		19.0
	3		22.7
	4		27.9
	1	*A. nodosum* extract, single application	11.7
	2		13.5
	3		14.1
	4		21.5
	1	*A. nodosum* extract, dual application	19.8
	2		10.0
	3		17.8

	4		17.5

9.2 R code

DVAR = dependent variable
DATABASE = imported data source

One-way ANOVA – generalized linear model

This code analyzed normally distributed data using one-way analysis of variance through a generalized linear model.

```
#Levene's Test tests the homogeneity of variances, an assumption of ANOVA.
library(car)
my.levene <- with(DATABASE, leveneTest(DVAR, Treatment))
my.levene.pval <-max(my.levene$'Pr(>F)', na.rm=TRUE) #Removing NA value
#If the p-value is greater than the alpha (0.05), variances are equal
(homoscedastic).
my.levene.pval
my.levene.pval > 0.05

#Shapiro-Wilk’s Test tests for normality, an assumption of ANOVA.
my.shapiro <- shapiro.test(DATABASE$DVAR)
#If the p-value is greater than the alpha (0.05), data are normally
distributed.
my.shapiro$p.value
my.shapiro$p.value > 0.05

#Making a Generalized Linear Model
glim <- glm(DVAR ~ Treatment,
      gaussian(link = identity),
      data = DATABASE)

#Running the GLM through ANOVA
ANOVA.glim <- anova(glim,
      test = "F")
      print(ANOVA.glim) #Displaying ANOVA

#Running a Tukey post-hoc test on the GLM
library(multcomp)
tukey <- glht(glim,
      linfct = mcp(Treatment = "Tukey"))
summary(tukey)
cld(tukey, decreasing = TRUE) #Displaying Tukey test
```

If data was not normally distributed, the following code was changed as such:

```
#Making a Generalized Linear Model
glim <- glm(DVAR ~ Treatment,
      Gamma(link = log),
      data = DATABASE)
```

One-way ANOVA – visualization
This code generated graphs for the one-way analyses of variance.

```
#COMPUTING BAR GRAPH
library(dplyr)
library(ggplot2)
options(dplyr.summarise.inform = FALSE) #Package updated, hides message
about an experimental ".groups" paramater

my.summary <- DATABASE %>% #Establish data frame
group_by(Treatment) %>%   #The grouping variable
      summarise(n_DW = n(),  #Sample size per group
      mean_DW = mean(DVAR),  #Mean of each group
      SE_DW = sd(DVAR)/sqrt(n())) #Standard error of each group

my.plot <- ggplot(my.summary, aes(Treatment, mean_DW)) +
      geom_col() +
      geom_errorbar(aes(ymin = mean_DW - SE_DW, ymax = mean_DW + SE_DW),
width = 0.2)

#Assigning label names
my.labels <- c("a","a","a","a","a","a") #CT, DG1, DG2, PS, SE1, SE2
my.ycord <-c(my.summary$mean_DW/2)

#DRAWING BAR GRAPH
my.plot +
      labs(y="Average DVAR ± SE", x = "Treatment") +
      theme_classic() + #Removing background lines
      scale_y_continuous(expand = expansion(mult = c(0, .1))) + #Removing
empty space at the bottom
      geom_text(label = my.labels, y = my.ycord, size = 20) + #Adding bar
labels

theme(axis.line = element_line(colour="black",size = 1),
      axis.ticks = element_line(colour="black",size = 1),
      axis.title.y = element_text(vjust=1.5,size=12),
      axis.text.y                                                     =
element_text(colour="black",vjust=0.5,size=12,angle=0),
      axis.title.x = element_text(vjust=-0.5,size=12),
      axis.text.x                                                     =
element_text(colour="black",vjust=0.5,size=12,angle=0))
```

