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Kaolinite as an Amendment for Counteracting Hydrophobicity in Artificial Peat-based Potting Substrates

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KAOLINITE AS AN AMENDMENT FOR COUNTERACTING HYDROPHOBICITY IN ARTIFICIAL PEAT-BASED POTTING SUBSTRATES

by

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A thesis submitted to the University of Plymouth in partial fulfilment for the degree of

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AUTHOR'S DECLARATION

At no time during the registration for the degree of Research Masters has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

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School of Biological Sciences Showcase. Postgraduate Society of Plymouth’s Nobel Sessions (presented lecture on the science behind Terraforming). Postgraduate Research Showcases. Global Challenges Research Fund Event. Global Challenges Research Fund event. Women in STEM (2016 & 2017). British Society of Soil Science annual conference, 2016. The Sustainable Earth Institute conference (2016 & 2017). European Geosciences Union Annual general meeting – EGU17

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SARAH BETTANY

It has been demonstrated in pot experiments at Duchy College Rosewarne, Cornwall, U.K. that adding kaolinite (china clay) to growing media results in an increase in plant biomass. However, the underlying reason for this response is unknown, though, it is speculated that it improves the plants' ability to tolerate stressful conditions such as heat and drought. In this study four artificial organic substrates (peat, peat/green waste, John Innes no.2 and a bark-based substrate) containing different concentrations of kaolinite (0%, 5%, 10%, 20% and 40%) were tested for capillary rise and water drop penetration time (WDPT).

In addition, plant growth experiments investigated biomass accumulation of *Brassica juncea* (green mustard) and *Triticum aestivum* (winter wheat) grown in pots in substrates containing a range of kaolinite concentrations (0%, 0.5%, 1%, 1.5%, 2%, 5%, 10%, 20%, 25%, 40%, 50% and 100% in different experiments). Capillary rise and WDPT tests showed that the presence of kaolinite significantly counteracted substrate hydrophobicity and the incorporation of Kaolinite in growing substrate increased biomass production in *B. juncea* in treatments (0%, 5%, 10%, 20% and 40%) when compared to those grown in substrates without Kaolinite. Further, the addition of Kaolinite (in the peat/green waste substrate) improved water penetration in substrates that were hydrophobic due to drought. The results of this study suggest that the addition

of kaolinite in commercial potting composts may have a role to play in the management of irrigation in pot plant production.

Kaolinite did not negatively affect biomass production in peat-based potting substrate, and does counteract hydrophobicity in lab tests, most likely due to its crystalline 1:1 structure, texture and hydrophilic nature. A tentative optimum concentration of 10% is suggested for its potential use as a substrate amendment, but more study is required.

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Glossary

Initials	**Term**	**Meaning**
AFP	Air filled porosity	The percentage or volume of a substrate that is air.
	Bolting	Term used to describe the flowering stage of food plants where flowering is not desired. The morphology of the plants change, becoming taller, with more but smaller leaves.
BF	bulb fibre substrate	50% peat, 50% green waste plus some fertiliser, manufactured by Westland Horticulture.
CC	Container capacity	The amount of water held by a substrate under gravity.
CEC	cation exchange capacity	The ability of a substrate to be able to exchange ions with free ions in solution, enabling nutrient uptake by plants.
FC	Field capacity	The amount of water held by soil under gravity – similar to potting substrate, except that water behaves differently in a plant pot.
JI	John Innes no.2	Supplied by J. Arthur Bower, the John Innes no.2 used for this study was a combination of topsoil, peat and sand, with fertilisers and limestone.

PWP	Permanent wilting point	The point of wilting beyond which a plant cannot be revitalised.
SWR	Soil water repellency	
WL	Watering Lane mix	Mixed by Melcourt Industries, this is 40% composted bark, 50% composted wood and 10% loam along with limestone, fertiliser and a wetting agent.
WDPT test	Water drop penetration time test	The most commonly employed test for hydrophobicity in substrates Three drops of deionised water are placed on the surface and the time taken for the drops to penetrate the substrate is recorded (see chapter 2.0).
WHC	Water holding capacity	The percentage water held by a substrate.

1.0 Introduction

Globally the market for ornamental plants is increasing (Drüge, 2000; Ferrante *et al.*, 2015), with potted plants being transported world-wide. In the UK alone the cut flower and indoor plant market is worth £2.2 billion at the retail level (The Flowers and Plants Association, n.d.).

The tolerance of potted plants to a domestic sales environment that is not really set up for horticultural products is an issue for some retail outlets (Hicken, 2017). Many chain stores in the U.K. sell live plants on a seasonal or occasional basis, and generally sales staff are often not trained in how to care for them (Hicken, 2017; Thompson, 2017). A substantial number of plants are discarded because they have been allowed to pass beyond the permanent wilting point. Some of this occurs because by the time a staff member waters the plants, the substrate has dried out and become unwettable – hydrophobic – so even if the plants are not yet at their permanent wilting point, they cannot be saved (Hicken, 2017; Thompson, 2017).

Kukkonen and Vestberg (2007) found that most professional Finnish growers (who overwhelmingly used peat either by itself or mixed) considered hydrophobicity to be the main problem in their substrate that they would alter if they could. Edwards (2017) also made it clear that the U.K. nursery industry is fully aware of the problem. Current research has focused on improving the resilience of plants, however it appears from the literature that little research seems to have been conducted into how the substrate used could either prevent stress or aid the plant in tolerating it.

In the U.K. the total market for growing media in 2013 was over 4.2 million m^3, of this figure over half was peat (Department for Environment, Food and Rural Affairs, 2017). There was a 0.5% increase in peat usage in 2014 which matched an increased sale in garden products (Agriculture and Horticulture Development Board, 2015), despite a drive in the U.K. to reduce peat use in gardening. As the need for food outstrips the suitable land in Europe available to grow it in, the demand for growing media is increasing (Department for Environment, Food and Rural Affairs, 2010a). While the search for adequate peat substitutes continues, there seems little doubt that it will remain the principle substrate for commercial and private potting compost for the foreseeable future (Di Benedetto and Pagani, 2012).

Not only are commercial interests affected by properties such as hydrophobicity in substrates, revegetation schemes to reduce erosion or to restore degraded land are also affected (Gautam and Ashwath, 2012). Revegetation to combat soil erosion is increasingly important. It has been estimated that 27 to 37 gigatonnes of top soil are lost annually to water, tillage and wind erosion (Food and Agriculture Organization of the United Nations and the Intergovernmental Technical Panel on Soils (FAO and ITPS, 2015), and that 25% of the dry land on Earth is already degraded (FAO, 2015). The United Nation's (U.N.) F.A.O. has estimated that there are 60 years of top soil left (FAO, 2015), in the U.K. that figure is estimated at 100 harvests (Withnall, 2014). Revegetation is very effective at reducing erosion, it also reduces water loss, and helps to reduce or prevent contamination of water courses (Arienzo & Teixeira da Silva, 2006)

According to Gautam and Ashwath (2012) revegetation schemes in arid and semi-arid areas often fail because plants are raised in nurseries with organic potting substrate (often peat-based) which, once dried out, will not rewet easily. Thus when the rains do come the plants cannot access the water through the hydrophobic substrate (Tordoff, Baker and Willis, 2000). Sowing directly into the soil have similar problems, with success rates of around 5 – 30% reported in some cases (Muños-Rojas *et al.*, 2017). Water-stress creates an extra level of difficulty in designing successful revegetation schemes in order to reduce soil degradation (e.g. Ffolliott, Gottfreid and Rietveld 1995; Roldán *et al.*, 1996; Gao *et al.*, 2002; Arienzo & Teixeira da Silva, 2006).

In previous research (Bettany, 2014) adding kaolinite to a peat-based growing media was found to significantly increase the biomass production of *Brassica juncea* in a glasshouse experiment (Figure 1.1), as did the crushed basalt rock dust also trialed. It was considered likely that the two mineral additions had different mechanisms due to their very different structures. Unlike basalt, which has a high cation exchange rate (increasing the mobility of nutrient ions), there was no clear reason why kaolinite improved the biomass production, however the climate controls in the experimental glasshouse had failed on a number of occasions putting the plants under water and heat stress, therefore it was hypothesised that the kaolin had protected the growing system against these conditions.

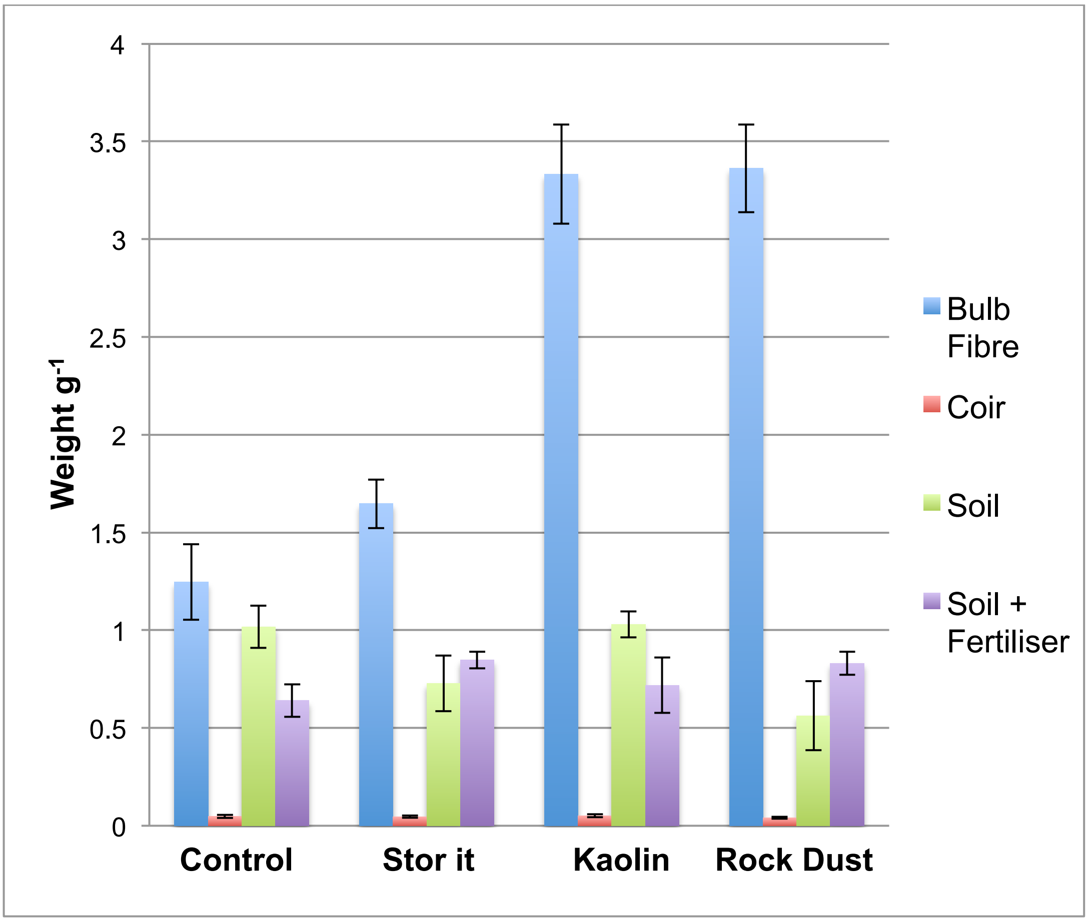


Figure 1.1 Total mean dried biomass production of *Brassica juncea* grown in four different media with three mineral soil improvers (BSc Dissertation, Bettany, 2015). Data are mean (n=4) ± 1 standard error.

The following study into the effect of kaolinite on plants grown in pots was conducted with the hope of improving plant longevity commercially and in environmental efforts. Finally kaolinite was chosen because it was an unexpected result that was worthy of further investigation.

1.1 Aims of the present study

Following on from the previous BSc research, where adding kaolinite in a weight ratio of 1:20 to bulb fibre resulted in increased growth and biomass in *Brassica juncea* plants grown in a glass house (Figure 1.1). The purpose of this study is to follow a narrative of discovery in relation to the effect of adding kaolinite to potting substrate on plants.

In the glasshouse, the study sought to:

- confirm the results of the original BSc experiment.
- discover whether an effect on biomass growth of *brassica juncea* could be observed with small additions of kaolinite.
- discover how large additions of kaolinite affect biomass growth.
- find the optimum level of kaolinite addition for greatest plant biomass.
- consider whether this was an effect only observed with *Brassica juncea* by testing it with *Triticum aestivum* (winter wheat).
- test the hypothesis that kaolinite improves the ability of plants to survive under dry conditions.

In the laboratory, the properties of the substrates were investigated with different treatments of kaolinite, collecting data often looked for by professionals and scientists (e.g. bulk density, container capacity, pH, organic content) with an emphasis on the behaviour of water (capillary rise and Water Drop Penetration Time tests).

1.2 Kaolinite

Clays are soil minerals that have undergone alterations through chemical weathering (Rowell, 1994). They are fine grained structures of aluminium and silicates bonded by oxygen and hydroxyl groups into thin tretrahedral (silica) and octahedral (alumina) layers (Rowell, 1994; Bridges, 1997; Chen *et al.*, 2017) (Figure 1.2). How these layers are arranged determines what kind of clay the mineral is, and what its properties are (Chen *et al.*, 2017).

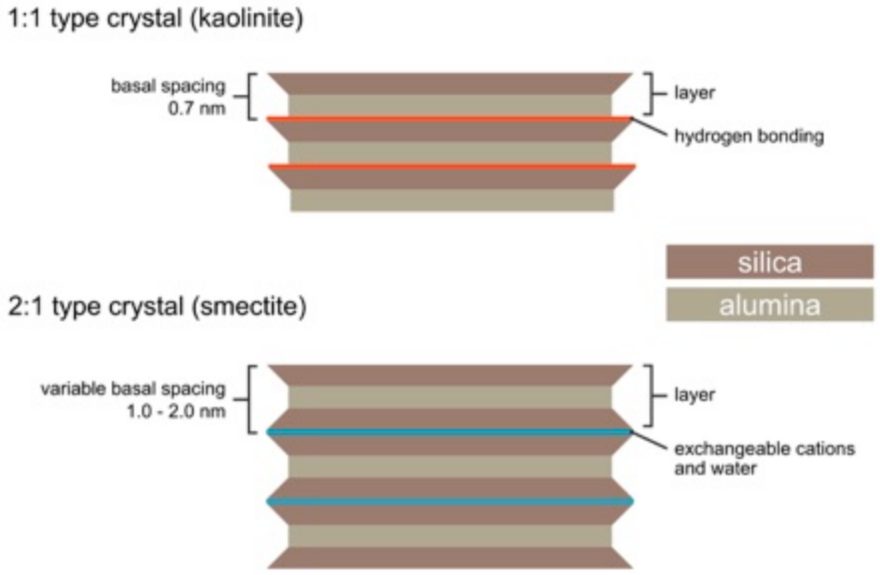


Figure 1.2 Crystal arrangement of clay minerals (Kettless 2017, copyright granted)

Kaolin, so named from the Gaolin region in China is known as china clay in the U.K. (Dill, 2016). The clay can develop from virtually any parent material, even those low in alumina and silica (Dill, 2016), as a result it is one of the most common minerals on the planet (Chen, Anandarajah and Inyang, 2000; Dill, 2016) (Figure 1.3 shows a typical soil kaolin). In this work, the refined mineral will be referred to as kaolinite, and otherwise as kaolin (Murray, 1963).

Kaolinite is a hydrated aluminosilicate with a 1:1 structure describing a crystal unit of a tetrahedral sheet of S_iO_4 bonded by shared oxygen atoms (two thirds of the total) to a octahedral sheet of Al^{+3} (Figures 1.2 and 1.4). Repeating layers of these crystals are hydrogen bonded, as such the entire structure is significantly compact with few inner bonding sites making it highly resistant to swelling (Quintelas *et al.*, 2009), unlike clays with a 2:1 structure (Bhattacharyya and Gupta, 2008; Miranda-Trevino and Coles, 2003; Quintelas *et al.*, 2009) (Figure 1.2). Indeed, its tendency is to disperse when in water (Murray, 1963).

Kaolin is inert and while a perfect structure would have no charge, generally speaking the broken crystal edges hold a small negative charge (Bhattacharyya and Gupta, 2008). Depending on the grade of kaolin there will be more or less contamination by oxides which will also affect the variable charge, positively, negatively, or both depending on the pH of its environment (Denef and Six, 2005; Denef and Six, 2006; Quintelas *et al.*, 2009; Chen *et al.*, 2017). Never-the-less its cation exchange capacity (CEC) is the lowest of all clays (Suraj, Iyer and Lalithambika 1998): an examination of seven Georgian (U.S.A.) kaolins showed CEC of no higher than 6.4 meq/100 g for the lowest grade (Lim *et al.*, 1980); in comparison, Montmorillonite (a 2:1 clay) was calculated as having a CEC value of 65±2 mmol/100g (Meier and Nüesch, 1999).

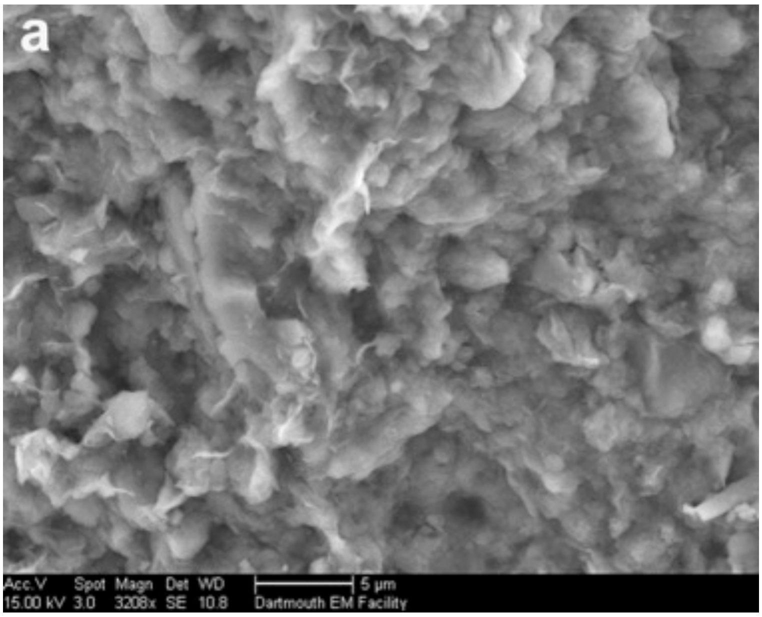


Figure 1.3 Soil kaolin from Costa Rica (Burch, Fisher and Ryan, 2006, copyright granted).

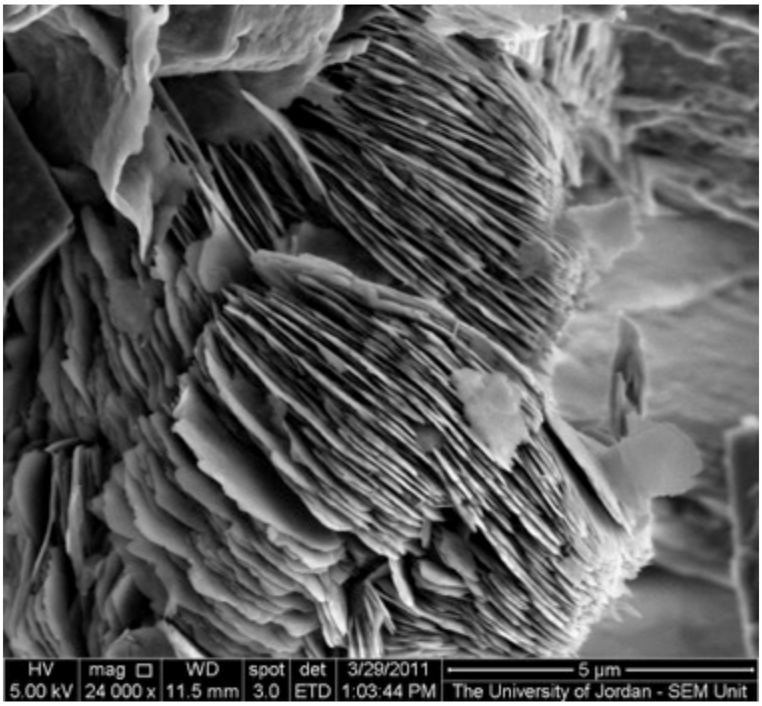


Figure 1.4 Kaolinite Sheets (Mahmoud/Thermo Scientific Fisher, 2011, copyright granted).

1.3 Possible reasons for kaolinite causing increased biomass growth in *Brassica juncea*

Texture

The addition of a mineral component introducing finer particles could give the substrate a more varied texture allowing for better water movement with subsequent smaller pore spaces that are better suited to holding water (larger pores being more likely to be air-filled (Harpstead, Hole and Bennett, 1988)).

pH

Most plants take up nutrients optimally within a pH range of 5.5 to 6.5, commercial substrates are often at the lower end of this (Gruda, Qaryouti & Leonardi, 2013). Most kaolin has been recorded as acidic (Dill, 2016), but the kaolinite producer Kerakaolin lists their clays as ranging between a pH of 6 and 8 (Kerakaolin, 2015). If the CEC was improved through pH alteration, then more nutrients could be available to the plants for growth.

Biofilms

Interactions between soil microbial/faunal life and plants symbiotically improve the growth of all species through the increase of available nutrients, soil resilience and response manipulation (through chemical signaling) in order to trigger protective behaviour (Bonkowski *et al.*, 2000). The work of researchers such as Vieira *et al.* (2001) has shown that kaolin strengthens biofilms and encourages their formation.

Even though the bulb fibre substrate was bought as a sterilised product, it can be assumed that it did not remain so for long, thus it is possible that the presence of kaolinite increased biofilm strength and the symbiotic microbial/plant activity. Moreover soil particle binding by biofilms in the rhizosphere improves plant-soil-biota interactions and affects soil-water, -air and -erosion, making the soil more stable and resistant to environmental vagaries (such as drought or flooding) and improving its ability to support plants (Amézketa, 1999; Zhang, Hallett and Zhang, 2008).

Heat exchange

Kaolin acts as a thermal bridge in soil (Sakaguchi, Momose and Kasubuchi, 2007), it also allows water to spread further through the soil structure as the kaolinite bridges larger spaces in the soil structure (Sakaguchi, Momose and Kasubuchi, 2007) increasing the thermal conductivity of the media still further, as well as improving the spread of water to roots. This suggests that in situations of greater heat or water stress, growing media treated with kaolin would be able to support plants better, or at least longer, than growing media without it.

Water-repellency

Water-repellency in soils is of great concern to farmers in many parts of the world, and is a known issue in the nursery and potting substrate industries (Edwards, 2017). Being hydrophilic (Chiang, Richardson and Wong, 1988) kaolin has been found to be one of the most effective ameliorants for this issue in soil (Cann, 2000; McKissock, Gilkes and Walker, 2002). It is thought that its tendency to disperse in water, rather than aggregate, allows it to coat the water repellent soil particles providing a barrier between the hydrophobic compounds and water (McKissock, Gilkes and Walker, 2002).

1.4 Plants chosen for assessment

Since experimentation was to continue year round certain qualities were required of the plants to be worked with. The plants needed to tolerate temperature differences, both cold and hot, and to be day-neutral. They also needed to be relatively fast growers and at least the main species needed to require a fertile environment in order to fully test the substrates. The secondary species was required to be substantially different to the primary species in its growing habit.

Brassica juncea **(green mustard)**

Brassica juncea (Indian mustard/ brown mustard/ giant green mustard) (Figures 1.5 and 1.6) was selected as the model plant because it is a fast growing plant that is day-neutral. Although growth rates alter seasonally, experimentation could continue throughout the year.

Figure 1.5 Köhler's Medizinal-Pflanzen: *Brassica juncea* (Köher,1897)

Figure 1.6 *Brassica juncea*.

B. juncea is an annual dicotelydon thought to be a natural hybridisation of *Brassica nigra* and *Brassica rapa* with a hypothesised origin of the middle east (Canadian Food Inspection Agency, 2012; Xu *et al.*, 2016). Its roots reach a depth of 90 – 120 cm (Purdue University, 1997), but like most other members of the Brassicacea family they do not make associations with mycorrhizal fungi (Glenn, Chew and Williams, 1988; Sinegani and Yeganeh, 2017). Most land plants do make symbiotic associations with arbuscular mycorrhiza (Frew *et al.*, 2017), gaining increased pathogen resistance (Frew *et al.*, 2017; Pérez-de-Luque *et al.*, 2017) and increased growth and nutrient content (Bona *et al.* 2017, Del-Saz *et al.*, 2017), this growth enhancing association could increase the variables present in the experiment.

B. juncea is used in seed oil production and as a leaf herb (Canadian Food Inspecion Agency, 2012), but researchers are looking closely at it for the phytoremediation (Ebbs and Kochian, 1998) of pollutants such as some metals – such as cadmium, zinc and nickel (Belimov *et al.*, 2005; Adediran *et al.*, 2015; Rodríguez-Vila *et al.*, 2015) and pharmaceuticals (Gahlawat and Gauba, 2016) since while it is considered a medium level bioaccumulator, it has high biomass production (Belimov *et al.*, 2005). *Brassica juncea* is considered a useful bioaccumulator for difficult conditions such as an arid environment (Belimov *et al.*, 2005; Xu *et al*, 2016).

***Triticum aestivum* (wheat)**

Triticum aestivum (JB Diego) (Figures 1.7 and 1.8) is a winter wheat, and chosen because it is another annual crop with a very different growing habit, in particular a monocotelydon. Its roots comprise of primary, deep roots and nodal, shallow roots, maximising water and nutrient uptake (Steinemann *et al.*, 2015). Due to its nature as a grass, growing from the base rather than the tip, *T. aestivum* can be grazed before allowing it to develop into a cereal crop, without any significant effect on root development (unless grazing is allowed at a very early stage) (Kirkegaard *et al.*, 2015, abstract). This suggested that it would be tolerant to the necessary manipulation during data collection.

Figure 1.7 *Triticum aestivum*, Hitchcock, A.S. (1950)

Figure 1.8 *Triticum aestivum* (winter wheat).

1.5 Potting Substrates

Di Benedetto (2007, p.94) simplifies artificial potting composts as ‘essentially mixtures of different-sized particles’. It is a little more intricate. It must, at the very least, hold water and nutrients, allow gas exchange and provide an anchorage for plants (Argo, 1998). Depending on the plant choice, and to an extent the container to be used, a good potting compost should have:

- a pH of between 5.5 and 7.0
- high water holding capacity (WHC)
- good drainage
- good total porosity (TP) with air-filled porosity (AFP) at between 10% and 20%
- excellent cation exchange capacity (CEC)
- homogeneity from bag to bag and season to season
- low shrinkage when dry
- easily rewet
- sterile
- suitable weight for the intended use
- nutrient adaptability for different crops (peat is low in nutrients, making it an excellent base)
- resistant to pests and pathogens
- not phytotoxic
- will not break down further over time
- cost effective
- available

(Robbins and Evans, 2011; Owen and Lopez, 2015)

Potting composts are known to alter over time (Bilderback *et al.*, 2005). Most organic substrates will deteriorate over time as particles segregate, and the substrate settles as a whole, fibres and organic matter breakdown through decomposition and repeated drying and rewetting cycles cause shrinking and swelling leading to fibre breakdown, however, a decrease in AFP is matched by an increase in WHC (Di Benedetto, 2007).

Substrates

Peat

The statistics clearly show that in the opinion of most growers, peat is the best option for container growing (Kukkonen and Vestberg, 2007; Agriculture and Horticulture Development Board, 2015), and it does indeed possess many of the qualities listed at the beginning of the chapter: it is slightly acidic, has good WHC, excellent CEC, has low nutrients, which allows growers to adapt it to their needs, good porosity (Di Benedetto (2007) found Canadian peat to have a total porosity (TP) of 85.72% of the volume, whereas, for example, the TP of soil was found by Baiyeri and Aba (2012) to be 54.2%), lightweight, and the more decomposed it is (the most decomposed peat is known as ‘dark peat’ and is more humified (Goh & Haynes 1977)) the less it will break down and settle in the pot over time. It has been the traditional substrate of choice since the 1950’s (Gruda, Qaryouti and Leonardi, 2013; Owen and Lopez, 2015).

Formed of partially decomposed moorland plants – mostly mosses and sedges – in cool anoxic conditions, the sugars and cellulose decompose leaving the lignin and humus (Bunt, 1976; Gruda, Qaryouti and Leonardi, 2013). Differences in abiotic factors, and species present, alter the characteristics of peats from different geographical locations (Gruda, Qaryouti and Leonardi, 2013; Rezanezhad *et al.*, 2016).

Important to the current work is its relationship to water, which is different depending on the decomposition and botanical composition. Peat can easily become waterlogged, but equally it is also highly hydrophobic when dried and this water repellence is most pronounced in dark peats (Michel, 2015). Even when wetting agents were added to peat (sphagnum moss) Fields, Fonteno and Jackson (2014) found that it took ten wettings to overcome hydrophobicity.

Peat-based potting substrates

In order to reduce peat use, in line with current UK guidelines, manufacturers have been investigating other composted materials such as coir and green wastes (Caron *et al.*, 1998; Dede *et al.* 2011; Bilderback, n.d.b). Frequently potting composts are sold as a peat mix, often 50/50, with composts sourced from municipal wastes, coir dust, composted bark or wood, rice husks, river ‘peat’, cotton gin waste, spent mushroom compost or peanut hulls, for example (Di Benedetto and Pagani, 2012; Bilderback, n.d.a).

No one substrate has been found to completely take the place of peat, in particular there is often an issue with consistency, green waste in particular changes seasonally in texture and nutrients (Di Benedetto and Pagani, 2012). A temporary solution has been to mix these alternate substrates with peat, a strategy used by Westland Horticulture in their bulb fibre potting compost, which was widely used in the current study.

Composted Bark

Bark is a waste product of the timber industry. It is shredded and composted into a popular potting compost that can be used alone or mixed with other substrates. It tends to have an open structure allowing for high TP and AFP (Hicklenton, Rodd and Warman, 2001; Gruda, Qaryouti and Leonardi, 2013), but its WHC is usually low unless mixed with another substrate (Gruda, Qaryouti and Leonardi, 2013). Bilderback (n.d.a) notes that the more decomposed the bark the lower the AFP and the higher the WHC. Its CEC is high, but unless it is extremely well composted it will exhibit nitrogen leaching behaviour, pulling N from other substrates or causing growth problems (Di Benedetto and Pagani, 2012), some growers compensate by simply adding extra nitrogen to the mix.

Melcourt’s substrate designed for use at the Eden Project’s Watering Lane nursery, and one of the substrates used in this study, is 40% organically grown composted bark (Gray, 2017). Unlike most other bark composts, Melcourt screen out the ‘fines’ – the fine particles – and in doing so increase the air-filled capacity from a typical 39% to 59% according to their own figures (Melcourt Industries, n.d.).

John Innes no.2

John Innes substrates are a combination of topsoil (loam), peat, sand or grit, along with fertilisers (John Innes Manufacturers Association, n.d.) and mixed by various manufacturers using local materials (John Innes Manufacturers Association, 2010). John Innes no.2 has been carefully designed to support most plants in pots or boxes. The sterilised loam contains clays, delivering CEC and so improving nutrient ion exchange, the sphagnum moss peat increases TP and WHC (John Innes Manufacturers Association, n.d.), and sometimes will include lime in order to bring the pH to around 6.5 (John Innes Manufacturers Association, 2010). The mineral content is far higher than is usually found in potting composts, it is a much heavier product (greater bulk density), and well drained due to the sand content. The fertilisers include both macro- and micronutrients (John Innes Manufacturers Association, n.d.).

1.6 Hydrophobicity

Hydrophobicity - soil water repellency - is defined as the condition when a drop of water does not immediately infiltrate the substrate (Doerr, Shakesby and Walsh, 2000). It is now accepted that most soils exhibit hydrophobic behaviour when dry (Doerr *et al.*, 2009; Vogelmann *et al.*, 2013), as do most artificial organic growing media (Michel, Rivìere and Ballon-Fontaine, 2001; Blodgett *et al.*, 1993). A deeper analysis of the literature can be found in Appendix 1 (p.181).

Hydrophobicity in Soil

In soils hydrophobicity can lead to poor seed germination (Moody and Schlossberg, 2009), reduced plant growth (Doerr, Shakesby and Walsh, 1996; Naasz, Michel and Charpentier, 2008; Panina, 2010; Gautam and Ashwath, 2012), patchy plant growth (DeBano, 1981; Panina, 2010; Lozano *et al.*, 2013), increased erosion through run-off and rain-splash detachment (Doerr, Shakesby and Walsh, 1996; Jeyakumar *et al.*, 2014), reduced uptake of chemical treatments (Vogelmann *et al.*, 2010; Jeyakumar, 2014) and pollute the water table through preferential flow (paths of least resistance) (Chau *et al.*, 2014).

Since hydrophobicity can affect soil degradation, it is hardly surprising that most work on the matter of hydrophobicity has been focused on soils. Hydrophobicity has been documented around the world, from Australia (Blackwell, 2000; Cann, 2000; Franco *et al.*, 2000a; Rillig, 2005) where seven million hectares are estimated to be affected or under risk (Beckett, Fourie and Toll, 2016) to Norfolk, U.K. (Doerr *et al.*, 2006), but most commonly in arid areas, especially

Mediterranean biomes. In fact the only continent where it has not been reported is in Antarctica (Jordán *et al.* 2013; Natural Environment Research Council and British Antarctic Survey, 2017; Convey, 2017).

Diehl (2013) acknowledged that ‘SWR is subject to numerous antagonistically and synergistically interacting environmental factors’. He found that the arrangement of amphiphillic molecules altered when dry and argued that the higher degree of moisture, the less energy it took to alter their alignment.

When Mataix-Solera *et al.* (2008) investigated *terra rossa* soils in Spain, they found that some exhibited hydrophobicity after a fire event while others did not. The difference was the clay content - soils with a higher kaolin content were more wettable, Arcenegui *et al.* (2007) achieved similar results, but suggested that while it might be the kaolin, more research should be conducted into the role of iron oxides in counteracting hydrophobicity.

Hydrophobicity in artificial organic substrate

In the matter of hydrophobicity in artificial organic substrate there is much less research than in soils, possibly because the commercial industry is careful to keep their stock well watered and so it does not become an issue for them (Gautam and Ashwath, 2012; Edwards, 2017) although they are aware of the problem (Kukkonen and Vestberg, 2007; Edwards, 2017).

It is not yet fully understood why organic growing media exhibit hydrophobicity (Naasz, Michel and Charpentier, 2008; Matthews *et al.*, 2017) below at least a 15% moisture content (Mataix-Solera and Doerr, 2004; Gautam and Ashwath, 2012). Many studies have found a correlation between hydrophobicity and organic content (Robinson, 1999; Eynard *et al.*, 2006; Jordán *et al.*, 2009; Martínez-Zavala and Jordán-López, 2009), but not all (Harper *et al.*, 2000; Dekker and Ritsema, 1994, cited by Mirbabaei *et al.*, 2013; Ritsema and Dekker 1994, cited by Mirbabaei *et al.*, 2013).

Humic substances are broadly divided into three main categories based on their solubility under different pH: humin, humic acid and fulvic acid, with most investigations focusing on the acids for ease of use (Pettit, n.d.; Lin *et al.*, 2006). They are all hydrophobic (Lin *et al.*, 2006) with humic acid proved hydrophobic at the atomic level (Cheng *et al.*, 2009). It is considered thought likely that the humic acid present crystalises when dry, and these crystals are water repellent (Puustjavi and Robertson, cited by Argo, 1998). It could also be supposed that in regard to bark compost, which is usually from pines such as that used by Melcourt substrates, that organic compounds found to be hydrophobic in soil studies are also influential here. Gautam and Ashwath (2012), in their study of 43 different growing media found that, similarly to soils, the hydrophobicity increased as the pH decreased.

Hallet (2007) puts forward the theory, for soils, that organic materials from plants, which are very hydrophilic in nature when wet, bond strongly with each other and soil particles when dry, resulting in hydrophobic surfaces. This could explain hydrophobia in organic substrate, since artificial substrates are mostly decomposed plant matter, and the most hydrophobic substrate – dark peat – also displays one of the highest water holding capacities.

Most organic potting composts become hydrophobic when allowed to dry out (Michel, Rivière and Bellon-Fontaine, 2001; Gautam and Ashwath, 2012), in soils Bodí *et al.*, (2013) found that it was the most common variable in devising a prediction model for water repellency. This significantly alters the water retention properties of potting substrate (Naasz, Michel and Charpentier, 2008) and preferential flow can be observed, even in a plant pot, when one attempts to water a dried out pot (Heiskanen, 1995; Michel and Kerloch, 2017), just as has been observed in hydrophobic soils. Hydrophobicity in potting compost poses an extra problem for growers compared to soil-based growing, as often nutrients are provided dissolved in water (Urrestarazu *et al.*, 2008).

Generally peat shows the strongest water repellency (Heiskanen, 1995; Di Benedetto, 2007), in particular dark peat – that is the most decomposed peat (Michel, Rivière and Bellon-Fontaine, 2001), which has the greatest amount of humic acid present. As peats dry their surfaces move from bipolar (hydrophilic) through monopolar to non-polar (hydrophobic) positions (Michel, Rivière and Bellon-Fontaine, 2001). Rezanezhad *et al.* (2016) point out that peat's organic functional groups are able to adsorb both hydrophilic and hydrophobic compounds, in a similar way to how surfactants work (Fields, Fonteno and Jackson, 2014).

The wettability of a substrate can be affected by some species of algae and bacteria (Doerr, Shakesby and Walsh, 2000) and peat offers a conducive environment for some algae (Cronberg, 1991; Di Benedetto, 2007) and pathogenic fungi (Bonanomi *et al.*, 2007; Cotxarrera *et al.*, 2002) which can produce hydrophobins (Wessels, 1996), so it is possible that this may affect hydrophobicity, indeed Hallett (2007) suggests it is the main cause of this phenomenon. This is less likely to be observed with bark-based substrates which possess antimicrobial properties (Tunlid *et al.*, 1989; Kai, Ueda and Sakaguchi, 1990).

Wettability can be restored, ironically, through the reintroduction of moisture (Doerr, Shakesby and Walsh, 2000). Doerr, Shakesby and Walsh (2000) discuss how repeated wetting and drying restores hydrophobicity, but at a reduced level, in soils. However little is known about the mechanisms involved in the wetting/drying and rewetting cycles, or the threshold conditions – known as the critical water content (CWC) (Chau *et al.*, 2014).

1.6.1 Amelioration for hydrophobicity in potting substrates

Keeping potting substrate permanently moist is a general method of husbandry in commercial nurseries (Kukkonen and Vestberg, 2007; Edwards, 2017).

Wetting Agents

Wetting agents, which are often surfactants (Zontek and Kostka, 2012), reduce the surface tension of the water by enabling some of the hydrogen bonds to be broken allowing increased infiltration. They consist of a hydrophilic ‘tail’ and a hydrophobic ‘head’, the head will adhere to a particle, allowing the hydrophilic tail to create a new ‘surface’ (Fields, Fonteno and Jackson, 2014), temporarily reducing hydrophobicity.

Fields, Fonteno and Jackson (2014) found that even when wetting agents were added to a sphagnum peatmoss wetted to 25% moisture by weight (at treatment rates of 116, 232 and 348 $mL \cdot m^{-3}$) hydrophobicity was only overcome after ten irrigation events. Their results are inconsistent for their other substrates, but wetting agents have been found to be effective when used with rockwool and coir compost (Urrestarazu *et al.*, 2008).

Hydrogels

Hydrogels are cross-linked polymers capable of absorbing up to 400 times their own volume in water (Sarvaš, Pavlenda and Takáčová, 2007; Chirino, Vilagrosa and Vallejo, 2011). They are polyacrylamide, propenoate-propenamide or (biodegradeable) cellulose-based copolymers (Fonteno and Bilderback, 1993; Demitri *et al.*, 2013). First used in the 1970’s in glasshouse production (Orzolek, 1993), they are added to soil or growing media to increase the water holding capacity of the substrate (Chirino, Vilagrosa and Vallejo, 2011), to increase air capacity, increase nutrient holding ability, reduce compaction and reduce the need for irrigation (Orzolek, 1993; Fonteno and Bilderback, 1993). Hydrogels do not counteract hydrophobicity, but simply improve the substrate's ability to hold water.

Seaweed

Ozdemir, Dede and Celebi (2015) found that adding seaweed to uncomposted hazelnut residues reduced the hydrophobicity from severe to moderate. They suggested, reasonably, that this could be due to the seaweed comprising of 50% polysaccharide alginate, which is hydrophilic (Han, Clarke and Pratt, 2014).

Biochar

Biochar has been found to be effective in reducing or eliminating soil water repellency. Hallin *et al.* (2015) investigated a coarse and a fine biochar added to water repellant soil and found that the fine biochar added at 10% in weight reduced the repellency by 50% and a 25% addition removed it entirely. The coarse biochar had an ameliorant effect, but not to the same degree. To date no similar study appears to have been worked with potting substrates in place of soils.

Sepiolite clay

Chirino, Vilagrosa and Vallejo (2011) looked at Sepiolite as an additive to peat-based potting compost to improve the water holding capacity. As a 2:1 structured clay it is expandable and able to absorb two and a half times its weight in water (Galan, 1996; Alvarez, 1984, cited by Francis *et al.*, 2007), however while it was more successful than the control, it was not as successful as hydrogels in improving tree seedling survival (Chirino, Vilagrosa and Vallejo, 2011)

Kaolinite

Treatment with kaolinite, or illite clays as a top dressing or ploughed in will reduce water repellency in soils (Ma'shum, Oades and Tate, 1989 – abstract; Lichner *et al.*, 2006; Diamantis *et al.*, 2017) without altering bulk density (Reatto *et al.*, 2009), water holding capacity (Michel, 2009), or increasing shrinkage (Reatto *et al.*, 2009).

In Australia 'claying' - that is the addition of 5 – 7% kaolin-rich clays or soils (typically 30 – 40% kaolinite) to fields with organic carbon above 1% (Government of Western Australia, 2017) – has been standard practice where it is cost-effective for at least 47 years (Cann, 2000). This has improved cereal yields up to three times the original value (Carter *et al.*, 1998, cited by McKissock, Gilkes and Walker, 2002) and has doubled yields according to Cann (2000). Once present, the clay stays *in situ*, in Australia it has been found that kaolin will remain effective for several years (McKissock, Gilkes and Walker, 2002; Roper *et al.*, 2015) and Cann (2000) cites a personal communication (Obst) where he was told that kaolin spread thirty years before was still an effective ameliorant.

Kaolin is considered 'masking'. It is thought that because of its structure, which causes it to spread out in water, rather than clump together, it coats hydrophobic particles (Müller and Deurer, 2011; Diamantis *et al.*, 2017). Studies show it to be the ameliorant with the least risk to preferential flow, leaching and pesticide concentration.

Dlapa *et al.* (2004) pointed out that a substrates response to water is dependent on the Lifshitz-van der Waals forces, and that hydrophobicity reduces as the density of the charges and polar groups reduce, in particular hydroxyl groups. –OH^- groups can be found densely packed on the surfaces of kaolinite, making it hydrophilic in itself (Dlapa *et al.*, 2004; Lichner *et al.*, 2006). Lichner *et al.* (2006) also looked at Kaolinite and Ca-Montmorillonite, as well as Na-Montmorillonite. They found that Kaolinite and Na-Montmorillonite were both effective at reducing hydrophobicity, and suggested that the differences in inner-particle forces in the two kinds of Montmorillonite explain the different results.

Some researchers have found that a wetting then drying cycle was necessary to trigger the masking effect of kaolin (Ward and Oades, 1993, abstract), however the work of McKissock, Gilkes and Walker (2002) suggested that this was not necessary to obtain amelioration, but that a wetting/drying cycle did improve the effect – they suggested that this was due to the water spreading the kaolinite more evenly through the soil. As can be seen from Figure 1.9, especially image c, kaolin clings to sand particles even when dry.

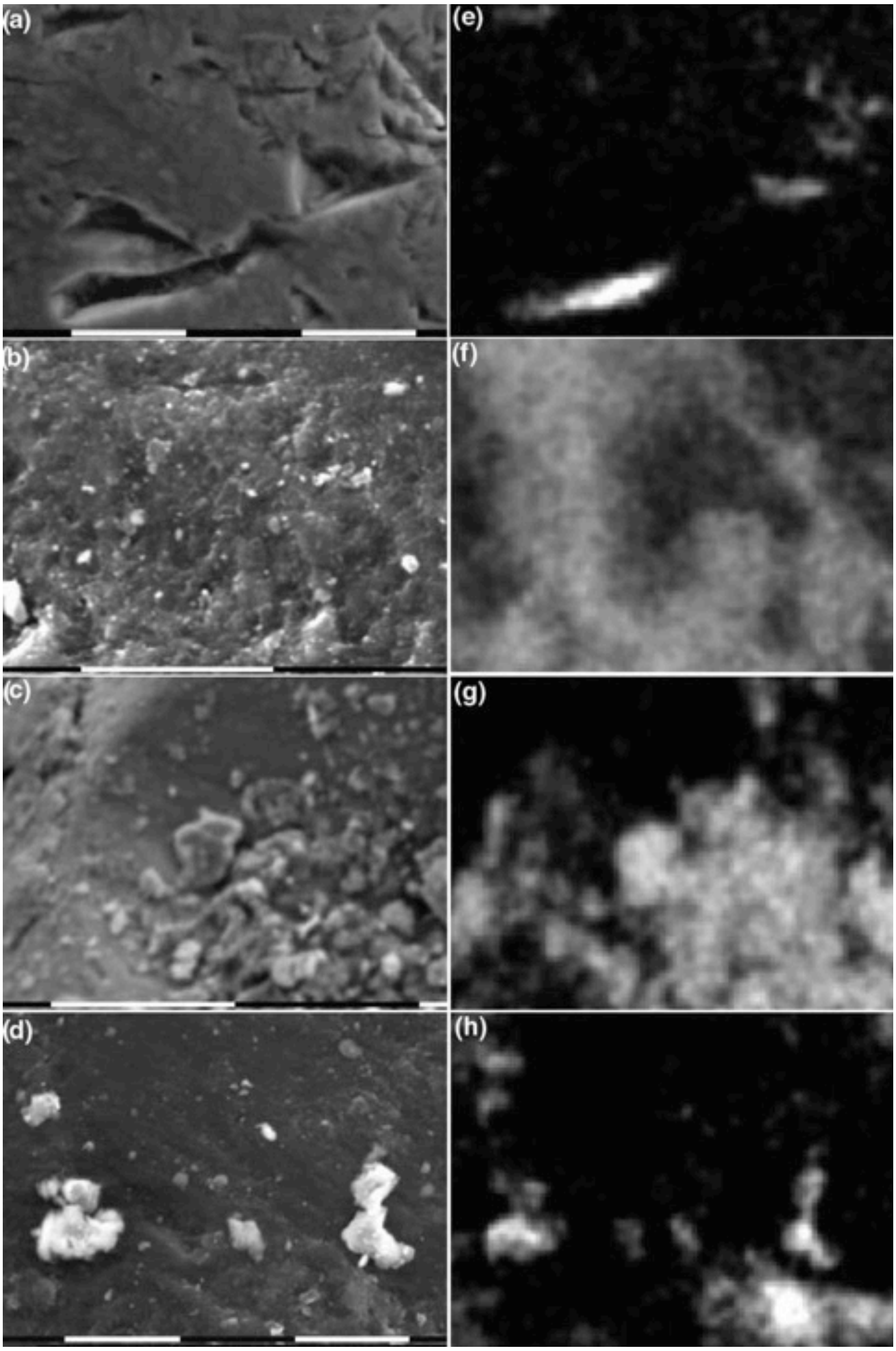


Figure 1.9 'Scanning electron micrographs showing the distribution of clay on the surface of sand grains. The four images on the left are secondary electron images of the surface of sand grains: (a) sand grain after treatment to remove clay and organic matter; (b) surface of untreated sand grain showing a discontinuous coating of clay sized material; (c) sand with Georgia kaolinite added (dry mix); and (d) sand with Wyoming bentonite added (dry mix). The corresponding images on the right (e, f, g, h) are derived from energy dispersive X-ray dot maps showing the distribution of aluminium on the surface of the sand grains. Aluminium is present in clay minerals. The scale bars represent 10 mm in each case.'

(McKissock, Gilkes and Walker, 2002, p.236, copyright granted).

2.0 The laboratory-based experiments

A suite of experiments were performed in the Eden Project Learning laboratory to identify the physical properties of the substrates to be used in the growing experiments (bulb fibre potting compost, peat, John Innes no.2 and Melcourt's Watering Lane nursery substrate mix) and minerals being studied, in particular to investigate their relationship to water.

Unless otherwise stated, the balance used was VWR LP-1002 (VWR International, USA), weighing from 0.01g to 1000g. Substrate samples were dried in an oven (VL115, 115l oven heating from 12˚C to 220˚C; VWR, USA) at 75˚C for two days, unless stated otherwise.

Particle Distribution

As with most particle distribution tests, which can be useful in gauging water retention and hydraulic conductivity, the sand fraction has been measured in this study - that is particles from 2 mm^{-1} to 0.02 mm^{-1}. In this study the finest sieve was <0.063 mm^{-1}.

Where kaolinite was to be added it was done so before drying, and mixed thoroughly by hand. 100g (± 0.02g) of substrate, oven dried at 75˚C for two to three days, was put in a sieving tower consisting of ten separate aluminium sieves with brass meshes (Table 2.0.1) (supplied by Timstar, Winsford, UK). Any lumps were gently pressed using a pestle and mortar or by hand, the intent being to break down any aggregates caused by the packaging or sample preparation but to retain its properties as would be found in a commercial or private setting (Parkinson, 2016).

The tower was shaken for ten minutes by hand, then the contents of each segregated mesh size was collected and weighed, the value recorded, then totaled to make sure that the result was close (± 2g) to the original value.

Table 2.0.1 Mesh sizes of the sieving tower.

mesh size	mm
10	2
20	0.841
30	0.595
40	0.420
60	0.250
80	0.177
100	0.149
120	0.125
250	0.063
Bottom pan	<0.063

pH

Ranging from 1 to 14, pH describes the balance of hydrogen atoms to hydroxyl atoms, the more hydrogen present the lower the pH figure and the more acidic, at pH7 the atoms are present in equal numbers, then the higher the number the more alkaline the object of measurement is (Harpstead, Hole and Bennett, 1988). A pH of between 5.2 and 7.0 is considered optimum for healthy plant growth (Bilderback, 1982; The Extension Foundation, 2017).

Five replicates of each substrate were measured for pH. 5g of sieved substrate (<2mm) was added to 25ml of deionised water and shaken vigorously for a minute five times over 24 hours. pH was recorded using a calibrated pH meter (VWR pH110, VWR International, USA). The mean of each set of repeats was then calculated.

Bulk density, container capacity, water holding capacity and air-filled porosity

Bulk density (BD) measures the dry mass per unit volume (g cc^{-1}) (Gruda *et al.*, 2013), this becomes important when considering where a container is going to be placed, a container on a glasshouse bench needs to be lighter – have a low BD – for ease of use, where as a container outside, where the wind or passing traffic may knock it over requires a higher BD. There is a relationship between BD and Total Porosity - the higher BD, the lower TP (Argo, 1998).

The amount of moisture that soil can hold against gravity is called the Field Capacity (FC). However water in containerised substrate behaves differently since moisture levels are not consistent throughout the container. This is affected by the height of the container (Bunt, 1976; Haynes and Goh, 1978). The volume also affects moisture behaviour (Di Benedetto, 2007) as does the number of drainage holes (Allaire, Caron and Gallichand, 1994). The CC is the average moisture content throughout the pot (Argo, 1998).

Beardsell, Nichols and Jones (1979) illustrated the difference between WHC and moisture release very nicely. Investigating how different organic substrates behaved under watering regimes, they found that peat held the most water, but the plants wilted fastest, showing that while moisture content (WHC) was high, moisture available to plants was low.

The Air-filled Porosity (AFP) measures how much of the volume of a substrate holds air. Di Benedetto (2007) suggests an optimum level of between 10% – 20% of the whole, but says that realistically the upper values can vary without affecting plant growth, he also recognises that the value decreases over time. However, in a 14 month study, Allaire-Leung, Caron and Parent (1999) found that air diffusivity did not change in container-held substrate despite the reduction in pore size, similar results with the water retention were also noted.

These physical tests (BD, CC, WHC and AFP) were performed together in 50ml pots with three repeats each. Oven dried (75˚C for two days) substrate was put into the weighed pots (after determining their volume using a graduated cylinder, the substrate was added with gentle tapping against the bench to allow settling, the value was then read), leaving enough room for the substrate to swell, each repeat was exactly the same weight (±0.02g), which varied depending on the treatment depending on the swelling habits of the substrate when wet.

The pots were placed into a square plastic bowl of water to take up water from beneath (and so to avoid air pockets), then left for two or more days until fully saturated. The modeling clay Plasticine® was used to stop the holes (to keep the water in), the pots, substrate, water and Plasticine® were weighed then left for a day, after which the Plasticine® was removed (and weighed in order to be able to remove the value from the final result). After being left a day to drain, the pots were then weighed again.