Probability plots
This code generated plots comparing gaussian and gamma distributions against the desired dataset.

```
#Finding the max value, and rounding it to the nearest 5
DW.round5 <-(round(max(DATABASE$DVAR)/5)*5)+5
message(max(DATABASE$DVAR), " is now ", DW.round5)

#Establishing graph margins
par(mar = c(5, 4.5, 2, 2))

#COMPUTING & DRAWING HISTOGRAM
hist(DATABASE$DVAR,
```

```
main = NULL, #Removing title
xlab = "DVAR",
xlim = c(0,DW.round5),
breaks = seq(0, DW.round5, by = 5),
col = "darkgray"
)

#COMPUTING & DRAWING NORMAL DISTRIBUTION
length.DW <-length(DATABASE$DVAR)
mean.DW <-mean(DATABASE$DVAR)
var.DW <-var(DATABASE$DVAR)

lines(seq(0, DW.round5, 0.1),
length.DW*dnorm(seq(0, DW.round5, 0.1), mean.DW, sqrt(var.DW)),
lwd = 2,
col = "red")

#COMPUTING & DRAWING GAMMA DISTRIBUTION
rate.DW <-mean.DW/var.DW
shape.DW <-rate.DW*mean.DW

lines(seq(0, DW.round5, 0.1),
length.DW*dgamma(seq(0, DW.round5, 0.1), shape.DW, rate.DW,),
lwd = 2,
col="blue")

#DRAWING LEGEND
Legend.colours <- c("red", "blue")
Legend.labels <- c("normal", "gamma")

legend("topright",
title = "Distributions",
Legend.labels,
lwd = 2,
col = Legend.colours)
```

Two-way ANOVA – generalized linear model

This code analyzed normally distributed data using two-way analysis of variance through a generalized linear model.

```
#Levene's Test tests the homogeneity of variances, an assumption of ANOVA.
library(car)
leveneTest(DVAR ~ Crop * Treatment, data = DATABASE)

#Making a Generalized Linear Model
glim <-glm(DVAR ~ Crop * Treatment,
      gaussian(link = identity),
      data = DATABASE)

#Running the GLM through ANOVA
ANOVA.glim <- aov(glim)
summary(ANOVA.glim) #Displaying ANOVA

#Shapiro-Wilk’s Test tests for normality, an assumption of ANOVA.
shapiro.test(x = aov.residuals)
```

```
TukeyHSD(ANOVA.glim, which = "Crop:Treatment")
```

If data was not normally distributed, the following code was changed as such:

```
#Making a Generalized Linear Model
glim <-glm(DVAR ~ Crop * Treatment + Rep,
      Gamma(link = log),
      data = DATABASE)
```

Two-way ANOVA – visualization
This code generated graphs for the two-way analyses of variance.

```
#COMPUTING BAR GRAPH
library(dplyr)
library(ggplot2)
options(dplyr.summarise.inform = FALSE) #Package updated, hides message
about an experimental ".groups" parameter

the_summary <- DATABASE %>%
group_by(Crop, Treatment) %>% #Grouping variables
dplyr::summarise(the_n = n(), #Sample size per group
the_mean = mean(DVAR), #Mean per group
the_SE = sd(DVAR)/sqrt(the_n)) #Standard per group

the_plot <- ggplot(the_summary,
      aes(x=factor(Treatment), y = the_mean, fill = Crop)) +
      stat_summary(fun = "mean", geom = "bar", position = "dodge") +
      geom_errorbar(aes(ymin = the_mean - the_SE, ymax = the_mean +
the_SE), width = 0.2, position = position_dodge(.9))

#Assigning label names
the_labels <- c("a","c","e","g","b","d","f","h")

#DRAWING BAR GRAPH
the_plot +

labs(y="DVAR ± SE", x = "Treatment") +

theme_classic() + #Removing background lines

scale_y_continuous(expand = expansion(mult = c(0, .1))) + #Removing empty
space at the bottom

geom_text(label = the_labels, vjust = 4.5, position = position_dodge(width
= 0.9), size = 20) + #Adding bar labels

theme(axis.line = element_line(colour="black",size = 1),
axis.ticks = element_line(colour="black",size = 1),
axis.title.y = element_text(vjust=1.5,size=12),
axis.text.y = element_text(colour="black",vjust=0.5,size=12,angle=0),
axis.title.x = element_text(vjust=-0.5,size=12),
axis.text.x = element_text(colour="black",vjust=0.5,size=12,angle=0)) +

scale_fill_grey(start = 0.5, end = 0.25, labels = c("Poplar", "Willow"))
```