From the results of these procedures the following calculations could be made:

Bulk density = mass of oven dried substrate/volume

(result expressed as χg cm^{-3})

Container capacity = drained weight, expressed as g g^{-1}

Air Filled Porosity % = $$\frac{(\text{saturated substrate g}^{-1} - \text{drained substrate g}^{-1})}{\text{drained substrate g}^{-1}} \times 100$$

Water Holding Capacity % = $$\frac{(\text{saturated substrate g}^{-1} - \text{drained substrate g}^{-1})}{\text{dry substrate g}^{-1}} \times 100$$

(Haynes and Goh, 1978; Rowell, 1994; Forsyth, 2015, Nason, 2017)

Organic content (Loss on ignition method)

100g (±0.02g) of samples (Bulb Fibre and peat from Westland Horticulture, John Innes no.2 from J. Arthur Bower and Melcourt's growing substrate mix developed for Watering Lane Nursery) (three repeats of each) were burnt in a pan outside over a butane gas hob until the sample had ceased smoking. The samples were cooled, and transferred into the lab where they were heated over a Bunsen burner for approximately 20 minutes. Once cooled they were weighed, then heated again. This cycle continued until the difference between weights was less than one gramme and it could be assumed that most of the organic matter had been destroyed.

Capillary rise

Water moves against gravity in soils and substrates via capillarity due to surface tension (Liu *et al.*, 2014), some researchers use this fact to indirectly measure hydrophobicity.

Oven dried substrate was sieved to <2mm. Glass test tubes (750mm long, 12mm internal diameter, 13 mm external diameter) open at each end were covered at one end with squares of muslin and marked 10mm from the bottom, to act as a guide for the waterline, then filled with the substrate mixes (three repeats for each mix). Clamps were set up with beakers of deionised water underneath and the test tubes secured partially submerged so that the water line matched the 10mm mark. The tubes were then left for at least two hours.

Once the water had stopped rising, the tubes were removed and the distance from the water line (the 10mm mark) to where the moisture stopped in the substrate was measured. The lowest and highest marks were measured, then the mean was calculated. Mean height of rise was used to calculate the differences in capillary rise against gravity in the samples tested.

Water Drop Penetration Time (WDPT) test

This measures the persistence/decay of hydrophobicity by measuring the time taken, in seconds, for a drop of deionised water to overcome the surface tension of a porous surface and infiltrate the substrate. Diehl (2013) states that different drop sizes are incomparable, expressing the need for relatively equal sized drops, while this was followed in the current work, it was found that the drop size actually made very little difference to infiltration times. The classifications are arbitrary (Diehl, 2013), but since they are generally accepted, work well and allow for comparison with other researchers works have been used here (Table 2.0.2).

Table 2.0.2 The standard classification for the water drop penetration time test (Diehl, 2013).

Classification no.	Seconds for infiltration/$_s$	Description
1	$<5_s$	wettable soil
2	$5_s – 60_s$	slightly water repellent
3	$61_s – 600_s$	strongly water repellent
4	$600_s – 3600_s$	severely water repellent
5	$>3600_s$	extremely water repellent

A tally of the papers used in this literature review suggests it is the most popular method for researchers, possibly because it is a very simple and cheap test to perform, one of only a few methods suitable for large sample sizes (Doerr, 1998), Doerr *et al.* (2009b) considers it the most ‘meaningful’ of the possible tests.

As with the capillary rise experiment, the substrate samples were dried at 75˚C for two days, then sieved to <2mm. The substrate was then carefully weighed and placed in tight fitting Ziplok® bags (177mm x 188mm). For each treatment three petri dishes were prepared by gently filling, tapping the petri dish once on the lab bench, then tapping along the top of the dish with the edge of a steel ruler to get a flat surface with minimum pressure on the substrate.

Three drops of deionised water (of an average of 46μm^3) were pipetted on to the surface of the substrate and the time taken for the water to infiltrate the surface was recorded – timing ended at one hour (3600s). Testing in this study was done for complete loss of repellency at <1 second.

The substrate was then returned to the Ziplok® bag and enough water added with a pipette to increase the moisture level by 5%. the bag was then manipulated and left for the water to be absorbed. The bag was then manipulated again, opened and rubbed through by hand for homogeneity. After this the petri dishes were prepared again, and the WDPT test repeated. This cycle continued until the time recorded was less than one second. It was found that leaving this experiment and returning the next day skewed the data, therefore once started it had to be completed without a break.

The resultant data was expressed as a $\log_{10}$ value in line with standard practice (e.g. Dlapa *et al.*, 2004*;* Doerr *et al.*, 2005; Mataix-Solera *et al.*, 2007) due to the large differences in data which would have otherwise been impossible to display. In order to test for significance, the data for each substrate at the point where the first concentration reached infiltration at $<1_s$, and all concentrations compared at that moisture level.

Data analysis

Data was managed using Microsoft® Excel® for Mac 2011 (version 14.4.7). Analysis of Variance (ANOVA) and Fisher Pairwise Least Significant Difference (LSD) were used for normally distributed data, and Kruskal-Wallis analysis of variance for data that was not normally distributed. All were derived using Minitab Express™ (Version 1.5.1, Minitab, Inc.). The raw data can be found in Appendix 3.

2.1 Bulb fibre

Westland Horticulture’s bulb fibre potting compost is half dark peat and half wood fibre from Sitka spruce (Jones, 2016a) with some grit for drainage. It is nutritionally balanced including trace elements (Westland Horticulture, 2017). It was tested with 0%, 5%, 10%, 20% and 40% concentration of kaolinite added by percentage weight. The raw data can be found in Appendix 3.1 p.237.

2.1.1 Particle Distribution

Following the protocol laid out in chapter 2.0 (Laboratory-based experiments) page 37, the kaolinite was mixed by hand into the substrate before drying. The particle distribution test (Figure 2.1.1) showed that the largest fraction of the substrate was in the >2mm range, contributing over 50% in the bulb fibre with no kaolinite, it was this fraction that also showed some of the greatest change over the different treatments, reducing to 20.14g in the 40% kaolinite treatment. At mesh size 30 (0.42mm) the proportion of the retained fraction are similar across all treatments before the previous trend (higher weights at 0%, lower at 40%) is reversed, with the greatest difference evident at mesh size 100 (0.125mm) with a value of 14.32g difference between the treatments with the lowest and highest kaolinite concentrations. At the finest meshes, the results maybe affected by the kaolinite blocking the pores of the sieves.

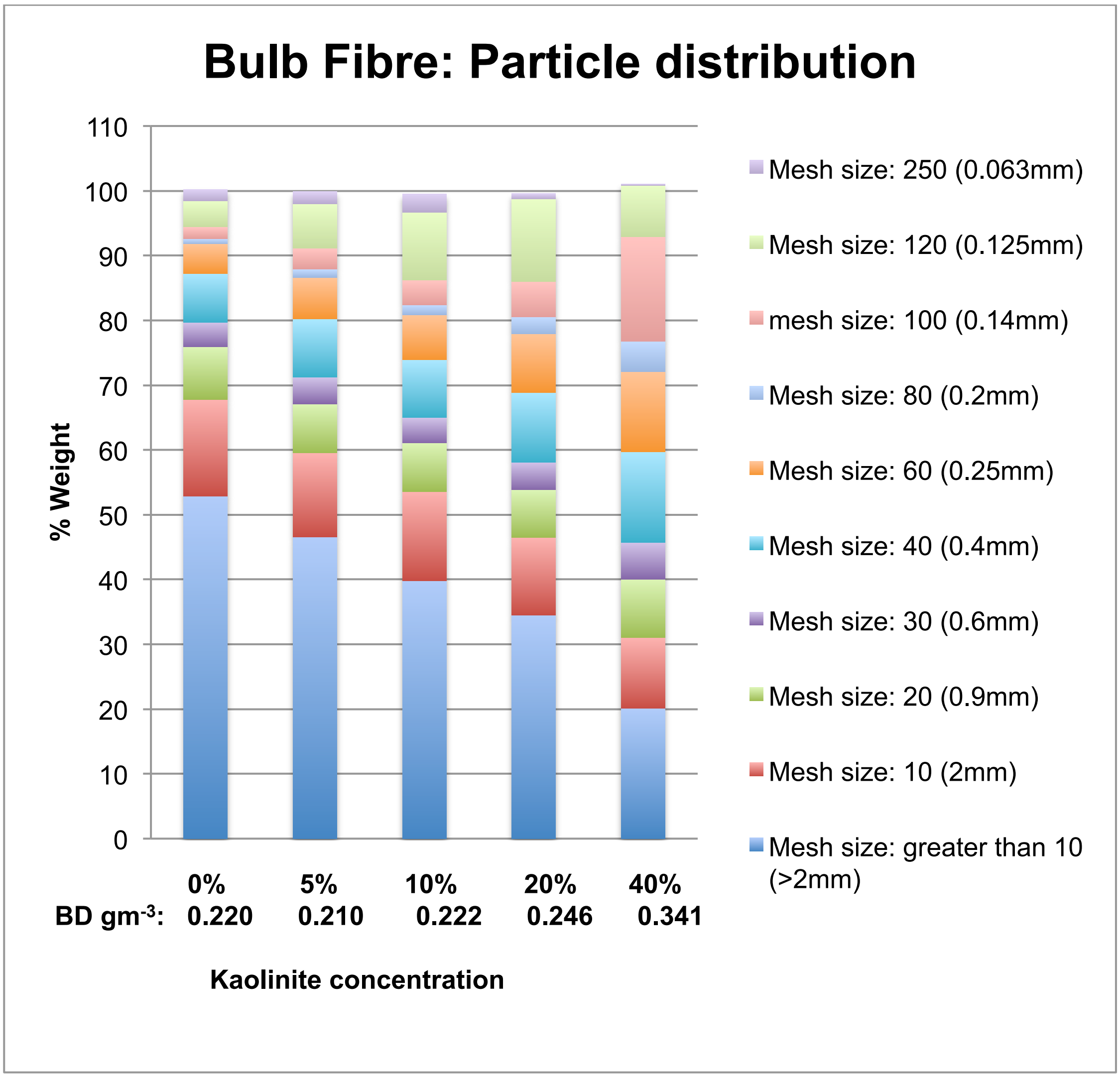


Figure 2.1.1 Particle distribution of bulb fibre (50% peat, with composted wood and grit), with different concentrations of kaolinite by percentage weight, between <2mm and >0.063mm. Bulk density values are shown beneath the x axis.

2.1.2 Physical characteristics

Bulk density (BD), Water holding capacity (WHC), Container capacity (CC) and Air-filled porosity (AFP).

The protocol to find BD was followed as described in Chapter 2.0 ‘Bulk density, container capacity, water holding capacity and air-filled porosity’ (p. 40). The bulk density did not alter significantly with the addition of kaolinite, with only the highest concentration of kaolinite showing a notable rise in value (FIgure 2.1.1). The bulb fibre with no kaolinite has the largest WHC at 66.2% (Figure 2.1.2), but with a high standard error (16.41), this value dropped to 34.18% for the 5% treatment which showed the lowest value of all treatments. There was a significant difference (P <0.05) between the 0% and others treatments.

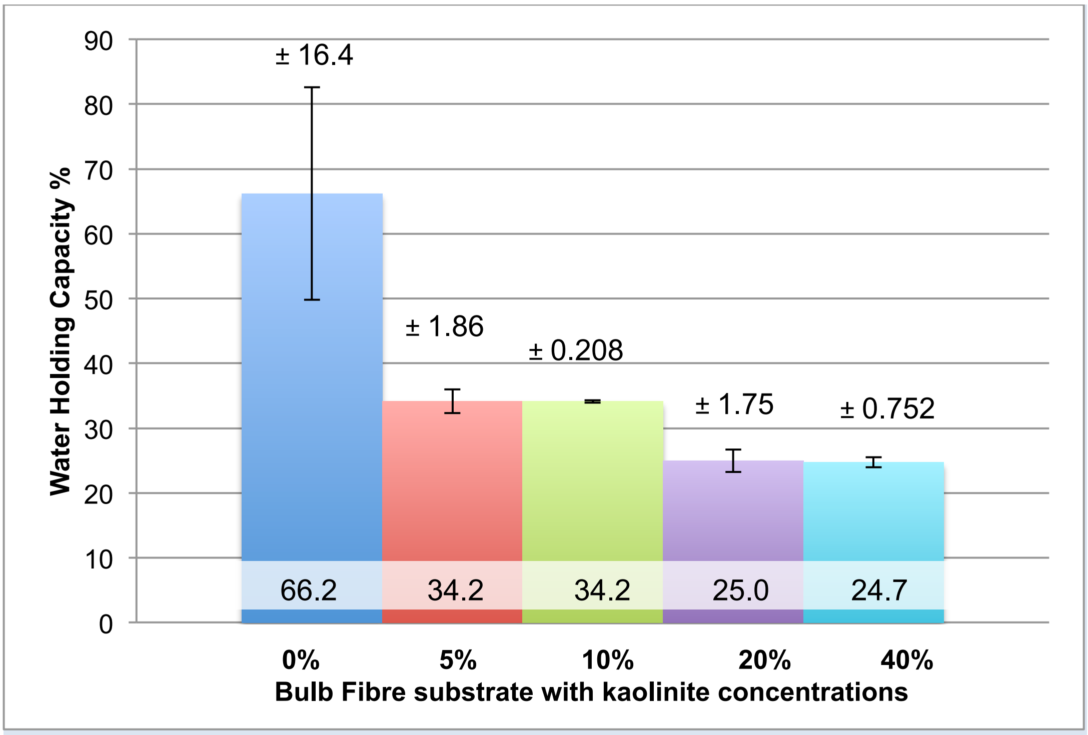


Figure 2.1.2 Water Holding Capacity of bulb fibre (50% peat, with composted wood and grit), with different concentrations of kaolinite by percentage weight, mean values shown at the bottom of the bars, rounded to three significant figures (n = 3)± 1 Standard Error (SE shown above the bars). P <0.05.

The container capacity results (Figure 2.1.3) showed a steady and significant (P<0.0001) decrease in values from the 0% (3.54g g^{-1}) treatment to the 40%

treatment (1.96g g^{-1}), LSD testing (Figure 2.1.3) put all treatments into separate groups, except for the 5% and 10% treatments.

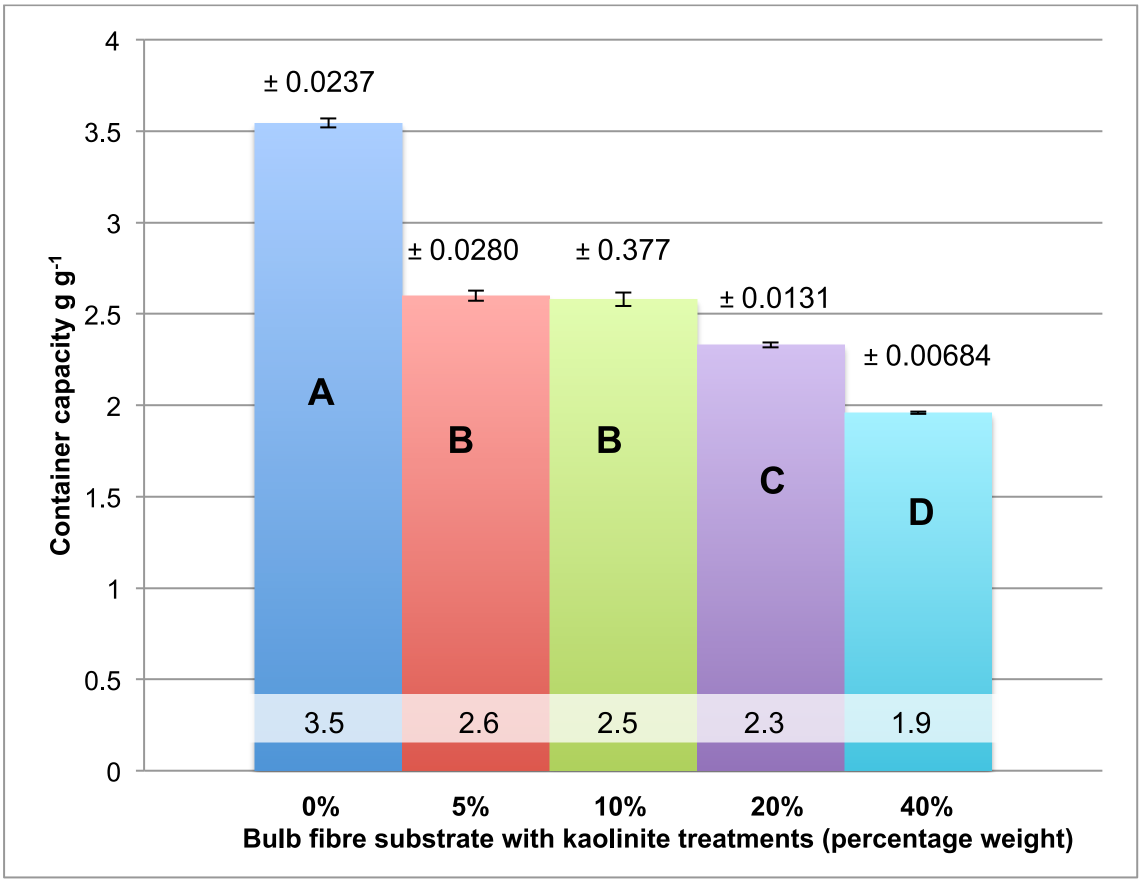


Figure 2.1.3 The container capacity of peat-based bulb fibre substrate with treatments of kaolinite added, mean values shown at the bottom of the bars, rounded to three significant figures (n = 3)± 1 Standard Error (SE shown above the bars). P <0.02, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The AFP shows no significant variation between the treatments (P >0.05) (Figure 2.1.4).

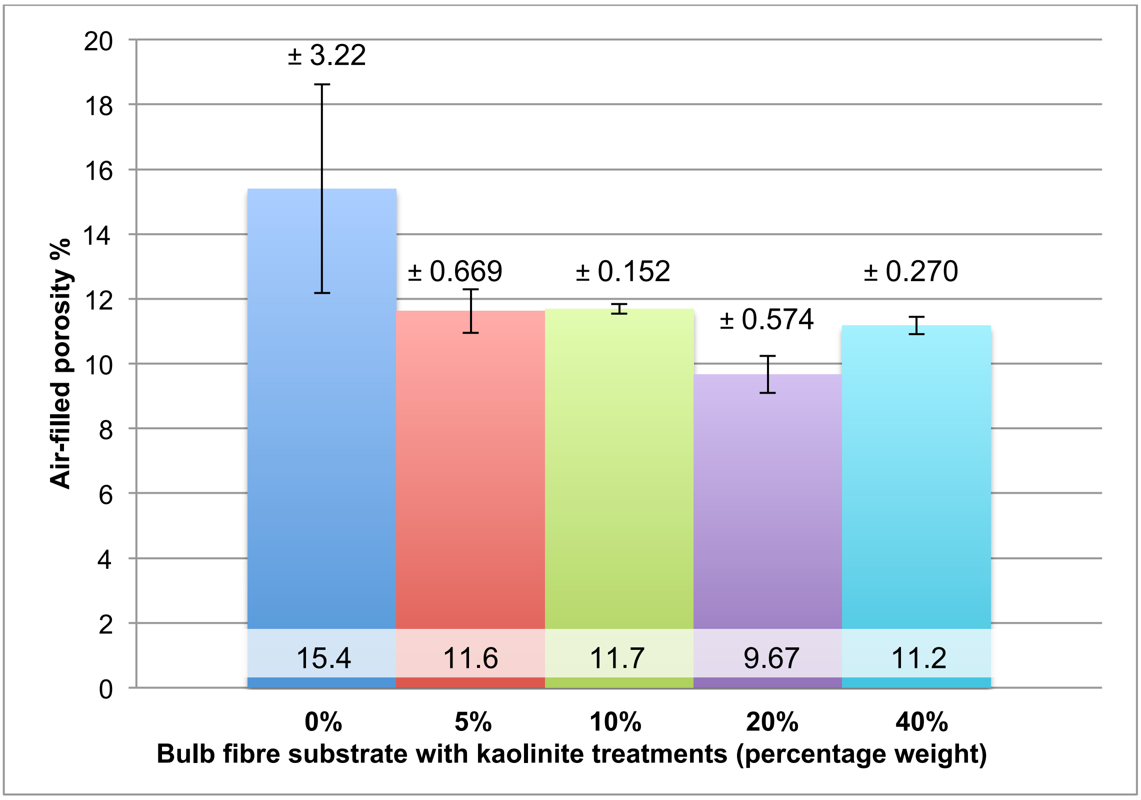


Figure 2.1.4 The air-filled porosity of peat-based bulb fibre with treatments of kaolinite, mean values are shown at the bottom of the bars, rounded to three significant figure, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P >0.05.

Changes in substrate behaviour over repeated wetting/drying cycles

Using the same protocol as for the CC, AFP and WHC, the substrate was saturated, weighed (first cycle) and allowed to dry out until the substrate pulled away from the sides and was judged to be close to the original dried weights, although they were not weighed. The cycle was then repeated (second cycle) to see if there was any alteration to the substrate behaviour. The results are shown in Table 2.1.1.

Adding kaolinite had no significant (P >0.05) effect of the physical properties over the course of a wetting/drying/rewetting cycle.

Table 2.1.1 The changes in the physical properties of bulb fibre substrate (50% peat, with composted wood and grit) with different concentrations of kaolinite (by % weight), before and after two wetting and drying cycles. Data are mean (n = 3) ± 1 Standard Error (SE) and rounded to three significant figures.

Treatment % kaolinite concentration		Water Holding Capacity		Container Capacity		Air-filled Porosity	
		%	SE	$g\ g^{-1}$	SE	%	SE
0%	1st cycle	21.7	±0.512	1.61	±0.0228	11.9	±0.264
	2nd cycle	26.1	±0.412	1.59	±0.0103	11.8	±0.329
Difference		-4.38		0.115		0.0255	
10%	1st cycle	18.0	±0.291	1.28	±0.00817	10.4	±0.2
	2nd cycle	21.1	±0.526	1.50	±0.00906	10.5	±0.193
Difference		3.16		-0.0371		-0.0331	
40%	1st cycle	17.7	±1.20	1.41	±0.00721	11.1	±0.712
	2nd cycle	19.0	±0.145	1.35	±0.00345	11.5	±0.813
Difference		-1.37		-0.0605		-0.353	

2.1.3 pH

The results (Figure 2.1.5) were significant (P <0.001), with the values divided into two distinct groups 10% and 40%, and the other treatments.

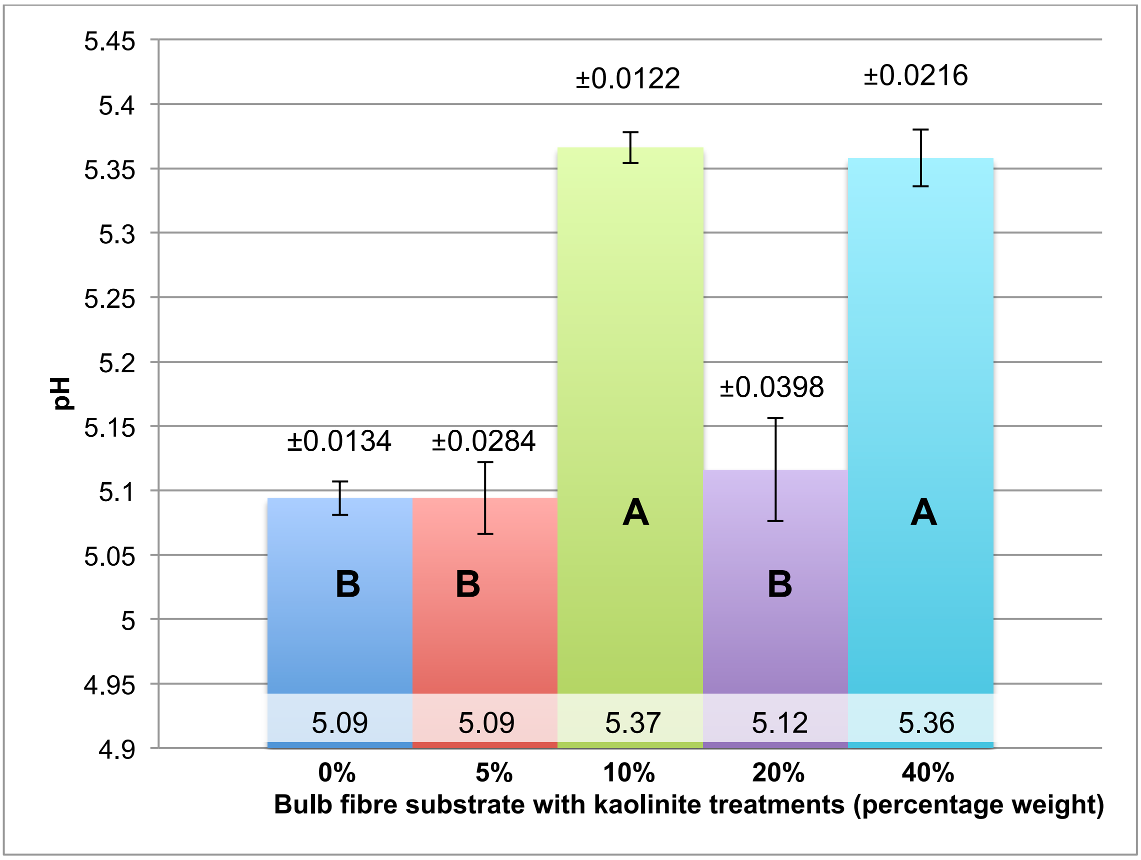


Figure 2.1.5 pH values of bulb fibre (50% peat, with composted wood and grit) with different concentrations of kaolinite by percentage weight, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 5) ± 1 Standard Error (SE values are shown above the bars). P <0.01, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Discussion

The presence of kaolinite did not appreciably alter the pH of the bulb fibre substrate, although enough to be significant ($P < 0.001$) as can be seen more clearly in Figure 2.1.5.

2.1.4 Organic Content (Ash content/loss on ignition)

The results (Figure 2.1.6) showed a predictable reduction in organic matter as the percentage of kaolinite was increased.

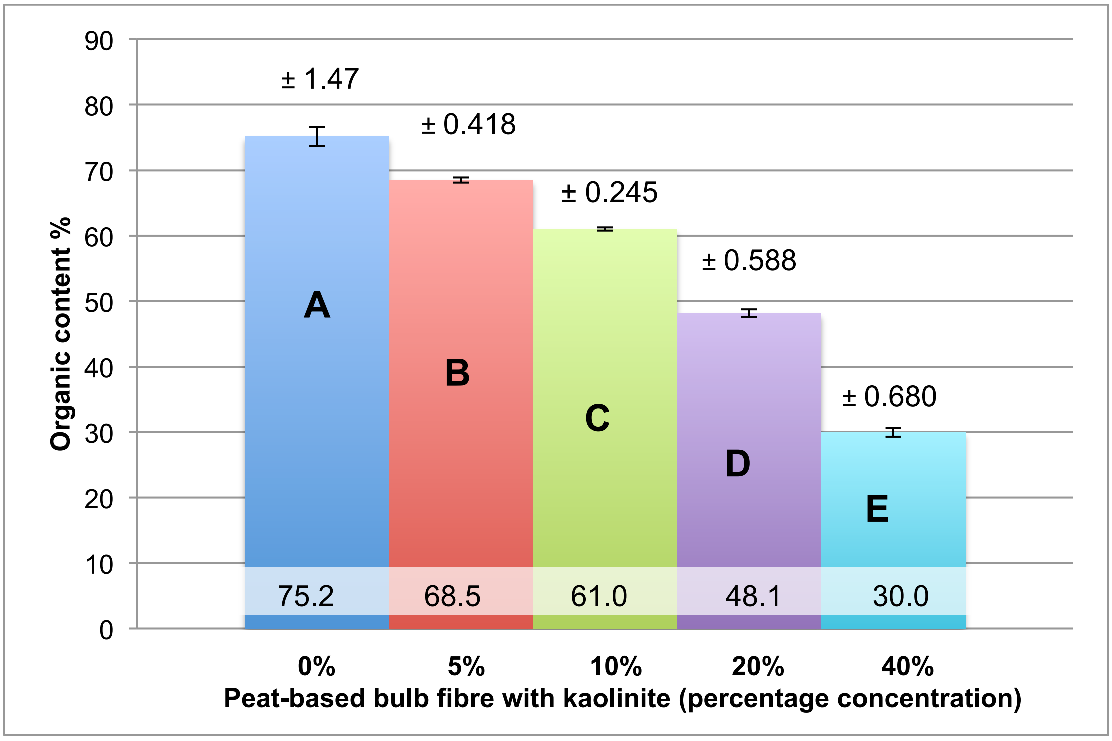


Figure 2.1.6 The organic content of bulb fibre (50% peat, with composted wood, grit, and kaolinite added by percentage weight) from ash content/loss on ignition testing, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). $P < 0.001$, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Significance was found at P <0.001. LSD (Figure 2.1.6) showed that each treatment was distinct.

Discussion

It was expected that the organic content would be reduced as the mineral content was increased. This was relevant to the current study since a link between organic matter and hydrophobicity had been identified (Lin *et al.*, 2006; Michel, Rivière and Bellon-Fontaine, 2001).

2.1.5 Capillary rise

As can be seen in Table 2.1.2 (see also Figure 2.1.7) the samples of the 0% treatment showed a negative value in the capillary rise test, in none of the repeats did the water rise above the water mark. The 10% treatment showed the greatest movement against gravity, rising to a significant ($P<0.0001$) mean level of 58mm, after which the values began to drop, with the 40% kaolinite treatment rising by 25.17mm above the water line. Under LSD testing (Figure 2.1.7) it was found that only the 5% and 20% treatments were similar, all others showing a significant difference from each other.

Table 2.1.2 Capillary rise of bulb fibre (50% peat, with composted wood and grit), with different concentrations of kaolinite by % weight. Data are mean (n = 3) ± 1 Standard Error (SE) and rounded to 3 significant figures.

Treatment %	Mean low capillary rise point	Mean high capillary rise point	Difference between low and high means	Mean of means	Standard Error
0	-7.67	-4.00	3.67	-5.83	±1.11
5	37.0	56.0	19.0	46.5	±4.60
10	53.7	62.3	8.67	58.0	±1.43
20	42.0	51.3	9.33	46.7	±2.37
40	22.7	27.7	5.00	25.2	±1.11

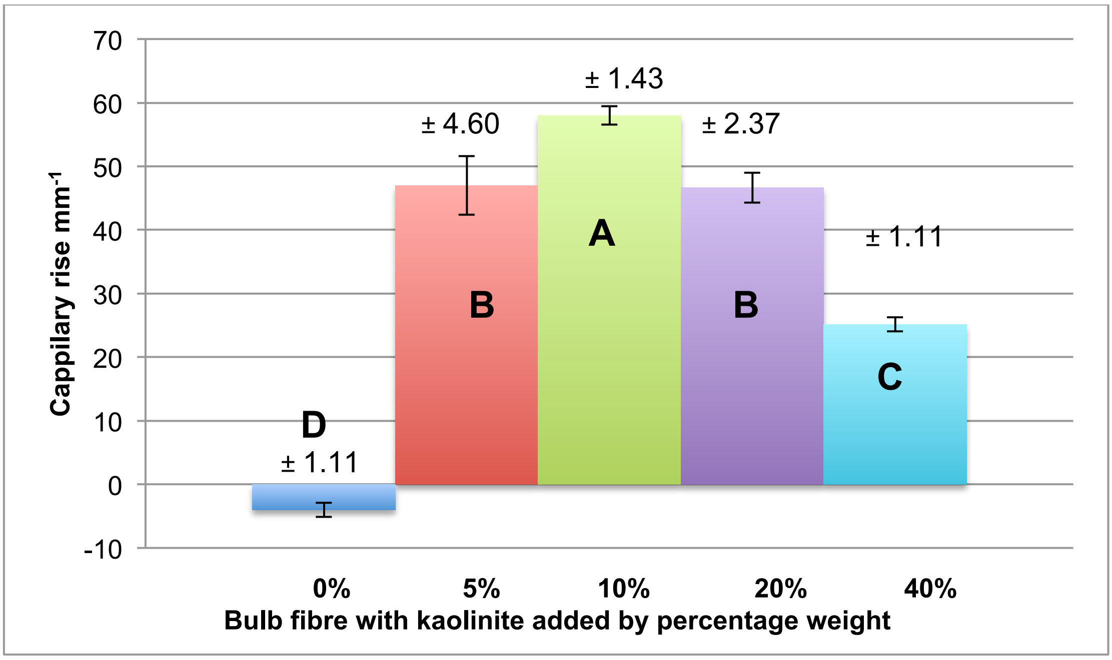


Figure 2.1.7 Capillary rise of bulb fibre (50% peat, with composted wood and grit, with different concentrations of kaolinite by % weight). Data are mean, to three significant figures, (n = 3) ± 1 Standard Error (SE, values shown above the bars). LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Discussion

The results show the extreme hydrophobicity of the bulb fibre substrate without kaolinite, with a negative value for capillary rise movement. Even the addition of 5% kaolinite was enough to counteract that behaviour (in agreement with the findings of McKissock, Gilkes and Walker, 2002), though the optimum concentration was the 10% kaolinite treatment with a rise of 58mm. As the percentage of kaolinite increased beyond 10%, the capillary rise value reduced, showing a curve (Figure 2.1.7), this could be due to the reduced container capacity (Figure 2.1.3) found in the substrates with higher kaolinite content.

2.1.6 Water Drop Penetration Time Test

Figure 2.1.8 shows the mean values at each level of moisture tested. To save time, the 0% kaolinite treatment was not tested between 5% and 25% moisture.

As can be seen in Figure 2.1.8 the more kaolinite added the less moisture is needed to overcome hydrophobicity. Although already classed as wettable when oven-dried the 40% kaolinite treatment was still tested to the point where it took less than one second for penetration to occur, the threshold being reached at 20% moisture (Figure 2.1.9). It took only 5% moisture for the 20% treatment to reach the ‘wettable’ class, and 25% moisture for infiltration to occur in less than one second. The 10% treatment took a little longer, only fully overcoming water repellency ($<1_s$) at 40% moisture, and the 0% treatment did not pass that threshold until 65% moisture.

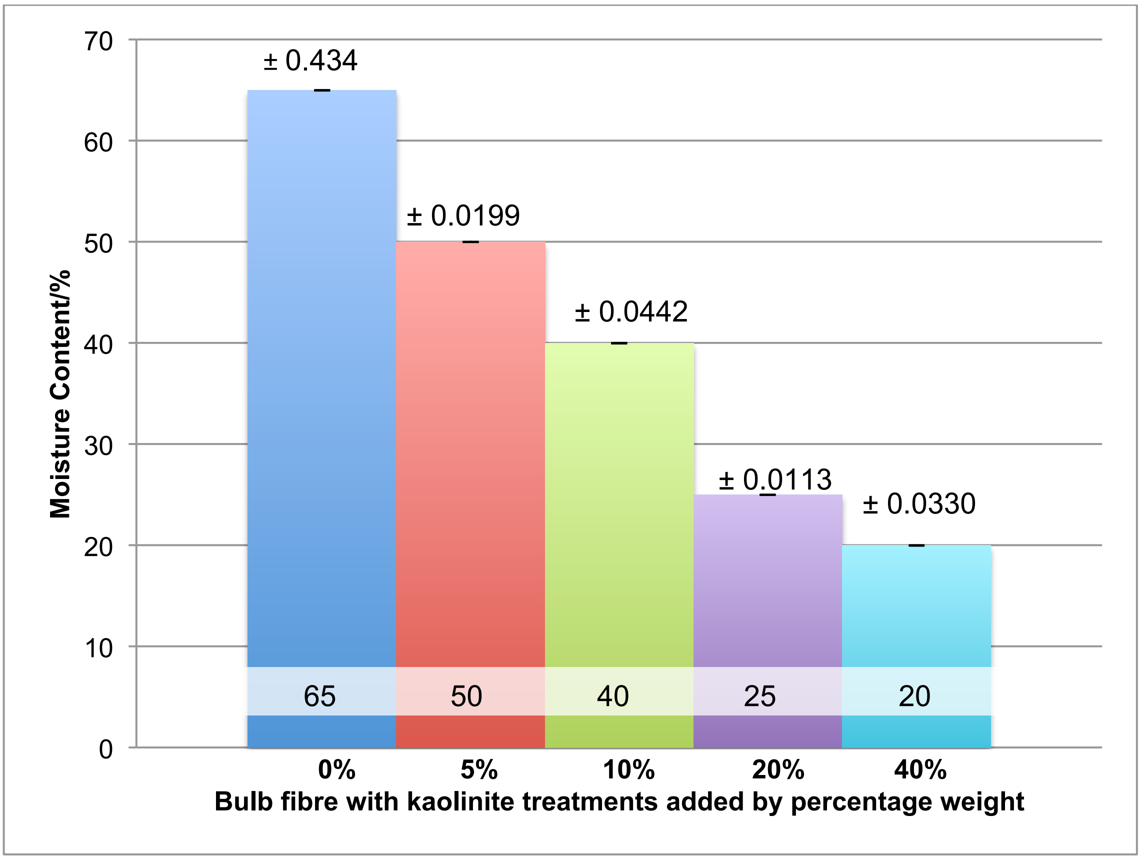


Figure 2.1.8 Water Drop Penetration Time test results for bulb fibre (50% peat, with composted wood and grit) with different concentrations of kaolinite by % weight, showing the point where hydrophobicity is completely overcome Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars), P <0.01.

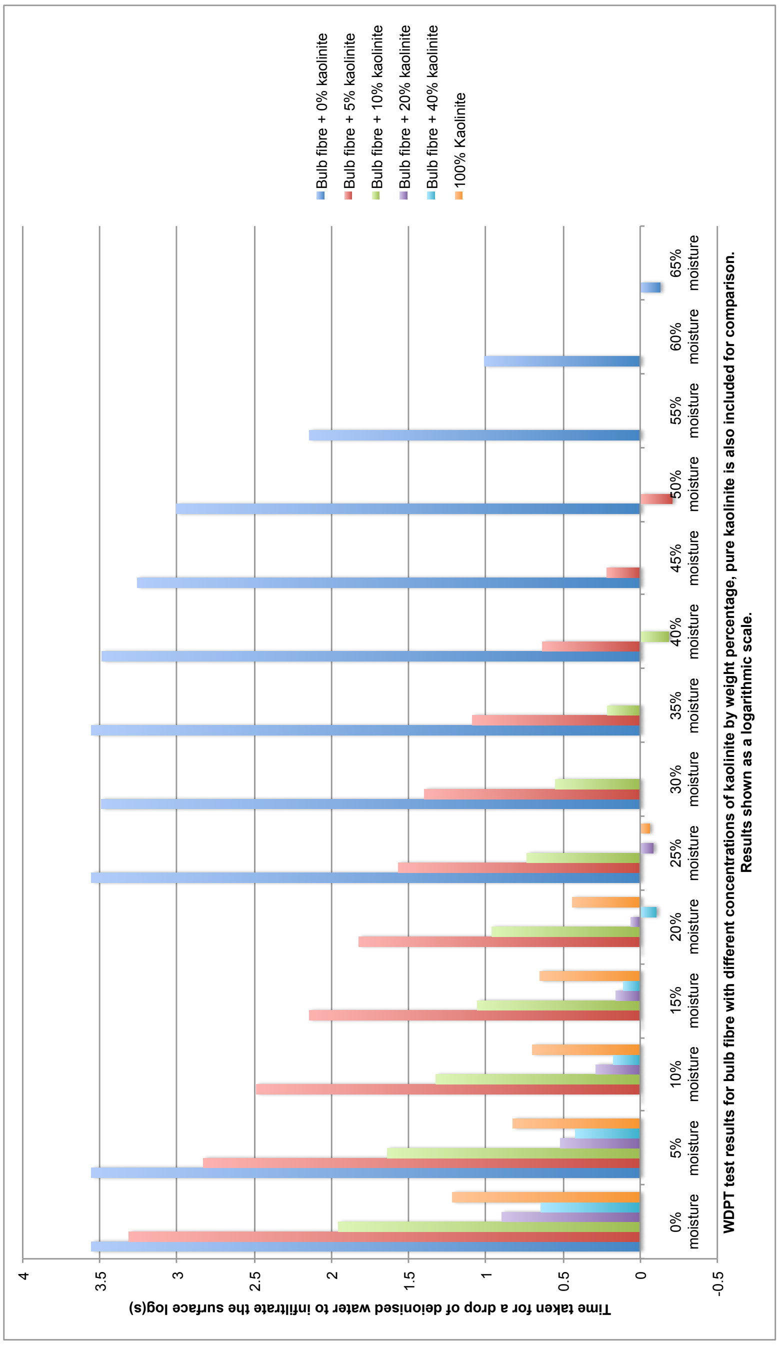


Figure 2.1.9 Water Drop Penetration Time test results (Log$_s$) for bulb fibre (50% peat, with composted wood and grit) with different concentrations of kaolinite by % weight, showing the changes in hydrophobicity until the state is completely overcome,100% kaolinite has been included for comparison. The tests for 0% kaolinite between 5% and 25% moisture were not performed for time economy. Data are mean (n = 3) ± 1 Standard Error (SE).

All concentrations except 20% and 40% were significantly different from each other (P <0.01).

Discussion

Following on from the previous capillary rise experiments, it was expected that the bulb fibre alone would show the most water resistance, with hydrophobicity only being completely overcome at 65% moisture. However unlike the capillary rise tests the WDPT results steadily reduced as the kaolinite increased. Gravity may be the main difference here, with kaolin offering less resistance with downward moving water, the mechanism needed to raise water up against gravity through capillary action is perhaps different. While increased kaolinite concentration results in decreased organic matter (and therefore hydrophobic humic substances), this decrease cannot be the cause of the capillary rise results as they show a curve in the data, peaking at 10%.

Figure 2.1.9 includes 100% kaolinite as a comparison. It is interesting to note that the pure kaolinite had a higher WDPT value than the bulb fibre with the 20% and 40% concentration. The kaolinite test was performed on a different day, so it is possible that ambient humidity caused this, but it is more likely that the more open nature of the substrate improved infiltration.

2.2 Peat

A dark Irish peat supplied by Westland Horticulture (UK).

2.2.1 Particle Size Distribution

The raw data can be seen in Appendix 3.2. (page 248) Figure 2.2.1 shows that the particle distribution reduces at the largest fractions (in particular >10mm) in exchange for an increase at the lower fractions (0.4mm to 0.25mm).

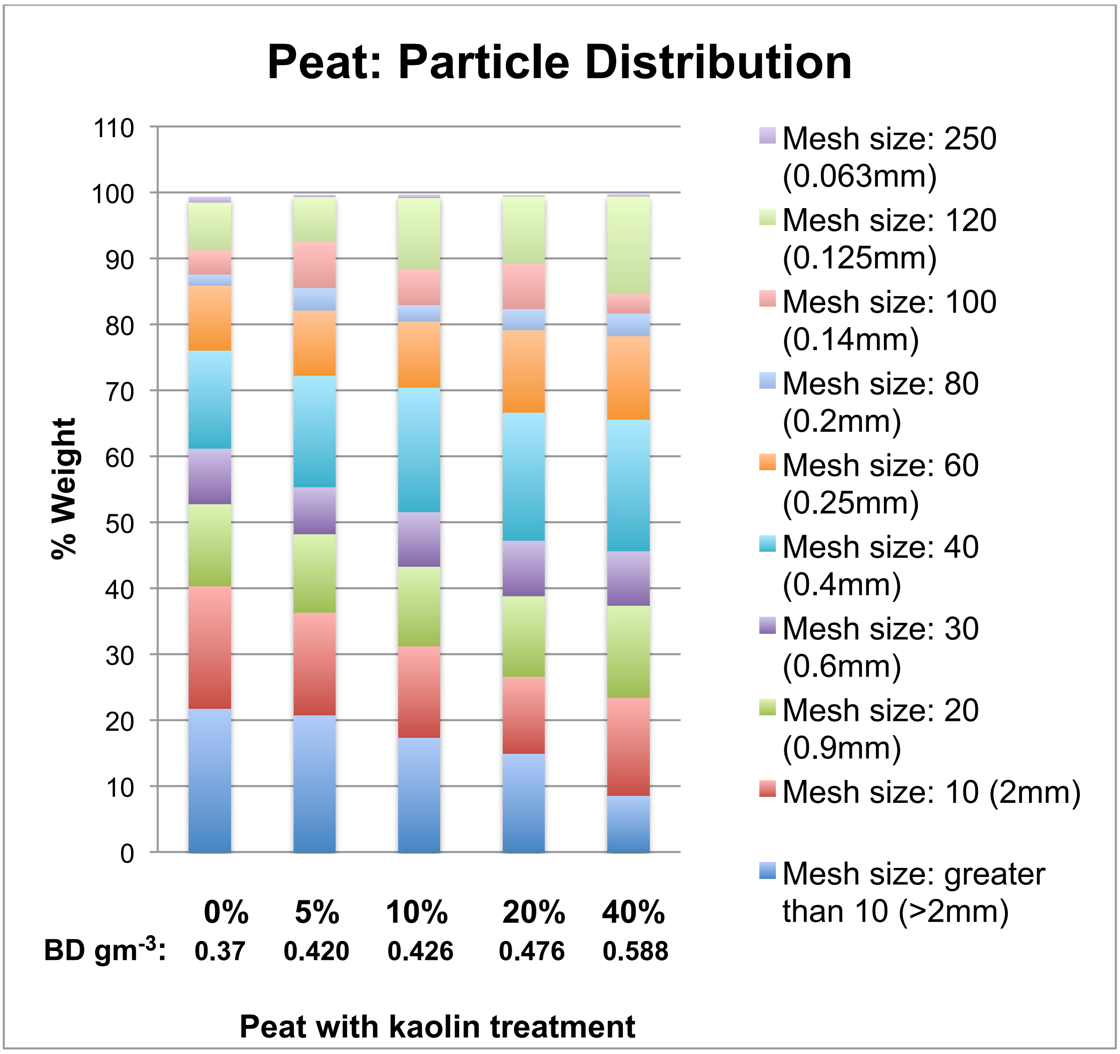


Figure 2.2.1 Particle distribution of dark peat, with different concentrations of kaolinite by % weight, between >2mm and 0.063mm. Bulk Density values are shown beneath the x axis.

Discussion

There was a more homogenous mix of the fractions than in the bulb fibre (Section 2.1), Figure 2.2.1 shows clearly how the larger fractions were reduced in favour of the finest in the higher kaolinite concentrations, which was as had been hypothesised (from mesh size 60 onwards). The distribution for the 0% treatment was similar to the peats tested by Goh and Haynes (1977).

2.2.2 Physical characteristics: Bulk Density (BD), Water Holding Capacity (WHC), Container Capacity (CC) and Air Filled Porosity (AFP)

The results were all significant. The water holding capacity (Figure 2.2.2) showed a significant difference (P <0.001) between the 0% treatment (60.52%) and the others, but also showed a significant difference at the lowest end of the scale for the 5% treatment.

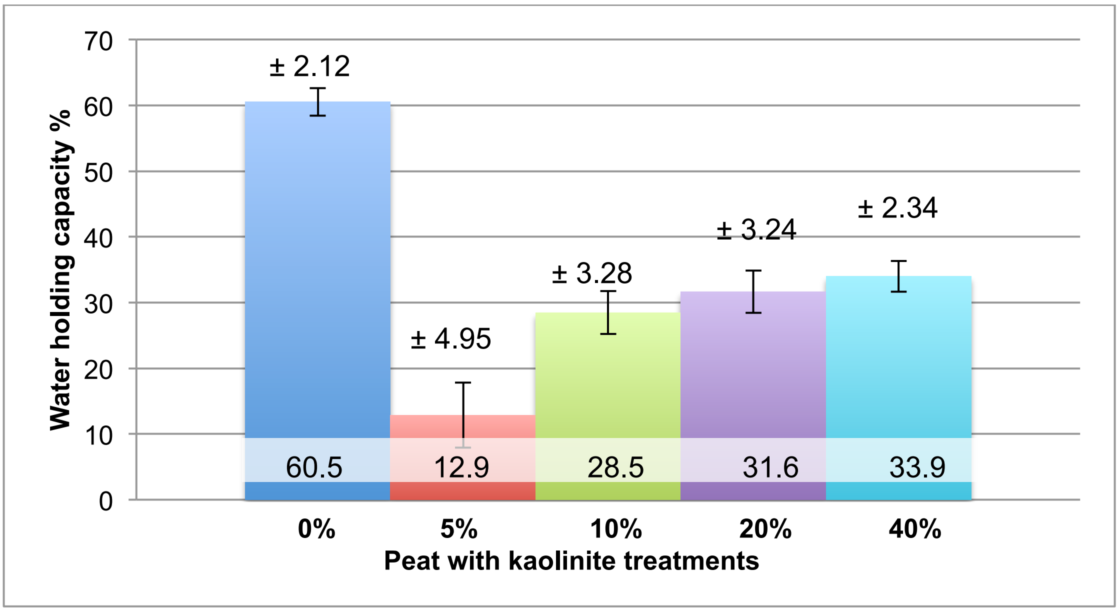


Figure 2.2.2 The WHC of dark peat with treatments of kaolinite added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars), P <0.001.

The water holding capacity (Figure 2.2.2) results for the peat with 0% kaolinite are unusually large in comparison to the other treatments. The experiment was run a second time but the oven-dried peat without any kaolinite proved too resistant to water to be able to retrieve any data from (saturation took over two months), however the other treatments had similar results to those shown in Figure 2.2.2, and the results obtained show a similarity to the results for the peat-based bulb fibre. It is possible that researcher error is to blame, the high degree of hydrophobicity causing an unconscious alteration in treatment of the substrate. The container capacity (Figure 2.2.3) of the peat showed a steady reduction from 0% to 40% kaolinite. These values are significant (P <0.0001), with each treatment distinct.

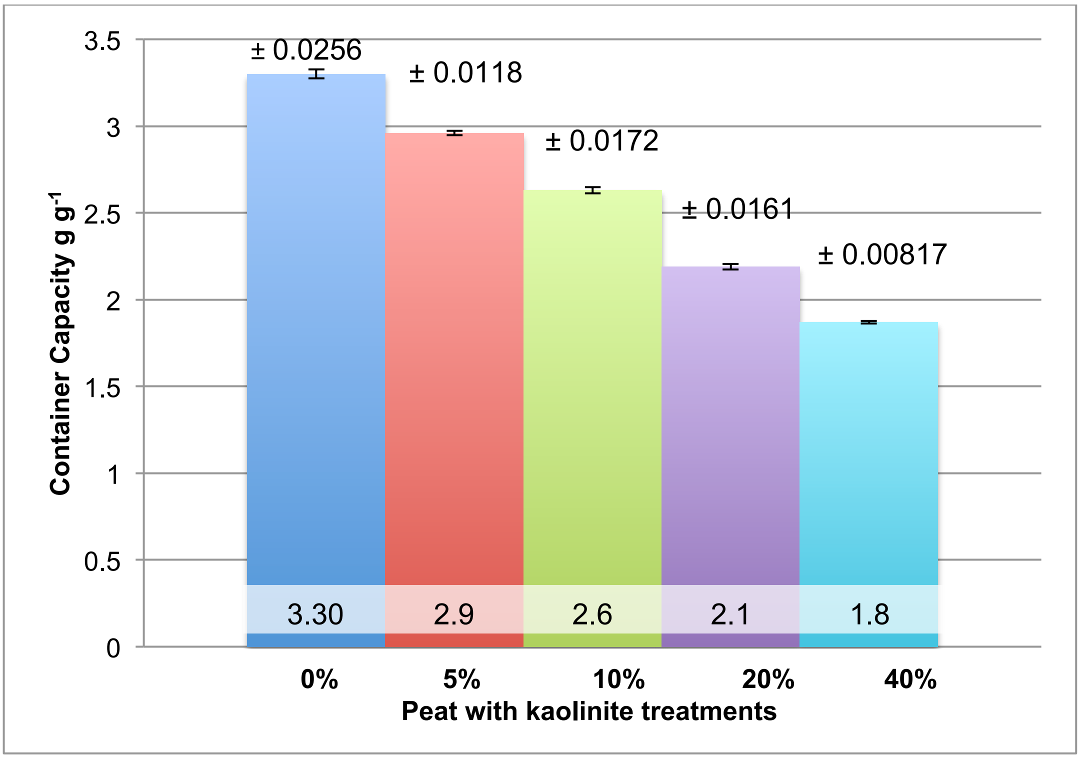


Figure 2.2.3 The container capacity (g g^{-1}) of dark peat with kaolinite treatments added by percentage weight, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars), P <0.0001.

The air-filled porosity values (Figure 2.2.4) showed the same pattern as the WHC, with a large value for the 0% kaolinite treatment, in particular in comparison to the 5% treatment at 4.36%. The values are significant to P <0.001 and showed three groups (Figure 2.2.4), with 0% and 40% significantly different from the 10% and 5% treatments, the 5% treatment was alone with the lowest value.

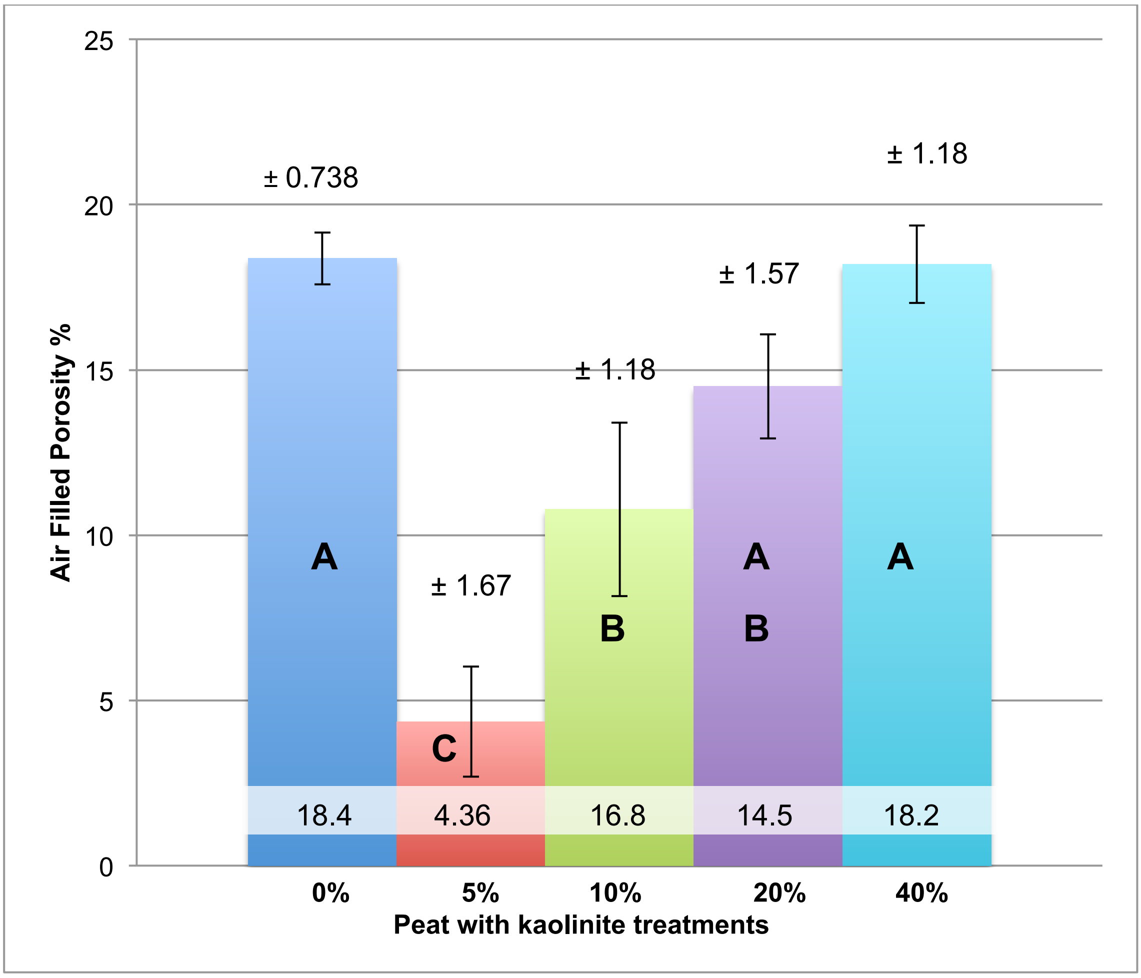


Figure 2.2.4 The AFP (%) of dark peat with different concentrations of kaolinite added, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Discussion

The bulk density of the peat samples showed a steady, though small, increase as the mineral content increased, which was expected, the BD of the peat with 0% kaolinite agrees with other findings (Goh and Haynes, 1977; Abad *et al.*, 2005), however it disagrees with the suggestion that as BD increases porosity decreases (Argo, 1998). The same pattern of increase was seen with the container capacity. However, apart from the 5% treatment, all AFP values are within a good range for growing plants that need little attention (Government of Western Australia, 2016).

2.2.3 pH

The results for pH (Table 2.2.1) showed no significant difference (P >0.05) in the values between all of the treatments.

Table 2.2.1 The pH values of peat with different concentrations of kaolinite added. Data are mean (n = 5) ± 1 Standard Error (SE) and rounded to 3 significant figures.

Treatment % Kaolinite concentration	pH	Standard Error
0%	4.81	±0.0115
5%	4.80	±0.0115
10%	4.80	±0.0102
20%	4.84	±0.0222
40%	4.84	±0.0158

Discussion

The peat tested was more acidic than the bulb fibre substrate which is in keeping with the literature (Government of Western Australia, 2016), the variations between the samples were insignificant, despite both the bulb fibre and the peat showing a slightly higher mean result with the 40% kaolinite concentration.

2.2.4 Organic content (ash residue)

With 88.26% organic matter in the 0% treatment (Figure 2.2.5), the dark peat used in this research is particularly high in organic matter. The fall in values in the treatments correspond to the percentage of kaolinite added (Figure 2.2.5).

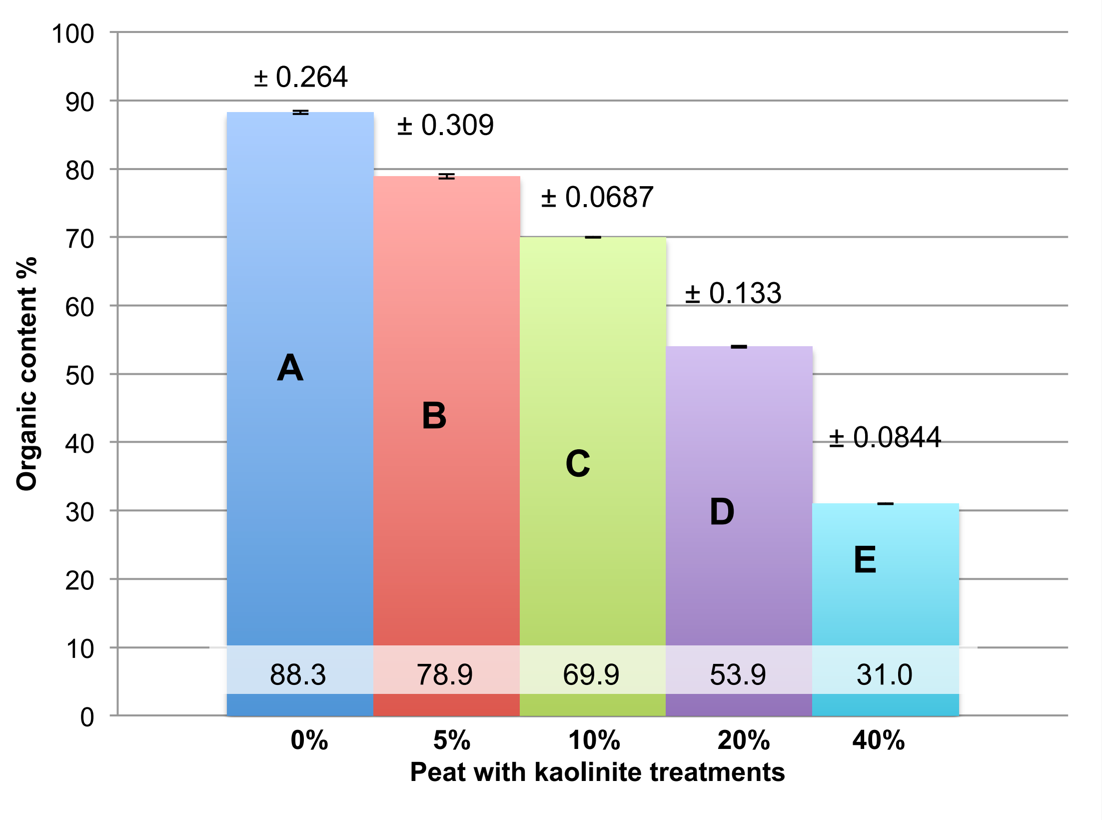


Figure 2.2.5 The organic content of dark peat with kaolinite treatments as found through loss through ignition, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.0001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The results were found to be significantly different (<0.0001), further testing (Figure 2.2.5) showed all treatments to be distinct from each other.

Discussion

Since peat is almost pure vegetation, with some minerals washed in over the centuries (Andriesse, 1988) the findings that the dark peat used in this research is 88.26% organic was expected. The reduction of organic matter as the mineral content is increased with the addition of kaolinite is predictable.

2.2.5 Capillary rise

The hypothesis was that adding kaolinite would decrease hydrophobicity in the oven-dried peat, in line with findings in soil science (Lichner *et al.*, 2006; Diamantis *et al.*, 2017). The peat with 0% kaolinite showed extreme water repellency in the capillary rise experiment (Table 2.2.2), its mean value of -9.33 showed that water barely penetrated the substrate, even below the water level. The results showed a large rise from the 5% treatment (1.17mm) towards the 20% treatment of 47.33mm (Figure 2.2.6), then falling away at 40%.

Table 2.2.2 The capillary rise of deionised water moving against gravity in dark peat with different treatments by % weight of kaolinite. (Data are mean (n = 3) ± 1 Standard Error (SE). Rounded to 3 significant figures).

Treatment %	Mean low point of capillary rise mm	Mean high point of capillary rise mm	Difference between the low and high means mm	Mean of Means mm	Standard error
0%	-9.33	-9.33	0	-9.33	±0.272
5%	-5.33	7.67	13.0	1.17	±3.41
10%	41.0	51.7	10.7	46.3	±1.44
20%	45.3	49.3	4.00	47.3	±0.828
40%	39.7	46.3	6.67	43.0	±1.43

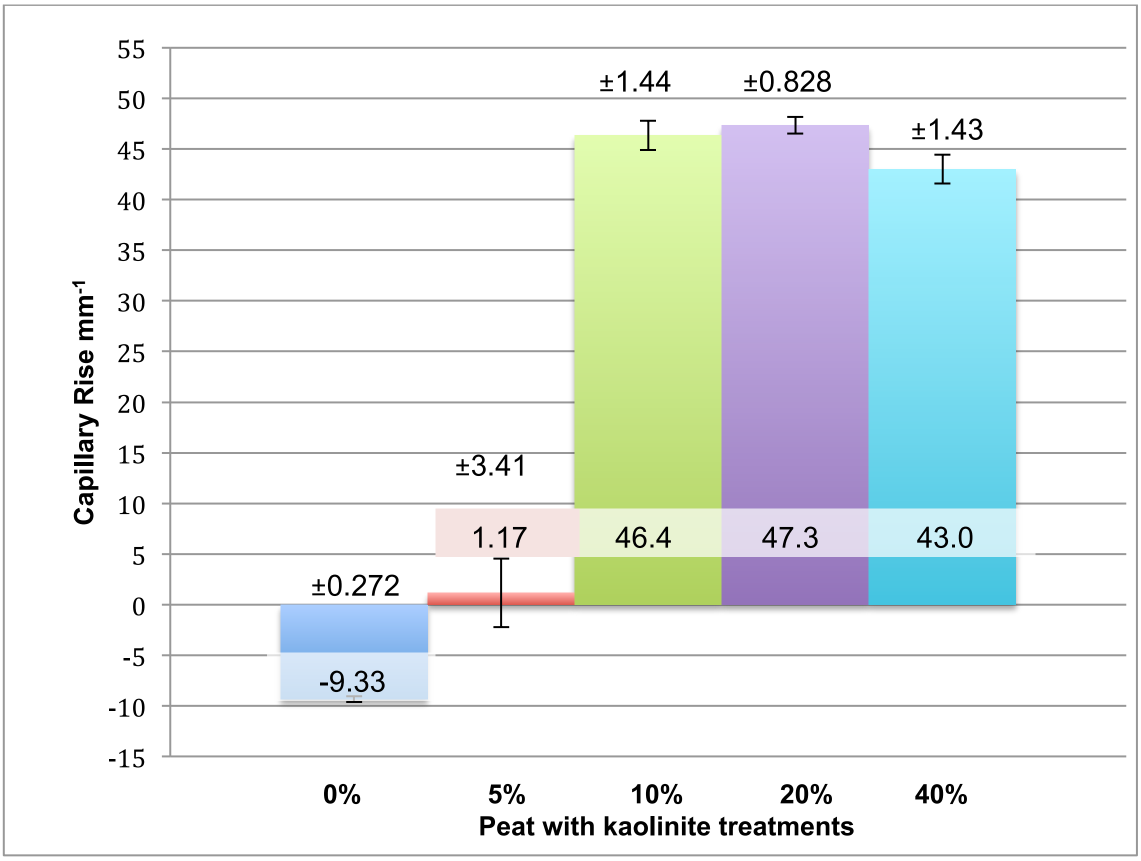


Figure 2.2.6 The capillary rise of deionised water moving against gravity in dark peat with different treatments by % weight of kaolinite. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.05, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The values did not follow a normal distribution, so the Kruskal-Wallis test was used. The P-value was significant at <0.05. Figure 2.2.7 shows that the 0% and 5% treatments were significantly different compared to the far higher values of the 10%, 20% and 40% concentrations.

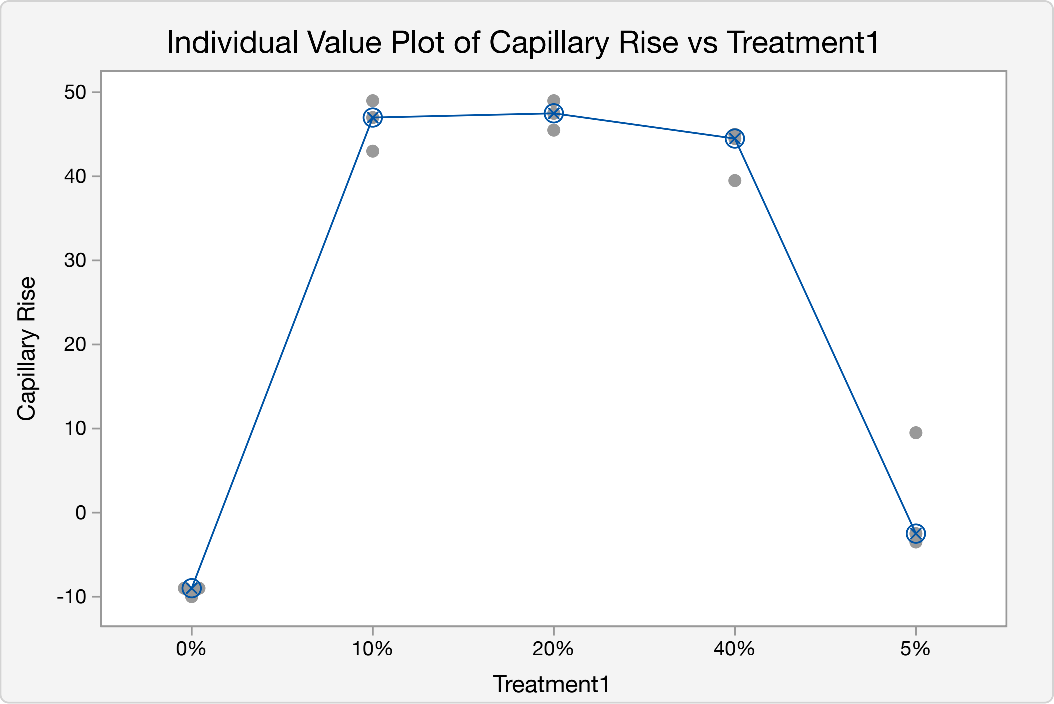


Figure 2.2.7 Kruskal-Wallis value plots of the capillary rise in oven-dried peat with kaolinite treatments added by percentage weight. Graph generated by Minitab®. Data are mean (n = 3).

Discussion

Peat has long been known to be highly hydrophobic when dry (Bunt, 1976; Gautam and Ashwath, 2012). The pure peat showed a greater degree of water repellence than the bulb fibre, and while there was some capillary rise in the peat with the 5% kaolinite concentration, albeit with a large degree of standard error, the results are notably different for this concentration in comparison to the bulb fibre results. The results varied less for the three larger kaolinite concentrations, with the 10% kaolinite addition being lower than for bulb fibre, the 20% concentration being of a similar degree, and the 40% concentration being higher than for the results with the bulb fibre.

2.2.6 Water Drop Penetration Time Test

The hypothesis was that the addition of kaolinite would improve the speed of infiltration for a drop of water in line with the results from the capillary rise test. Figure 2.2.8 show that even for the peat with 40% kaolinite, hydrophobicity was not completely overcome until the substrate reached 35% moisture, and the 0% kaolinite required 70% moisture before allowing a drop to infiltrate the surface within one second. Because of the expected hydrophobicity in the peat with 0% kaolinite, large jumps in between moisture levels were taken to save time.

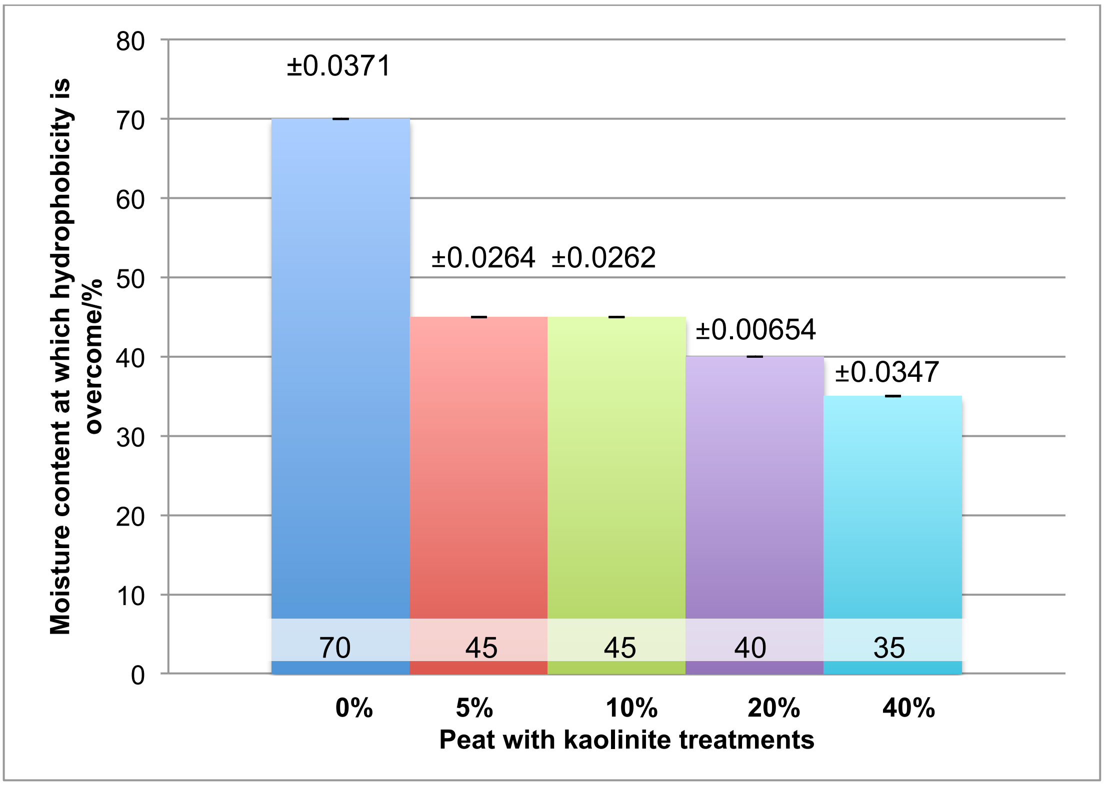


Figure 2.2.8 Water Drop Penetration Time test results for dark peat with different concentrations of kaolinite by % weight, showing the point where hydrophobicity is completely overcome, the values are shown in the boxes at the bottom of the bars, rounded to three significant figures (n = 3) ± 1 Standard Error (SE values are shown above the bars).

Figure 2.2.9 shows the development of wettability in the peat with kaolinite treatments using a logarithmic scale. The results are not as evenly distributed as those of the bulb fibre with both the 10% and 40% treatments, in particular, showing an uneven reduction of hydrophobicity. For the 10% treatment, at a moisture level of 30% the value was higher (18.97_s) than at 25% moisture (14.91_s) and both that treatment and the 5% overcame hydrophobicity at 45% moisture. As similar pattern occurred earlier on with the 40% kaolinite at 10% moisture.

At 35% moisture there was significance of <0.0001 between all treatments, except the 20% and 40% which still showed a significant difference, but at <0.02.

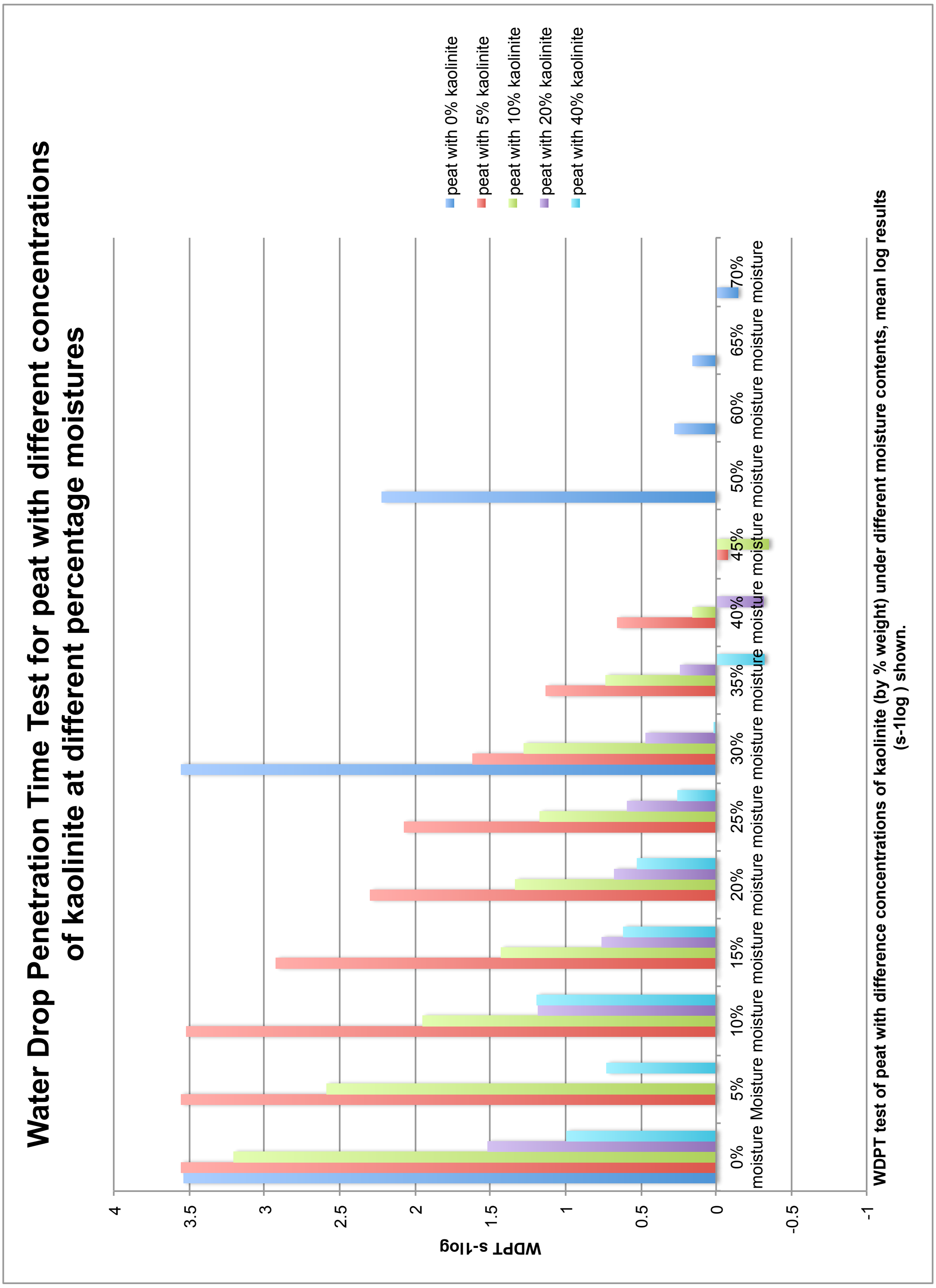


Figure 2.2.9 The results of the WDPT test for peat with different concentrations of kaolinite (by % weight) under different substrate moisture contents. The results have been translated into a logarithmic scale.

Discussion

The hypothesis has been partially upheld, showing significant difference at 35% moisture between all treatments, though it was expected that the results would display extreme hydrophobicity in the same curve seen in the capillary rise test, which did not occur. There is a corresponding increase in the speed of infiltration with the concentration of kaolinite.

2.3 John Innes no. 2, Melcourt’s Watering lane mix and Bulb fibre

The first growing experiment worked with bulb fibre substrate (BF), John Innes no. 2 (JI) and Melcourt’s composted bark substrate designed for use at the Watering Lane nursery (part of the Eden Project complex) (WL) with only 0g kaolinite or 8g kaolinite in each 2l pot, this resulted in the bulb fibre being mixed 80g:740g (4:37); John Innes no. 2 was 80g:1600 (1:20), and the Watering Lane mix 80g:800g (1:10). These ratios were used because the first experiment was designed to mirror the original BSc experiment to confirm its results, although bulb fibre has already been tested (Section 2.1), it was included again in these tests because of the different concentration used and the need to be able to use the results to inform the later growing experiments using these concentrations. The raw data can be found in Appendix 3.3, p. 259.

Melcourt’s Watering Lane nursery mix is a combination of 40% composted pine bark, 50% composted wood fibre and 10% sterilised loam (Gray, 2017), all the composted material was organically grown. It also contained some limestone, fertiliser and a wetter to reduce hydrophobicity. Unlike most other bark composts, Melcourt screen out the ‘fines’ – the fine particles – and in doing so increase the air-filled capacity from a typical 39% to 59% according to their own figures (Melcourt Industries, n.d.).

The John Innes no.2 used in this study was supplied by J. Arthur Bower and is a combination of topsoil (loam), sphagnum moss peat, sand, along with fertilisers (John Innes Manufacturers Association, n.d.) and limestone.

Bulb fibre – BF	Bulb fibre with kaolinite – BF/K
John Innes no.2 – JI	John Innes no.2 with kaolinite – JI/K
Watering Lane mix – WL	Watering lane mix with kaolinite – WL/K

2.3.1 Particle Distribution

Figure 2.3.1 shows the distinct differences in the different substrates clearly. The bulb fibre had the highest portion of >2mm particles in particular without the kaolinite, the figure was halved from 52.85g to 26.25g once kaolinite had been added. The bulb fibre without kaolinite had a larger percentage of the largest fraction (>2mm) than the treatment with kaolinite, which had a larger portion in the lower mesh sizes in particular 0.25mm and 0.14mm. The John Innes no.2 treatments showed very little alteration, while the Watering Lane mix showed the largest change in the 2mm fraction which was higher in the treatment with kaolinite.

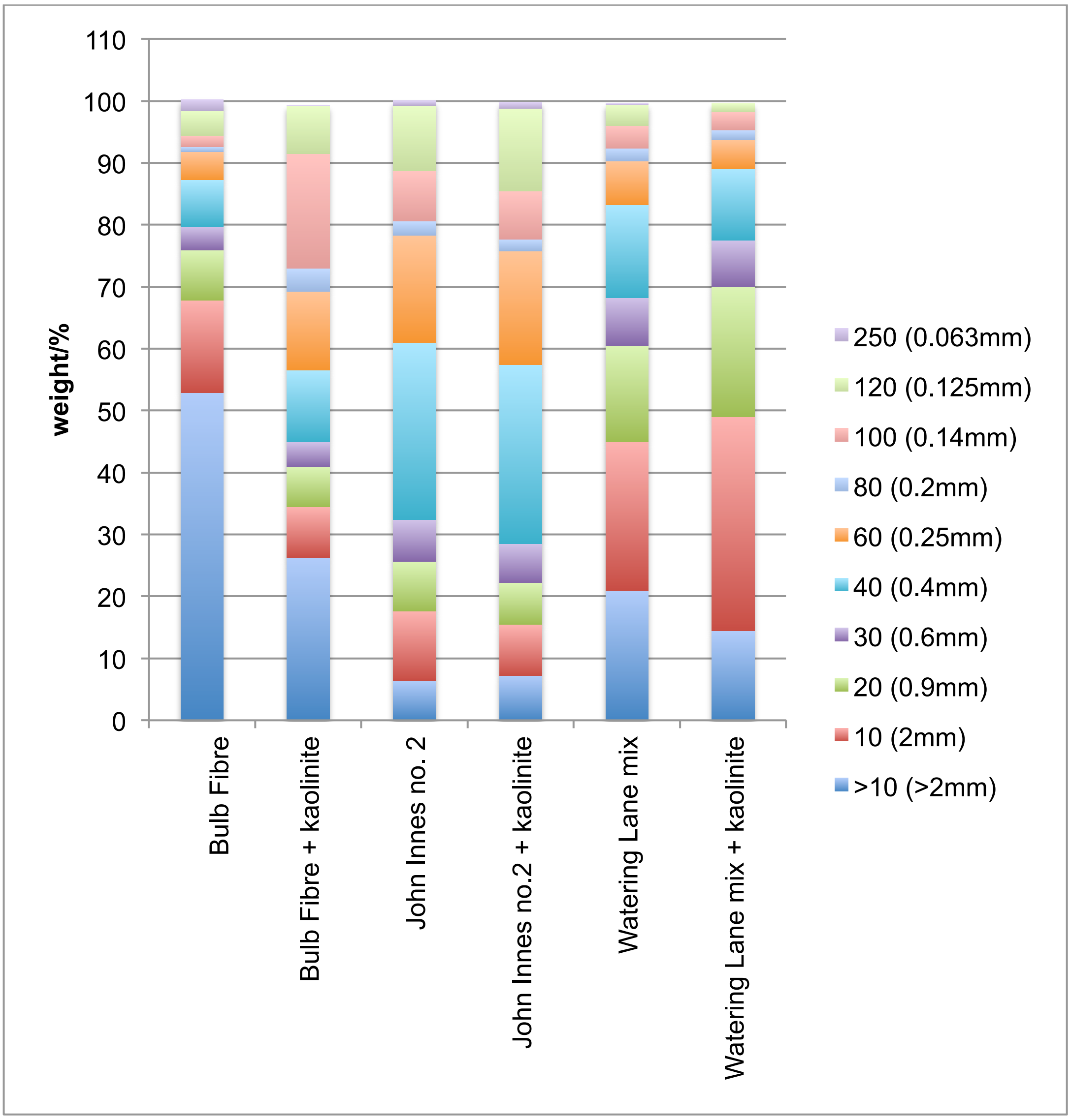


Figure 2.3.1 Particle sizes of bulb fibre, John Innes no.2 and the Watering Lane mix with and without kaolinite added by weight ratio (BF – 4:37; JI – 1:20 and WL – 1:10).

Discussion

It should be noted that due to the effort and time required to hand sieve each sample, only one repeat of each substrate was tested, therefore it was difficult to draw any conclusions, however the addition of kaolinite did not affected the particle distribution of the different substrates in a uniform way, and appears to have affected the John Innes no. 2 least. The presence of kaolinite increased the finer particles present in the bulb fibre.

2.3.2 Physical Characteristics: Container capacity (CC), Water holding capacity (WHC), Air-filled Porosity (AFP)

While there was a large mean difference in the WHC for the bulb fibre treatments (Figure 2.3.2), the WHC had a P-value of <0.05 which showed that the two Watering Lane treatments were significantly different from each other (Figure 2.3.2), but the kaolinite had not caused any significant difference between the other substrates.

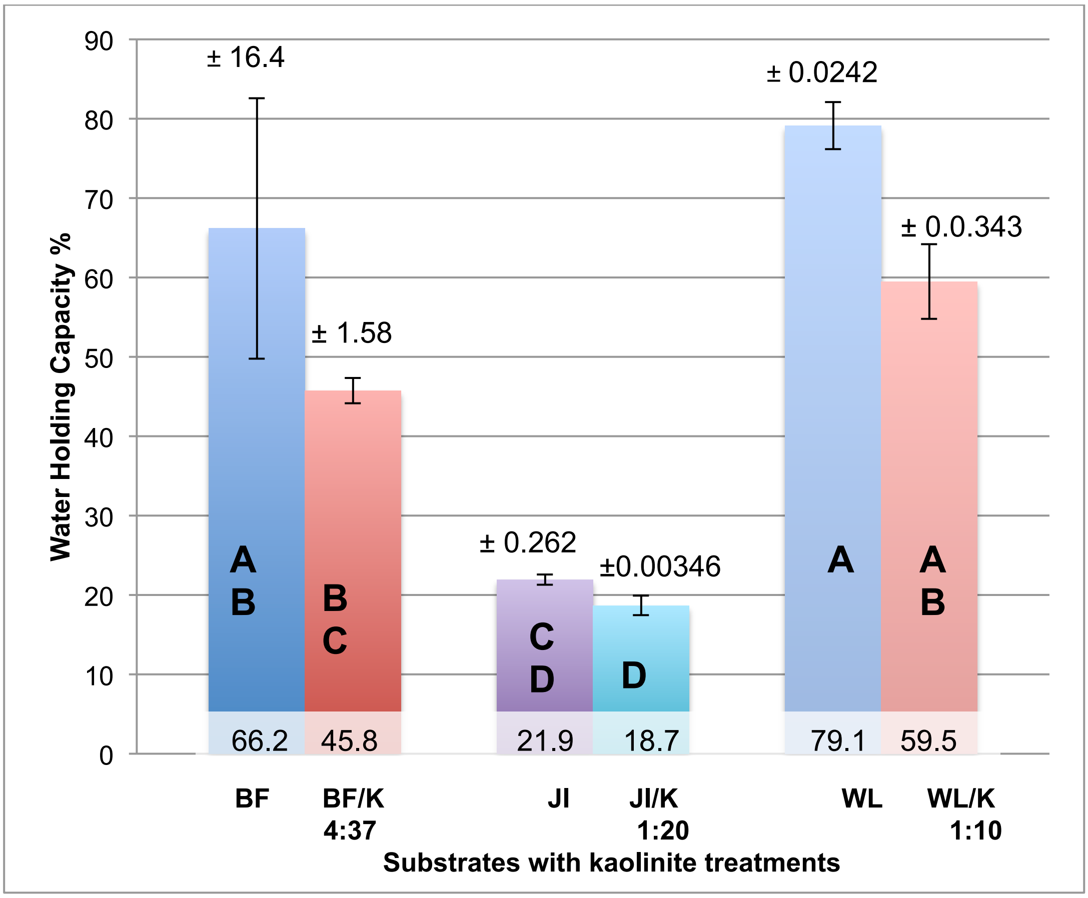


Figure 2.3.2 Water holding capacity of bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with and without kaolinite added by weight ratio, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.05, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The container capacity results (Figure 2.3.3) had a P-value of <0.0001, the bulb fibre and Watering Lane mixes both showed significant difference (Figure 2.3.3) between treatments, but the John Innes no.2 had no such significance.

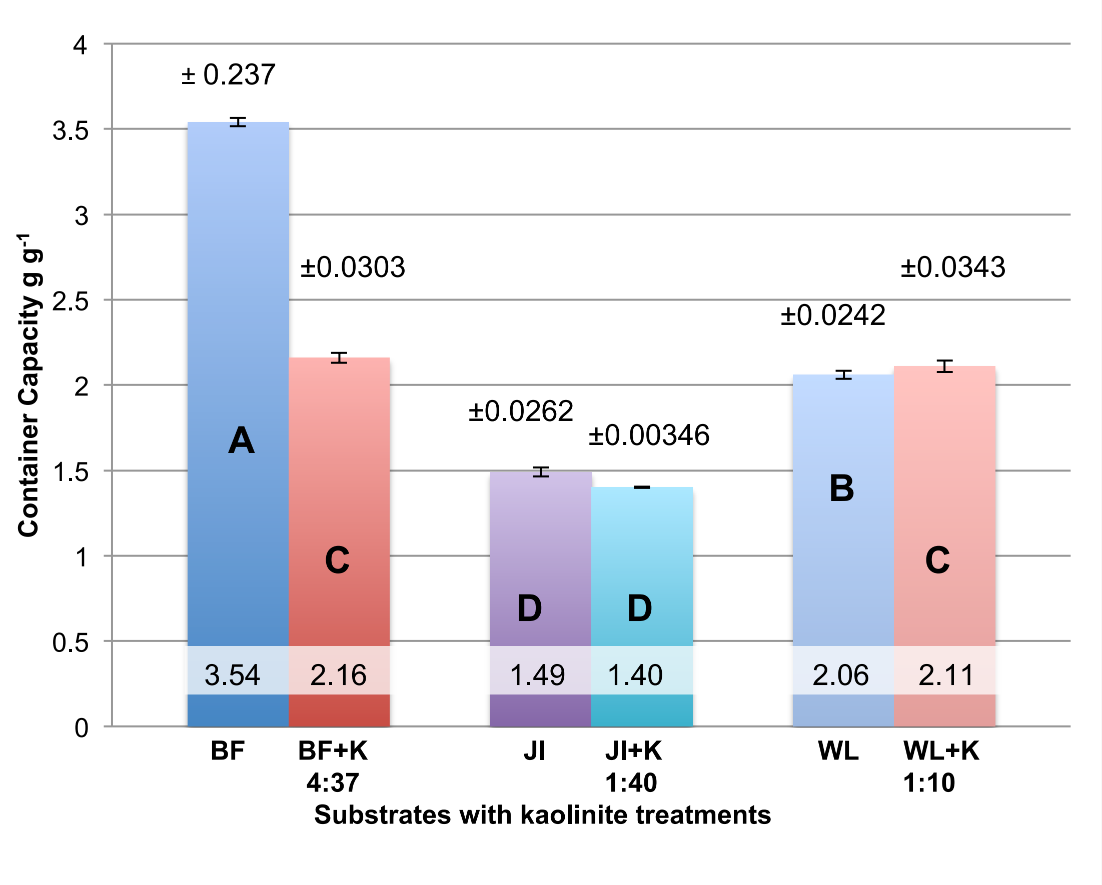


Figure 2.3.3 Container capacity of bulb fibre, John Innes no.2 and Watering Lane mix with and without kaolinite added by weight ratio, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.0001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The air-filled porosity results (Figure 2.3.4) (P <0.001) showed no significant difference within the substrate groups (Figure 2.3.4).

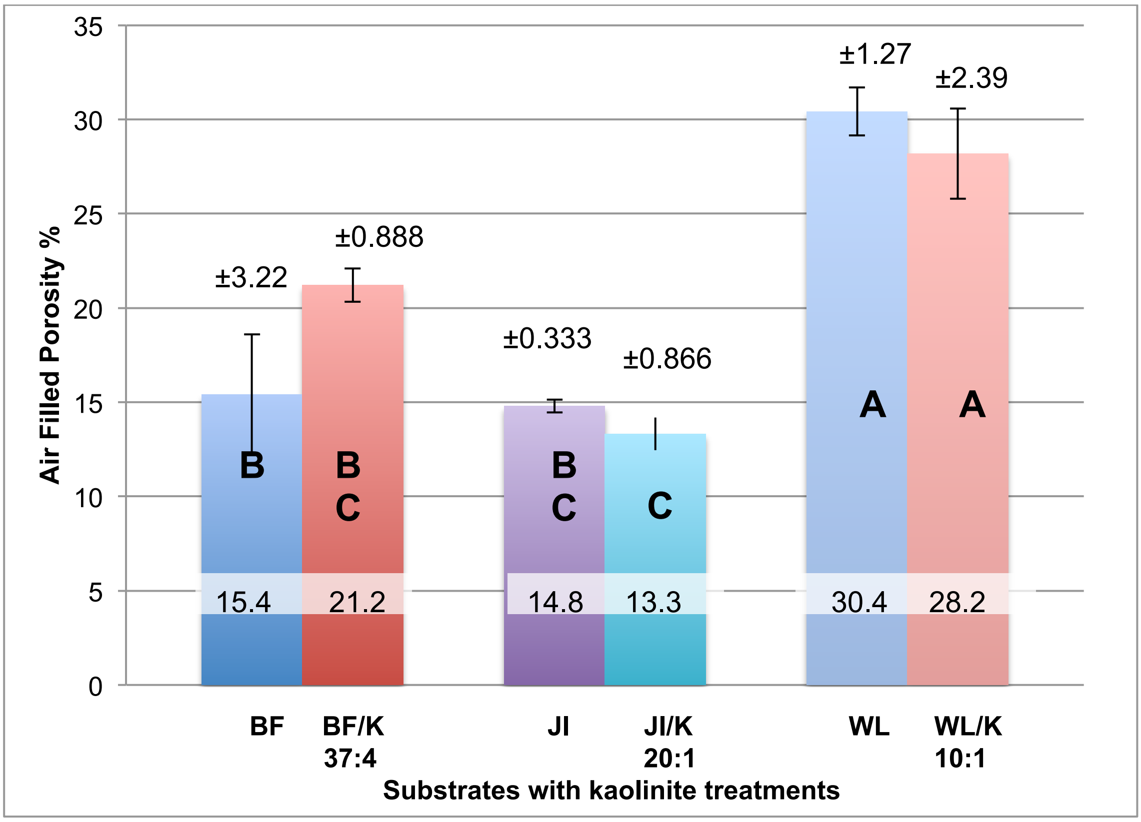


Figure 2.3.4 Air-filled porosity of bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with and without kaolinite added by weight ratio, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P<0.001 LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Discussion

The kaolinite made no significant difference to the physical properties of the John Innes no.2, and indeed there was nothing significant in the air-filled porosity for any of the substrates. The addition of kaolinite, however, did alter the water holding capacity and container capacity of the Watering Lane mix and bulb fibre substrate in opposite ways – decreased with WL and increased with BF. This suggests that any effect found in the first growing experiment is more likely to be due to water availability than air.

2.3.3 pH

The pH (Table 2.3.1 showed no significant alteration due to the presences of kaolinite (P >0.05) when the substrates were compared within their treatments.

Table 2.3.1 pH values of bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with and without kaolinite added by weight ratio. (Data are mean (n = 5) ± 1 Standard Error (SE). Rounded to 3 significant figures.

Treatment	pH	SE
Bulb fibre	6.02	±0.117
Bulb fibre + kaolinite (37:4)	5.89	±0.0191
John Innes no.2	7.07	±0.00938
John Innes no.2 + kaolinite (20:1)	7.07	±0.0258
Watering Lane mix	6.85	±0.0318
Watering Lane mix + kaolinite (10:1)	6.17	±0.00727

2.3.4 Organic content (loss on ignition/ash residue test)

The Bulb Fibre and Watering Lane mix substrates, consisting of mostly organic materials, showed the greatest difference in organic content between the treatments (Figure 2.3.5), with the John Innes no.2 showing very little difference (0.61%). With a P value of <0.0001, testing (Figure 2.3.5 placed the John Innes no.2 treatments together in their own group, and showed the other substrate treatments were significantly different from each other .

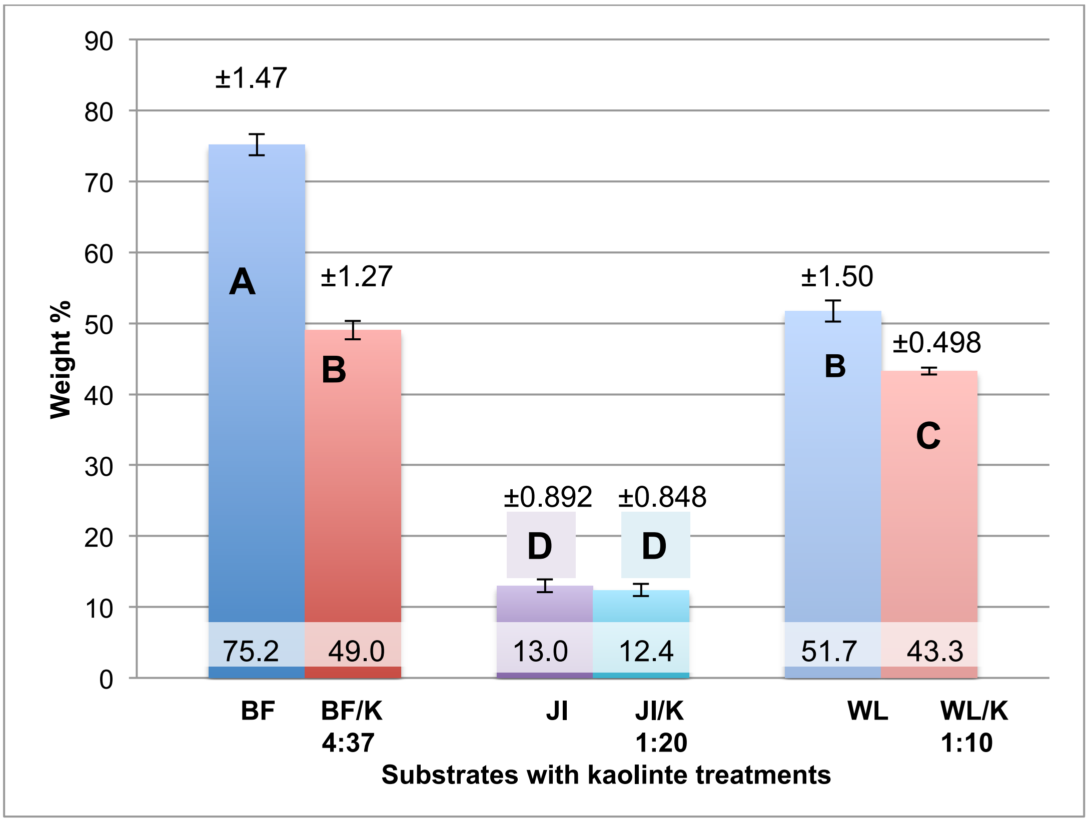


Figure 2.3.5 The organic content (by ash residue) of the substrates used in Experiment 1 with treatments of kaolinite, mean values are shown at the bottom of the bars, rounded to 3 significant figures, (n = 3) ± 1 Standard Error (SE values shown above bars). LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Discussion

As with the WHC, CC and AFP results, the organic content (loss on ignition) results showed significant difference between the treatments in bulb fibre and Watering Lane substrates, but not between the two John Innes no.2 substrate treatments. With the lower organic content present, it was likely that the John Innes no.2 would display less hydrophobicity than the other substrates.

2.3.5 Capillary rise

The hypothesis was that the addition of kaolinite would increase the capillary rise of water against gravity. All substrates showed an increase in the rise of water against gravity with kaolinite, the bulb fibre showing the greatest increase with a difference of 81.83mm (Table 2.3.2) Figure 2.3.6 shows the differences clearly, and suggests that there may be no significance in the John Innes no.2 results, this was born out with a P value of >0.05. The Watering Lane mix showed a P value of 0.01, and the bulb fibre a value of <0.001.

Table 2.3.2 Capillary rise of deionised water in Bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with and without kaolinite added by weight ratio. Data are mean (n = 3) ± 1 Standard Error (SE). Rounded to 3 significant figures.

Substrate and kaolinite treatment by ratio	Mean low point of capillary rise mm	Mean high point of capillary rise mm	Difference between low and high	Mean of means mm	Standard Error
Bulb Fibre	-7.67	-4.00	3.67	-5.83	±1.11
Bulb Fibre + kaolinite (4:37)	74.3	76.0	1.67	76.0	±7.56
John Innes no.2	68.0	82.7	14.7	75.3	±2.81
John Innes no.2 + kaolinite (1:20)	79.3	84.7	5.33	82.0	±2.72
Watery Lane mix	21.3	28.3	7.00	24.8	±6.41
Watery Lane mix + kaolinite(1:10)	67.0	70.7	3.67	68.8	±4.46

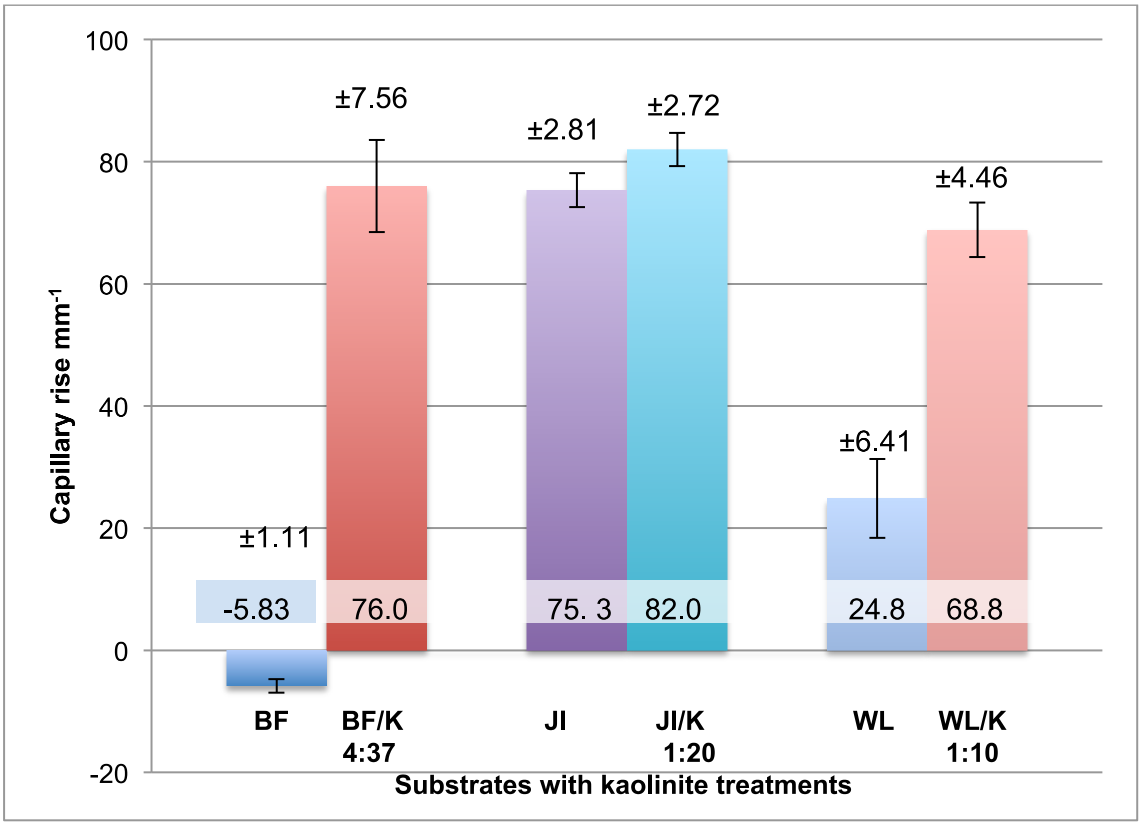


Figure 2.3.6 The capillary rise of deionised water in Bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with and without kaolinite added by weight ratio, mean values are shown at the bottom of the bars, rounded to 3 significant figures, (n = 3) ± 1 Standard Error (SE values shown above bars).

Discussion

In every case capillary rise was increased when kaolinite was present, thus upholding the hypothesis, with John Innes no.2 showing the smallest reaction, however it should be remembered that in effect it had the lowest concentration of kaolinite (added at a ratio of 1:20). This suggests that the presence of kaolinite should increase the ability of water to move against gravity in most substrates, which may be particularly useful for companies irrigating pot plants from beneath (such as those relying on capillary matting in supermarkets).

2.3.6 Water Drop Penetration Time Test

It was hypothesised that kaolinite would improve the time taken for a drop of deionised water to infiltrate the surface of a substrate.

As can be seen in Figure 2.3.7, hydrophobicity was completely overcome (taking less than 1 second) in the bulb fibre and Watering Lane mix with kaolinite using less moisture than without the mineral, in the case of the Watering Lane mix at 10% moisture compared to 30% moisture for the substrate without kaolinite. The John Innes no.2 overcame hydrophobicity completely (taking less than one second) at the same moisture content, but at 0% moisture the treatment without kaolinite was classed as strongly repellent whereas the John Innes no.2 with kaolinite was classed as wettable.

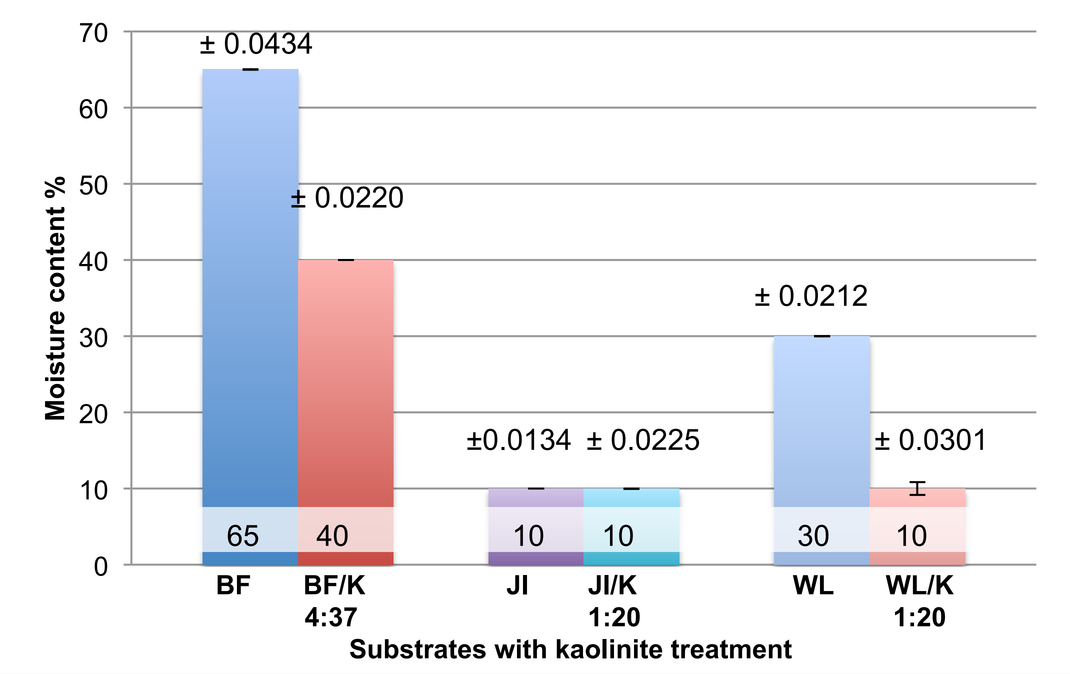


Figure 2.3.7 Water Drop Penetration Time test results for bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix with kaolinite added by weight ratio. Bulb fibre data taken from section 2.1 (Table 2.1.3). Data are mean (n = 3) ± 1 Standard Error (SE values shown above the bars).

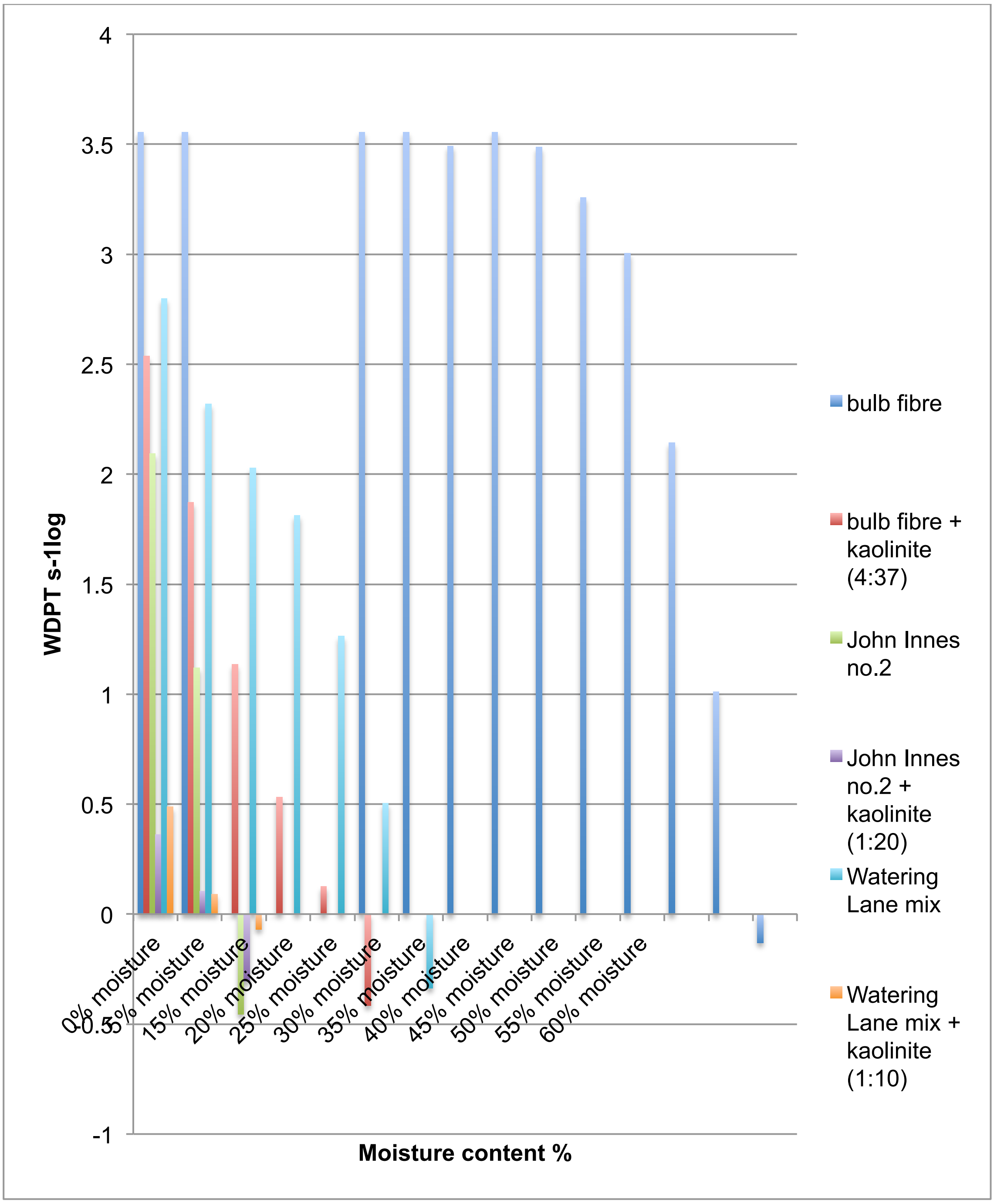


Figure 2.3.8 The development of the water drop penetration time test shown in a logarithmic scale for the substrates and treatments used in Experiment 1. Data are mean (n = 3).

Figure 2.3.7 shows the the positive effect of adding kaolinite to Bulb Fibre and the Watering Lane mix for improving water penetration, while the John Innes no.2 shows no effect (see also Figure 2.3.8). As can be seen in Figure 2.3.7, the John Innes treatments showed the least water repellency, and that at 10% moisture the previous repellency shown in the JI is completely gone, ANOVA results showed an expected significant difference between the two treatments at 5% moisture ($P < 0.0001$), but even at 10% moisture, where both samples showed no repellency, there was still a significance between them of $P < 0.05$. At the 10% moisture level there was also a significant difference ($P < 0.0001$) between the two Watering Lane treatments and the two bulb fibre treatments at the 40% moisture point.

Discussion

It might have been better, in hindsight, to have followed the same kaolinite concentrations as with the bulb fibre and peat, rather than using the concentrations used for the growing experiment. It was intended that these physical experiments inform the growing experiments, and only experience showed that the lab work would be arguably more informative.

The John Innes no.2 substrate completely overcame hydrophobicity, taking less than one second for water penetration, at 10% moisture for both treatments, after showing a large increase in wettability in the substrate without kaolinite after the 5% moisture test, however the John Innes no.2 with kaolinite was the only treatment to be classed as wettable (penetration taking less than five seconds) at 0% moisture, and at both 5% and 10% moisture levels they are still significantly different from each other. With all substrates showing an improvement in wettability with the mineral addition, it does appear that kaolinite is an effective way of counteracting the natural hydrophobicity of artificial organic substrates. The bulb fibre and bark-based compost, however, did show a positive reaction to the kaolinite in regard to overcoming hydrophobicity. Considering that the WHC and CC results for the Watering Lane mix were lower with kaolinite than without (even with the wetting agent added to the WL by Melcourt), these results suggest that the mechanism by which the kaolinite counteracts the hydrophobicity is not linked to water adsorption, but to the way water is able to move through the substrates.

3.0 Growing Experiments

The purpose of the growing experiments was to follow a narrative of discovery in relation to the effect of adding kaolinite to potting substrate on plants.

The study sought to:

- confirm the results of the original BSc experiment that suggested there was an effect, and discover whether kaolinite improved plant growth in different substrates.
- identify whether an effect could be observed with small additions of kaolinite (0%;0.5%;1%; 1.5%; 2%).
- investigate how large additions of kaolinite affected plant growth (0%; 25%; 50%; 100%).
- ascertain the optimum level of kaolinite addition for best plant growth (0%; 5%; 10%; 20%; 40%).
- repeat the experiment with a second species, specifically *Triticum aestivum* (winter wheat), with the same quantities of kaolinite as the previous experiment (0%; 5%; 10%; 20%; 40%).
- test the hypothesis that kaolinite improves the resilience of plants under dry conditions by simulating a revegetation event in a semi-arid area using both *Brassica juncea* and *Triticum aestivum*.

Experimental environment

Experiments were conducted in a greenhouse at Watering Lane Nursery, (Pentewan, Cornwall, UK) fitted with a thermal screen in the roof used to reduce solar gain during peak summer conditions. Pots were placed on to a raised bench (0.5m wide x 5.9m long and 0.7m above the ground). The bench was covered with 17gsm thick fleece (LBS Horticulture, Lancashire, U.K.) supported on five aluminum hoops (Figure 3.0.1). The bench was lined with black micro perforated polythene film (LBS Horticulture, Lancashire, U.K.). Glasshouse temperatures (°C) were recorded using an HOBO® Pendant Temperature/Light Data Loggers (#UA-002-64, Onset Computer Corporation) set to record data every half hour. Mean daily temperature was calculated from this data (software version HOBO® 3.7.8.v) and presented for each experiment conducted.

Figure 3.0.1 The glasshouse bench set up for the first experiment

Plant material

Two contrasting plant species, *Brassica juncea* and *Triticum aestivum* were used for the duration of these experiments.

Brassica juncea

Experiments were conducted using young plants propagated in a uniform environment prior to transplanting into experimental treatments. Seeds of *Brassica juncea* (Moles Seeds Ltd, Essex, UK) were sown into modular seed trays containing 54 cells (black plastic,6 x 9 cells, 40mm x 38mm x 5mm, single hole). Seeds were sown using Westland Horticulture’s bulb fibre substrate and trays placed on to a bench, irrigated (using a watering can to bring the pots back to container capacity) and allowed to grow until a two true leaf stage at which point they were deemed suitable for transplanting into the treatments.

Triticum aestivum

Triticum aestivum seeds (Winter wheat ‘JB Diego’ supplied by Aggrii UK) were sown directly into experimental conditions at a depth of 1cm and allowed to germinate.

Pots

Three sizes of black plastic pots (Teku, UK) were used in the studies presented here, 2 litre (125mm deep,165mm diameter); 1Litre (102mm deep,130mm diameter) and 9cm (86mm deep, 93mm diameter). Pots were washed prior to the start of each experiment.

Experimental design

Each treatment and replicate pot was assigned a code, randomised with the aid of a random number generator and subsequently laid out on the growing bench.

Pot filling and transplanting

Unless otherwise stated, the balance used was ADP 2100L, Algan Scale Corporation, USA. Unless otherwise stated, kaolinite was mixed within the experimental substrates by weight using a cement mixer to ensure uniform and consistent mixing. Pots were filled by weight then tapped twice on the bench to settle the substrate. Young plants were transplanted into each pot and placed in the predetermined position on the bench. Pots were watered as required with the aid of a hosepipe fitted with a lance and fine rose. No fertiliser was used.

Data collection

Fresh measurements

The height of the plants was recorded in millimeters using a steel ruler and measured from the substrate surface to the growing apex. The length of the longest leaf and the width at the widest point was also recorded.

Destructive harvest

Each plant was removed from its pot and the root ball carefully cleaned in water. Any detached roots were caught (where possible) and saved. Once cleaned the roots were cut at the point of the stem where it becomes white. The samples were then placed in appropriately marked bags/envelopes, weighed, and dried at 75˚C for two days in a fan assisted drying oven (ELE International, Leighton Buzzard, U.K.). The samples were then weighed again, using an empty, dried, bag/envelope to tare. Fresh and dry weights of the above ground biomass was recorded similarly.

Data analysis

Data was managed in line with the lab-based experiments (Chapter 2.0). Raw data can be found in Appendix 4 (page 269). Statistical analysis was not undergone for the growing data beyond calculating the standard error. It was felt that while statistical analysis of the data from the destructive harvest would be useful and could be displayed legibly, the amount of information statistical analysis would generate from the growth data would be impossible to display and keep it meaningful.

3.1 Experiment 1 – Confirmation of original experiment

3.1.1 Introduction

The purpose of this experiment was to confirm the results of the original BSc experiment. Westland Horticulture's bulb fibre was chosen because it achieved the best response in the BSc study, the John Innes no.2 was chosen because it mimicked soil closer than other sterile artificial substrates, and Melcourt's formula designed for the Eden Project's Watering Lane Nursery (Watering Lane mix) because it was very different in structure to the other substrates, also it was both freely available and homogenous. It was hypothesised that kaolinite would increase plant growth in the bulb fibre, Watering Lane mix and possibly the John Innes no.2 substrate.

3.1.2 Method

The original experiment (Bettany, 2014) was performed using the published advice from manufacturers (g m^{-3}), and not by using percentage weight or volume, which resulted in 80g kaolinite per two litre plant pot. This was repeated again, only in Experiment 1, since it resulted in different concentrations depending on the substrate:

Bulb fibre:kaolinite – 740g:80g (37:4)
John Innes no.2:kaolinite – 1300g:80g (20:1)
Watering Lane mix:kaolinite – 800g:80g (10:1)

A KERN – ECE – 50K20 (maximum 50kg, minimum 20g) (Kern & Sohn, Germany) balance was used.

Fifteen pots of each treatment (bulb fibre, with and without kaolinite; John Innes no.2 with and without kaolinite; Watering Lane mix with and without kaolinite) were mixed, labeled and set up randomly on the bench. On the 8th of January 2016 five *B. juncea* seeds were sown in each pot and watered, and seven weeks (49 days) later they were thinned to a single individual in each pot, with one exception - in one John Innes no. 2 + kaolinite pot only two seeds germinated, and both were sickly, so a seedling from another pot of the same treatment was transplanted. The long growth time is due to the cooler winter weather.

It was attempted to water each time to field capacity, but this proved impractical, only the researcher could do this, and since she was not able to access the nursery often enough, the plants sometimes became water stressed. Also the glasshouse leaked in the rain, Storm Imogen passed over during the period of this experiment (MetOffice, n.d.), therefore some plants received more water than others.

A midway destructive harvest of a third (five from each treatment) of the experiment was begun on the 4th of April and completed on the 6th, the individuals harvested were chosen randomly. The full term destructive harvest was performed 28 days later. Paper bags made from newspapers were used in both cases. Plant weights were taken on the nursery's lab balance.

3.1.3 Results

Environmental parameters

The mean temperature was 12.14˚C (±1 SE – 0.263) (Figure 3.1.1) and the mean light – 3,743.5 lux (±1 SE – 253) (Figure 3.1.2).

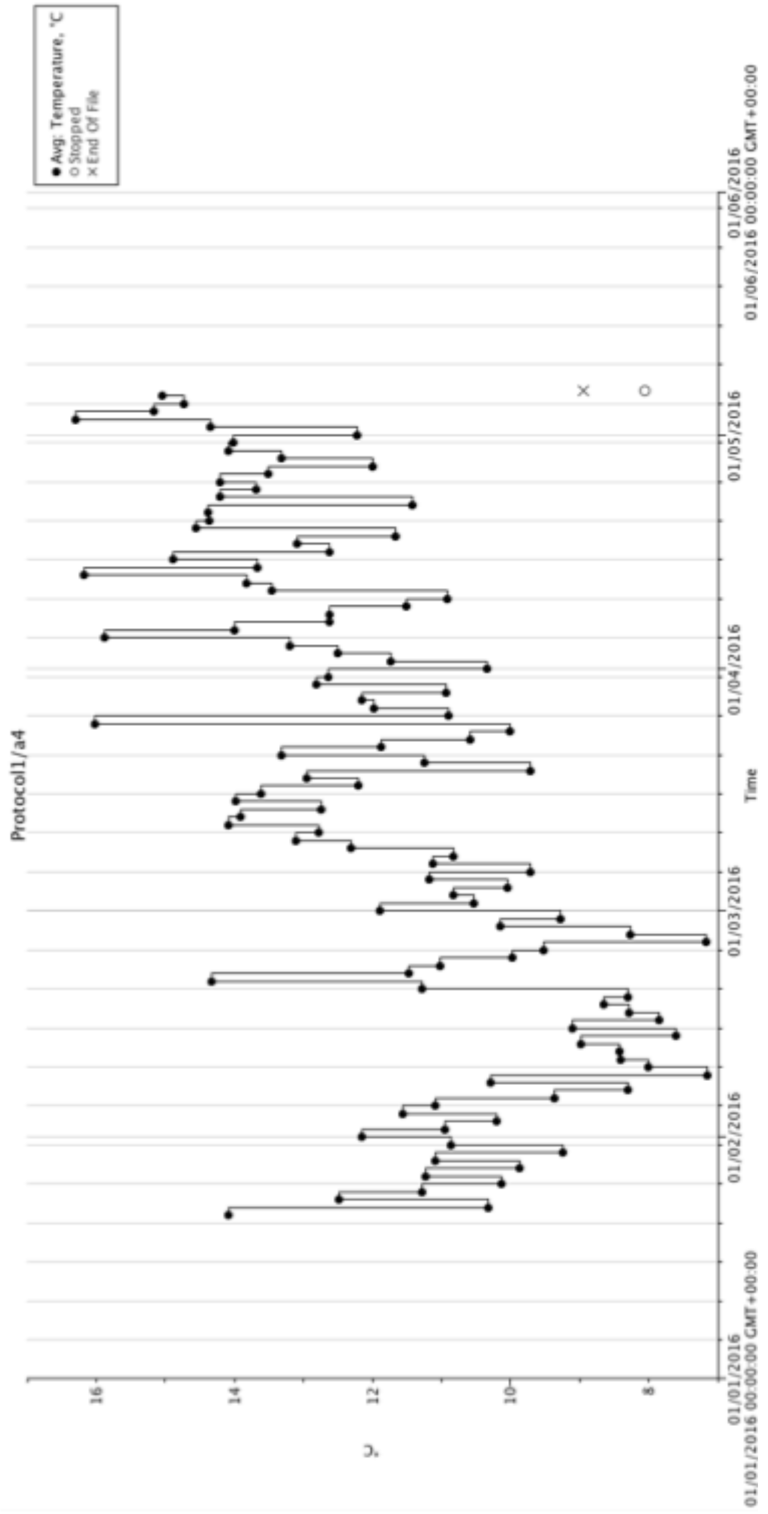


Figure 3.1.1 Temperature fluctuations (˚C) in the glasshouse during Growing Experiment 1.

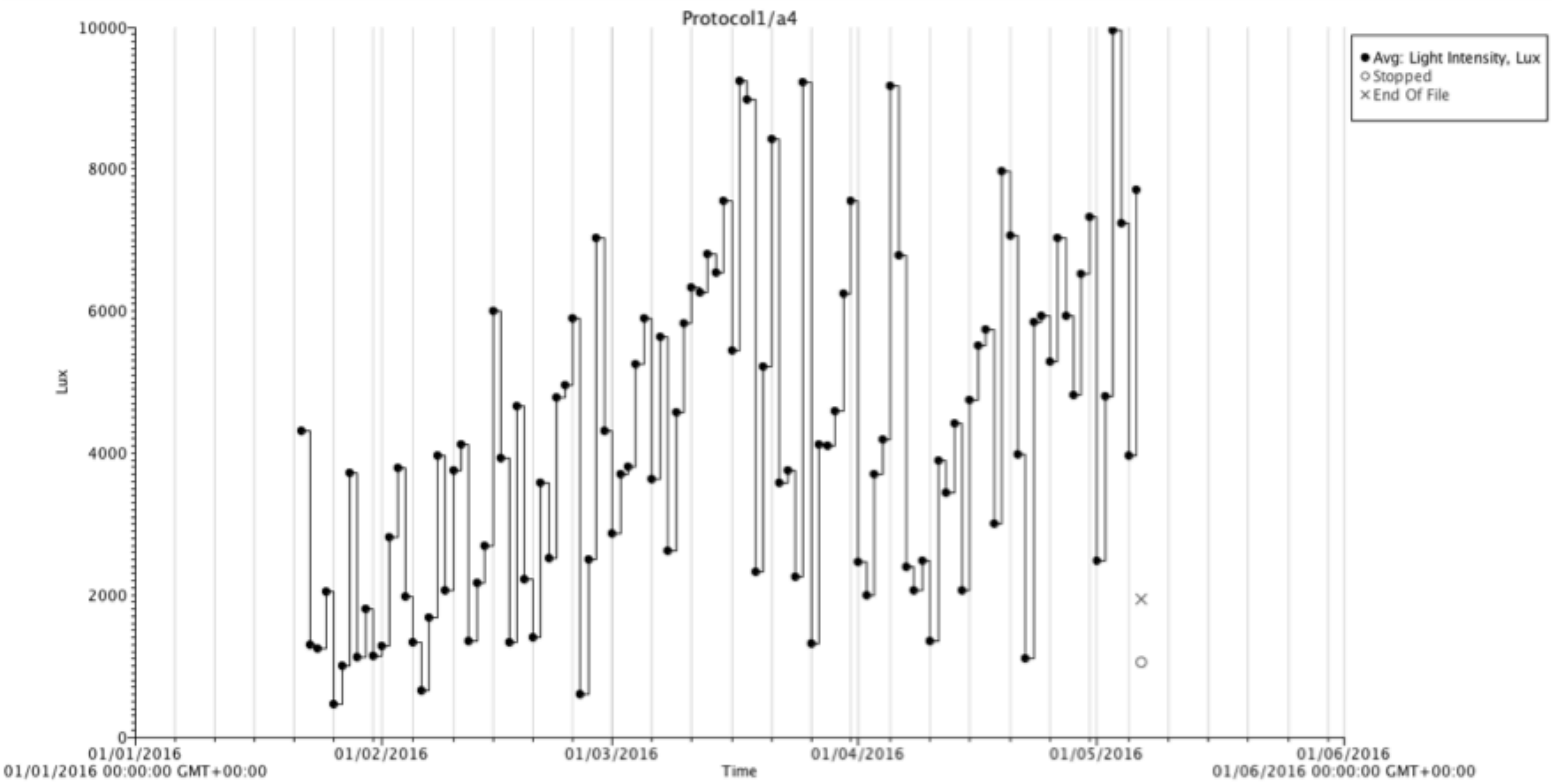


Figure 3.1.2 Light fluctuations (lux) in the glasshouse during Growing Experiment 1

Growth

The raw data can be found in Appendix 4.1 (page 268), Figure 3.1.3 shows the growth of the *Brassica juncea* stems. The treatments showed no variation from each other until the fourth week. The greatest difference was in the bulb fibre without kaolinite added and all other substrates and treatments.

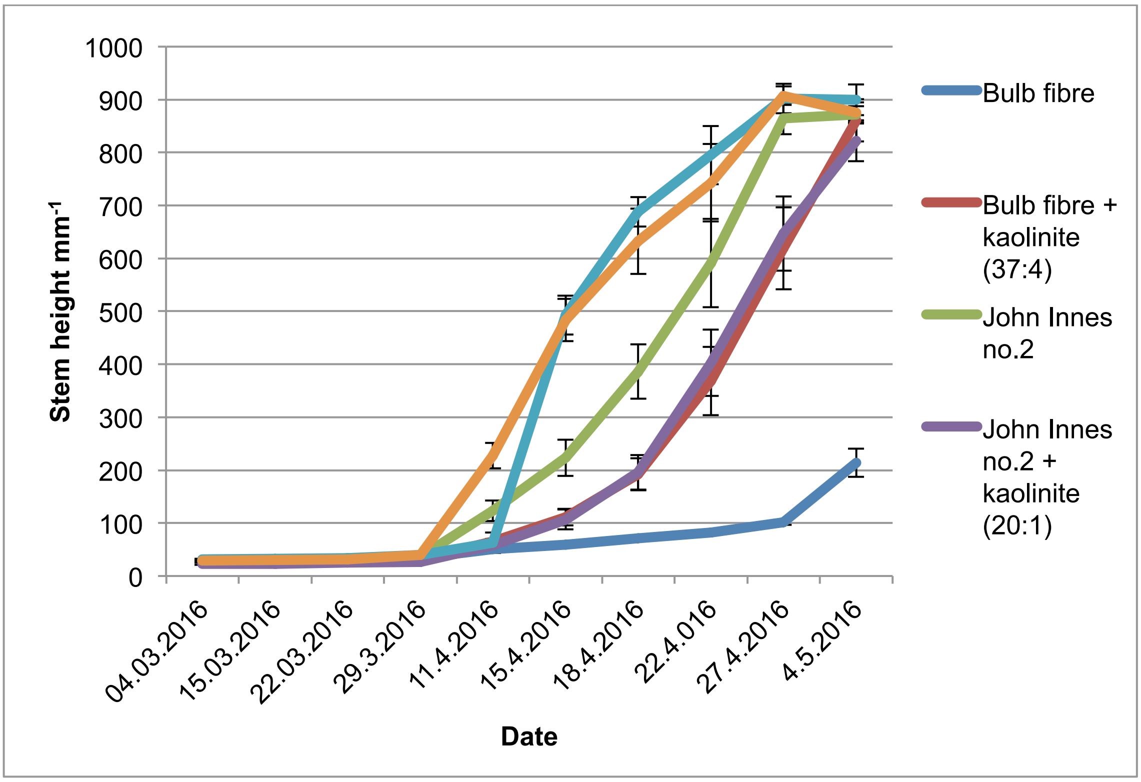


Figure 3.1.3 The mean plant heights of *Brassica juncea* grown in different substrates with and without kaolinite treatments (added by weight ratio) taken at the full term destructive harvest. Data are mean (n = 15 until 4.4.15, then n = 10), ±1 Standard Error.

As can be seen in Figure 3.1.3, plants grown in bulb fibre without kaolinite did not develop to the same degree as plants in any of the other treatments. The bulb fibre without kaolinite was also the only group that did not bolt (enter its flowering stage) within the period of the experiment. This bolting is the reason why, by the end of the experiment, it was also the treatment with the largest leaves (Figure 3.1.4) since plant morphology during bolting displays a reduction in leaf area. The John Innes no.2 treatments and the Watering Lane mix with kaolinite had the tallest plants over the period of growth, but for most of that period the *Brassica juncea* grown in the bulb fibre with kaolinite treatment had the largest leaves by both length and width. Only the data from the harvests underwent further analysis to find significance.

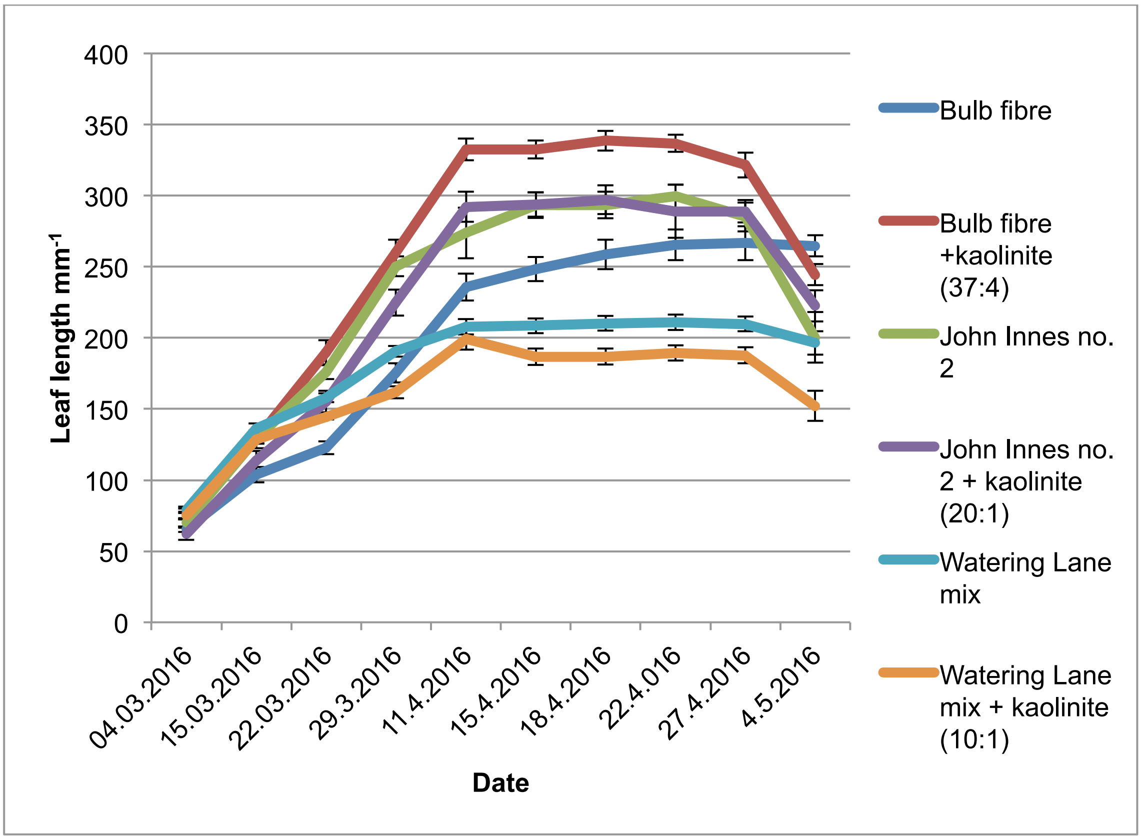


Figure 3.1.4 The leaf length of *Brassica juncea* grown in different substrates with and without kaolinite treatments (added by weight ratio) taken at the full term destructive harvest. Data are mean (n = 15 until 4.4.15, then n = 10) ±1 Standard Error.

3.1.4 Midway Destructive Harvest

Although a P value of <0.001 was found for the plant heights (see Table 3.1.1), this referred only to differences in the substrates, there was no significant difference found between the treatments within each substrate.

Table 3.1.1 Final growth data for the mid-trial harvest of *B. juncea* grown in three substrates with two treatments of kaolinite added by weight ratio. Rounded to 3 significant figures, data are mean (n = 5) ± 1 Standard Error.

Substrate and treatment		Stem length mm	Leaf number	Leaf length mm	Leaf width mm
Bulb fibre	Mean value	39.9	9.00	229	85.2
	SE	±1.95	±0.283	±8.25	±4.70
Bulb fibre + kaolinite (37:4)	Mean value	42.2	11.2	327	132
	SE	±4.25	±0.335	±11.8	±6.05
John Innes no.2	Mean value	42.2	11.2	304	120
	SE	±3.81	±0.335	±10.9	±4.56
John Innes no.2 + kaolinite (20:1)	Mean value	40.8	10.6	285	111
	SE	±3.23	±0.219	±10.3	±3.20
Watering Lane mix	Mean value	118	12.6	211	85.0
	SE	±19.5	±0.456	±7.65	±3.63
Watering Lane mix + kaolinite (10:1)	Mean value	76.0	12.8	164	66.6
	SE	±1.39	±0.335	±.7.84	±1.78

The leaf numbers (Figure 3.1.5) (P <0.001) showed that there was a significant difference only between the two bulb fibre treatments.

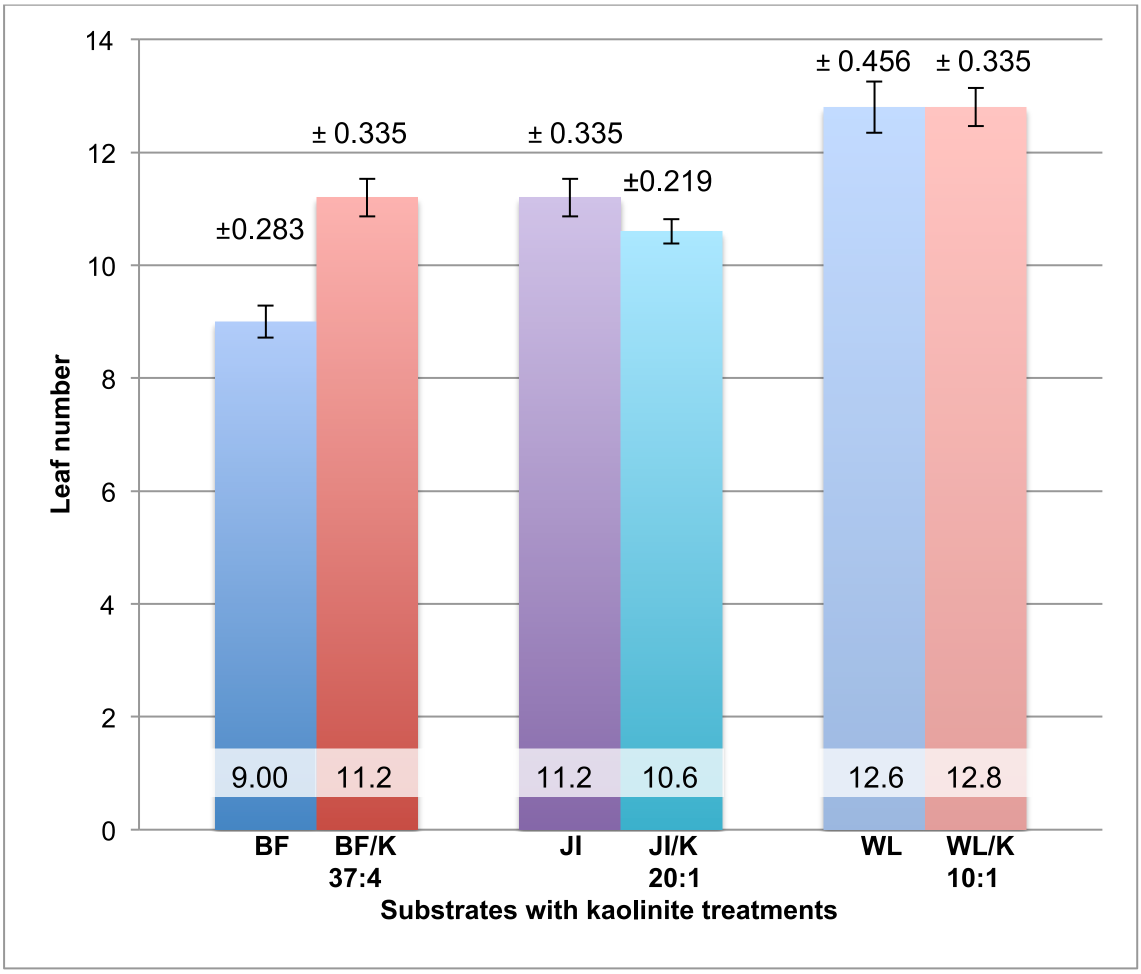


Figure 3.1.5 The leaf count of *B. juncea* at the mid-trial harvest, grown in three substrates with two kaolinite treatments added by weight ratio (mid-trial), mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 5) ± 1 Standard Error (SE values are shown above the bars). P <0.001 only for the Bulb fibre treatments.

The leaf size is illustrated well by the data for leaf length (Table 3.1.1 and Figure 3.1.6), showing positive significance (P <0.001) between the BF substrates (a greater value for the kaolinite addition) and negative for the WL (Figure 3.1.6).

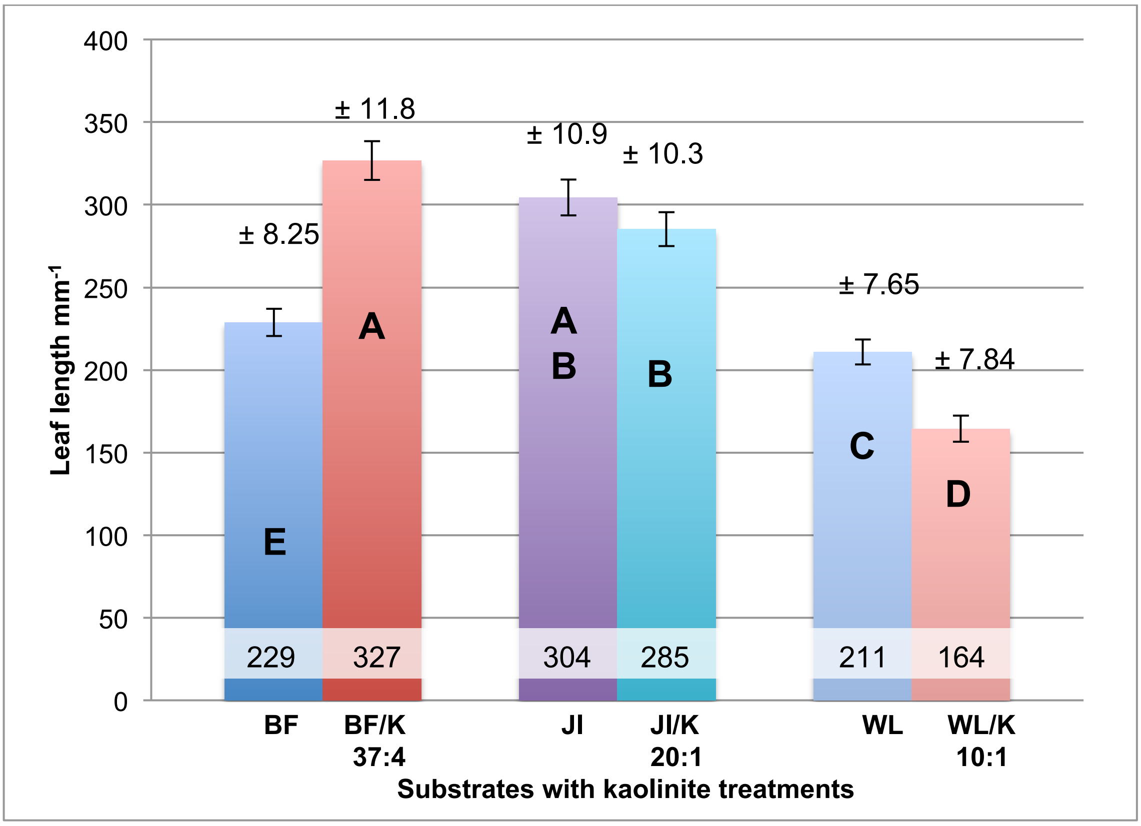


Figure 3.1.6 The leaf length of *Brassica juncea* at the mid-trial harvest, grown in three substrates with two kaolinite treatments added by weight ratio (mid-trial), mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001 for BF & BK/K and WL & WL/K, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Biomass

The biomass data (Figures 3.1.7, 3.1.9 and 3.1.11) showed a similar pattern to the growth data, with the most extreme difference being between the two bulb fibre treatments (above ground plant matter wet weight – 15.1g without kaolinite, 49.4g with the mineral).

Above ground plant biomass

The results of the mid-trial harvest showed a value of P <0.001 - in the dried above ground plant biomass results. The greatest significance lay between the two bulb fibre treatments (Figure 3.1.7). The Watering Lane mix treatments were also significantly different from the other substrates, but not from each other.

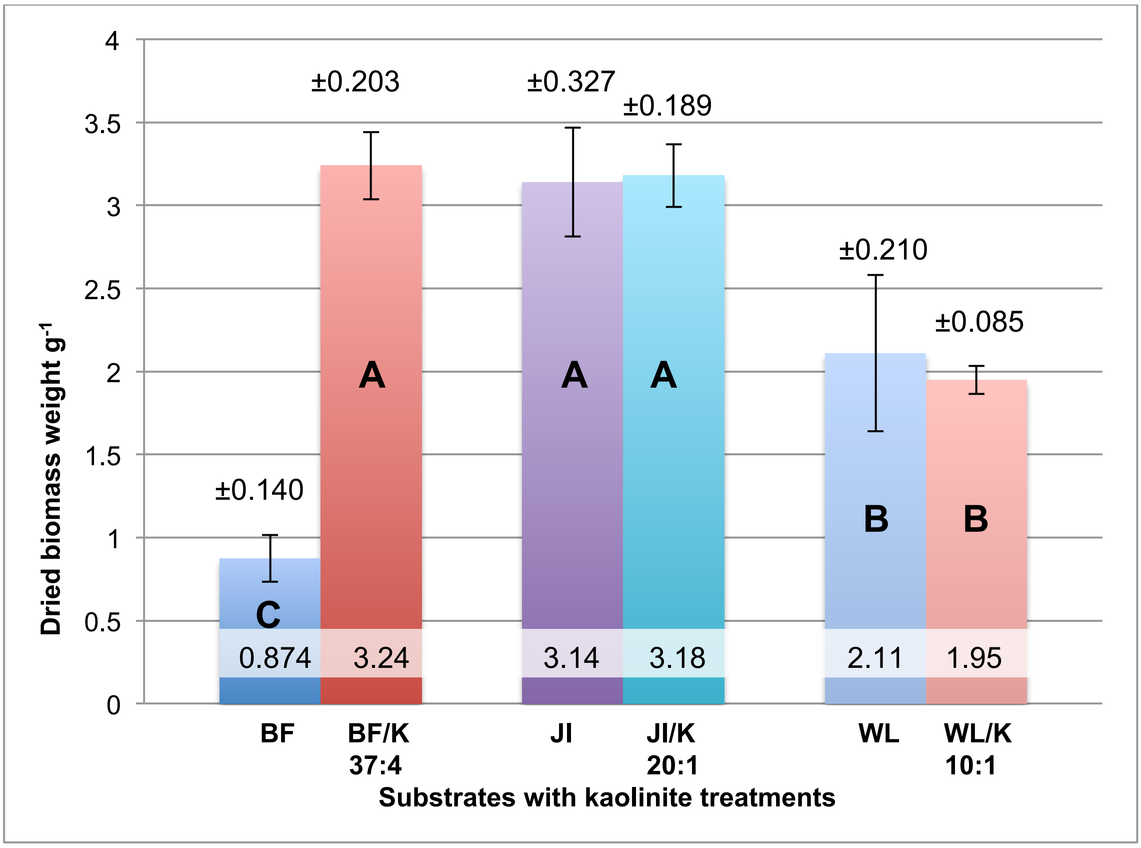


Figure 3.1.7 The dried biomass of the above ground plant material of *Brassica juncea* grown in three different substrates with two different treatments of kaolinite (mid-trial), added by weight ratio, mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The moisture content results (Figure 3.1.8) showed a P value of <0.001, this significance (Figure 3.1.8) was divided into three groups, the bulb fibre with the John Innes no.2 (no addition) being significantly different from the rest. The Watering Lane mixes are different from each other, but both share the John Innes with kaolinite in their groups. The lowest percentages of water are found in two of the kaolinite treatments, but not the bulb fibre substrate.

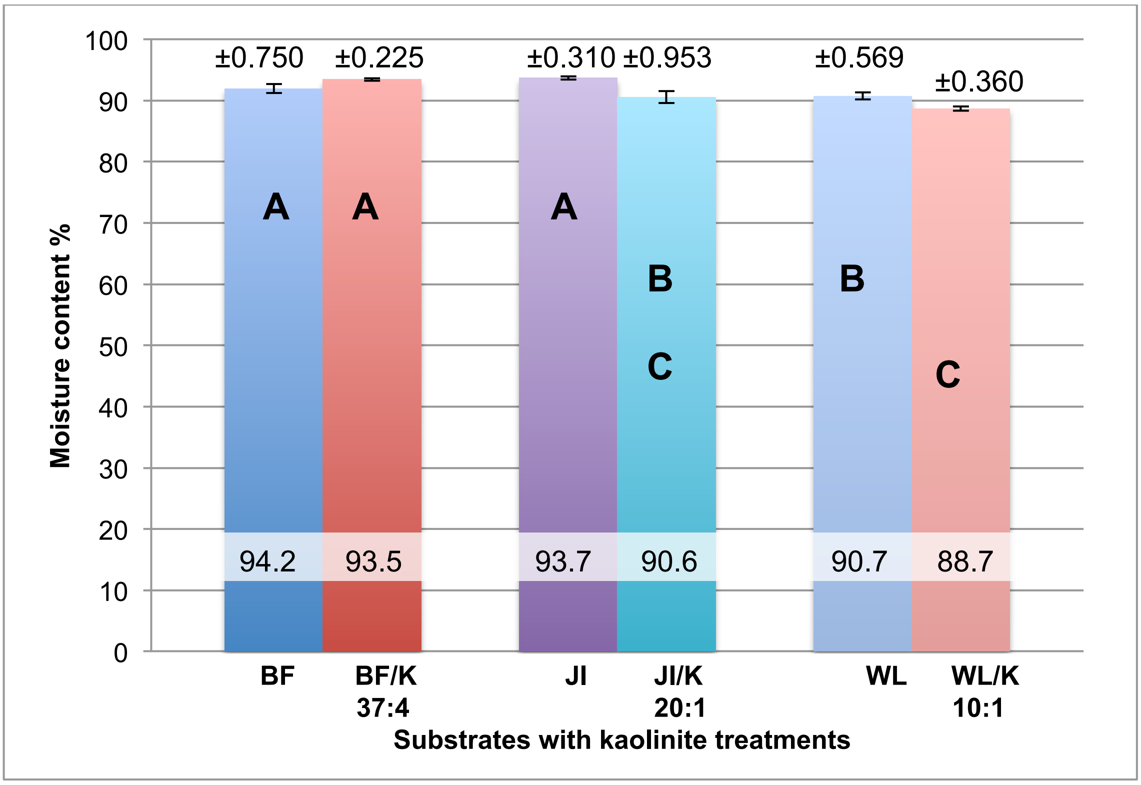


Figure 3.1.8 The moisture content, expressed as a percentage, of the above ground material of *Brassica juncea* grown in three different substrates with two different treatments – kaolinite added by weight ratio to reach 80g per pot, and a control of 0g (mid-trial). Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Roots

The means showed an increase in root biomass when kaolinite was added only with the peat-based bulb fibre substrate (Figure 3.1.9), however the standard errors are large.

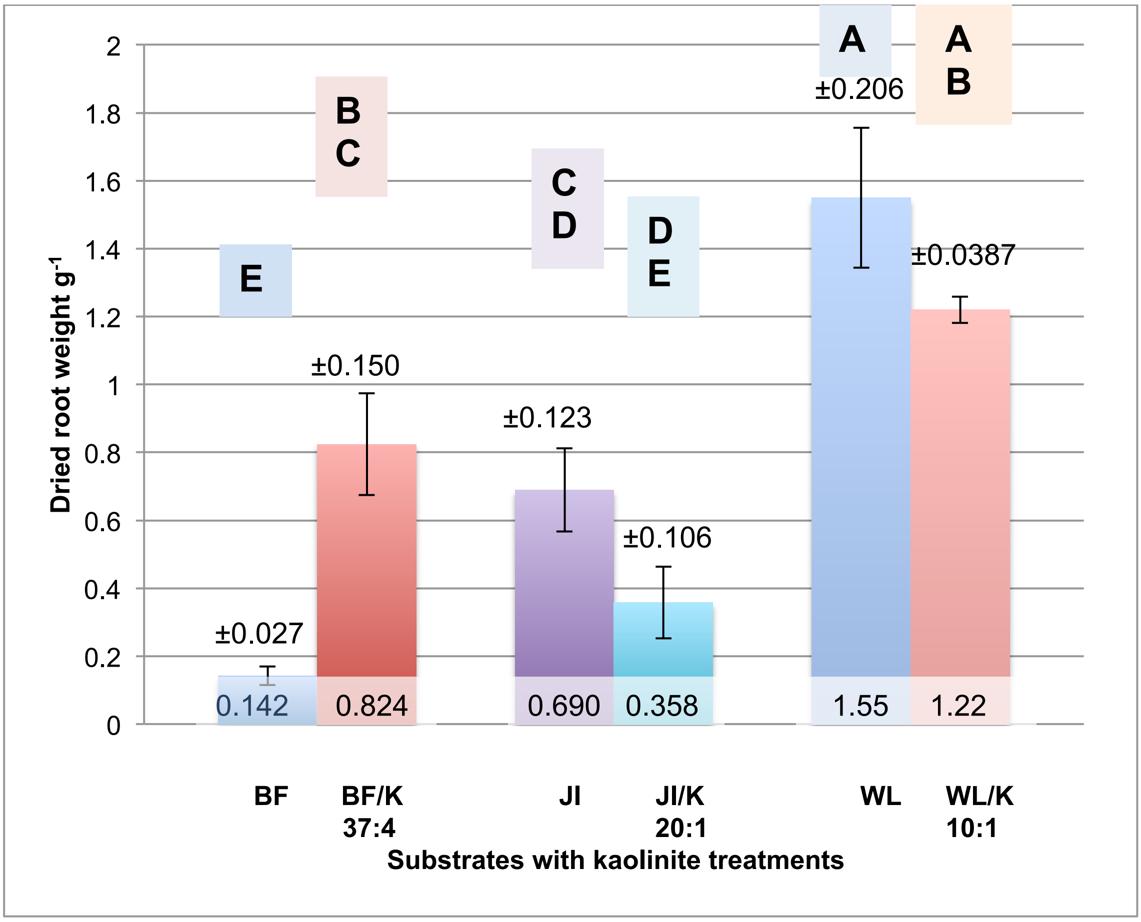


Figure 3.1.9 The dried biomass of the roots of *Brassica juncea* grown in three different substrates with two different treatments of kaolinite, added by weight ratio (mid-trial). Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The dried root biomass (Figure 3.1.9) showed significance (P <0.001) (Figure 3.1.9) with five different groups generated. However the only substrate with greater biomass present when grown with kaolinite was the bulb fibre, all the others showed mean results with lower values for kaolinite treatments.

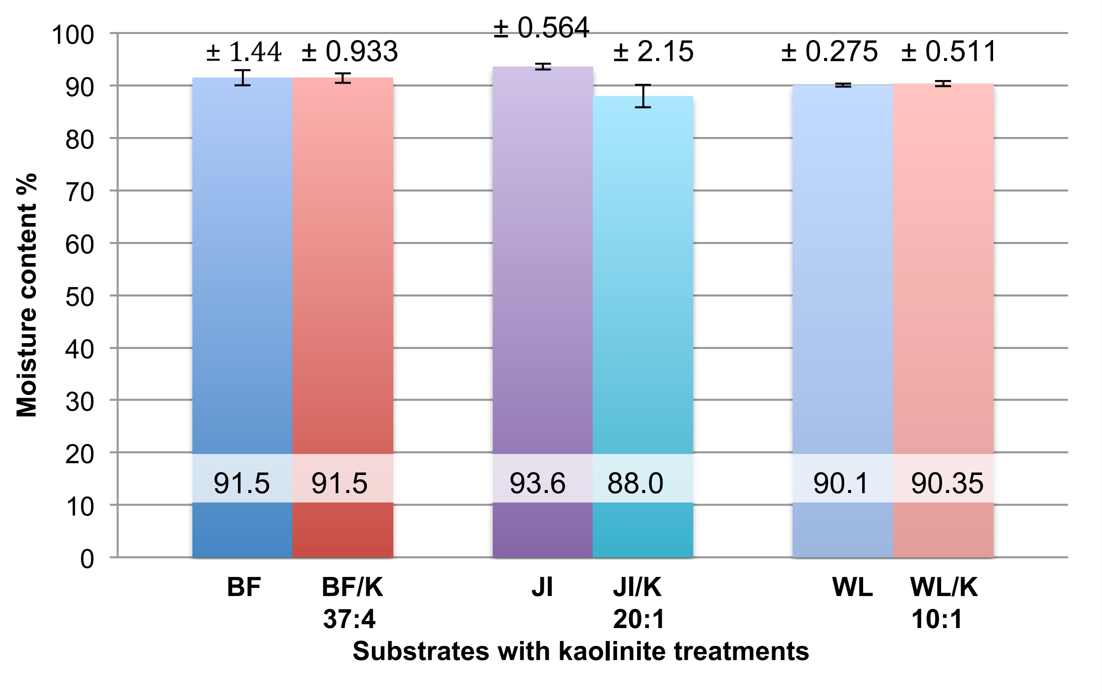


Figure 3.1.10 The moisture content, expressed as a percentage, of the roots of *Brassica juncea* grown in three different substrates with two different treatments – kaolinite added by weight ratio to reach 80g per pot, and a control of 0g. Experiment 1, mid-trial destructive harvest. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P >0.05.

The percentage moisture content (Figure 3.1.10) of the *Brassica juncea* showed a P-value of >0.05.

Total biomass

Unlike the results for the above ground plant matter, the total biomass (Figure 3.1.11) placed significance only in the separation of the bulb fibre without kaolinite from all other treatments (P <0.001) (Figure 3.1.11).

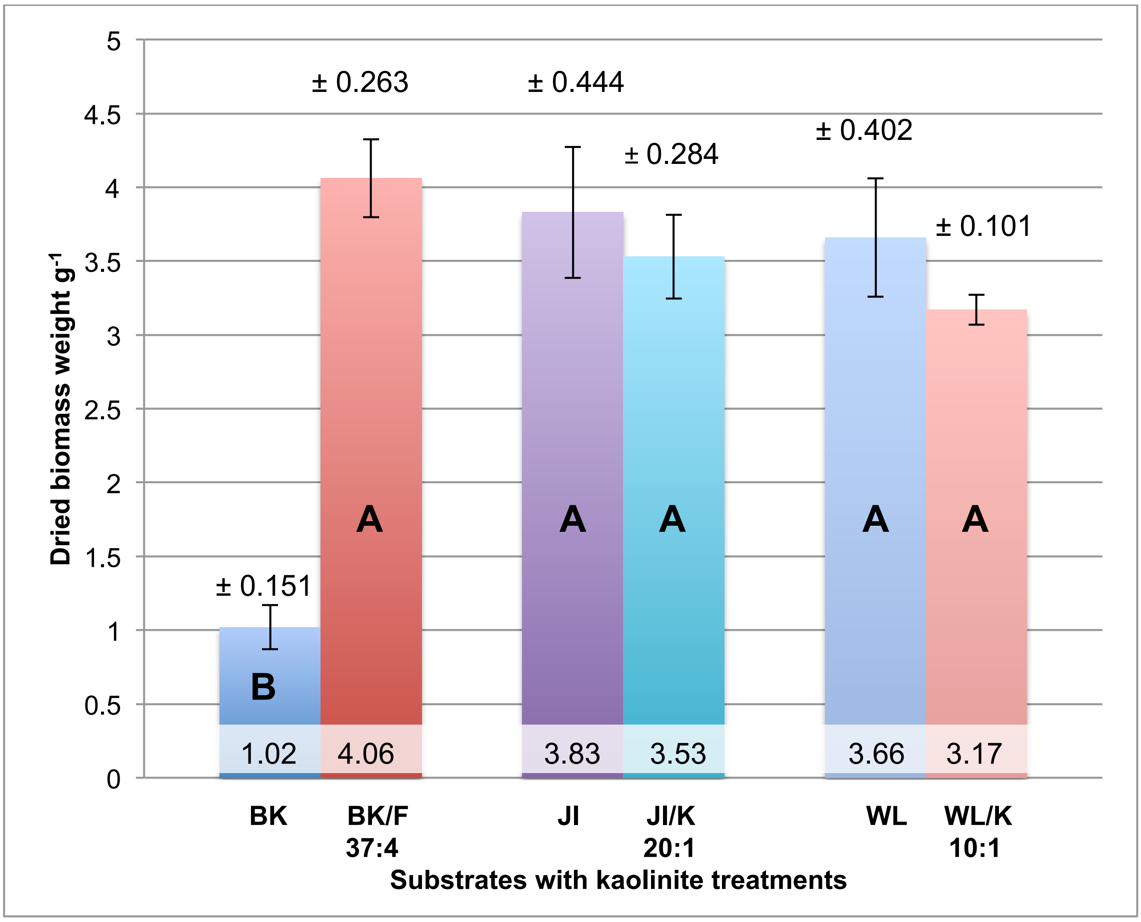


Figure 3.1.11 The total dried biomass of *Brassica juncea* grown in three different substrates with two different treatments of kaolinite added by weight ratio. Experiment 1, mid-trial harvest. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Above ground plant matter to root ratio

Both the John Innes no.2 and Watering Lane mix substrates with kaolinite showed a larger increase in the aerial parts to roots ratio, but the standard error bars were long (Figure 3.1.12).

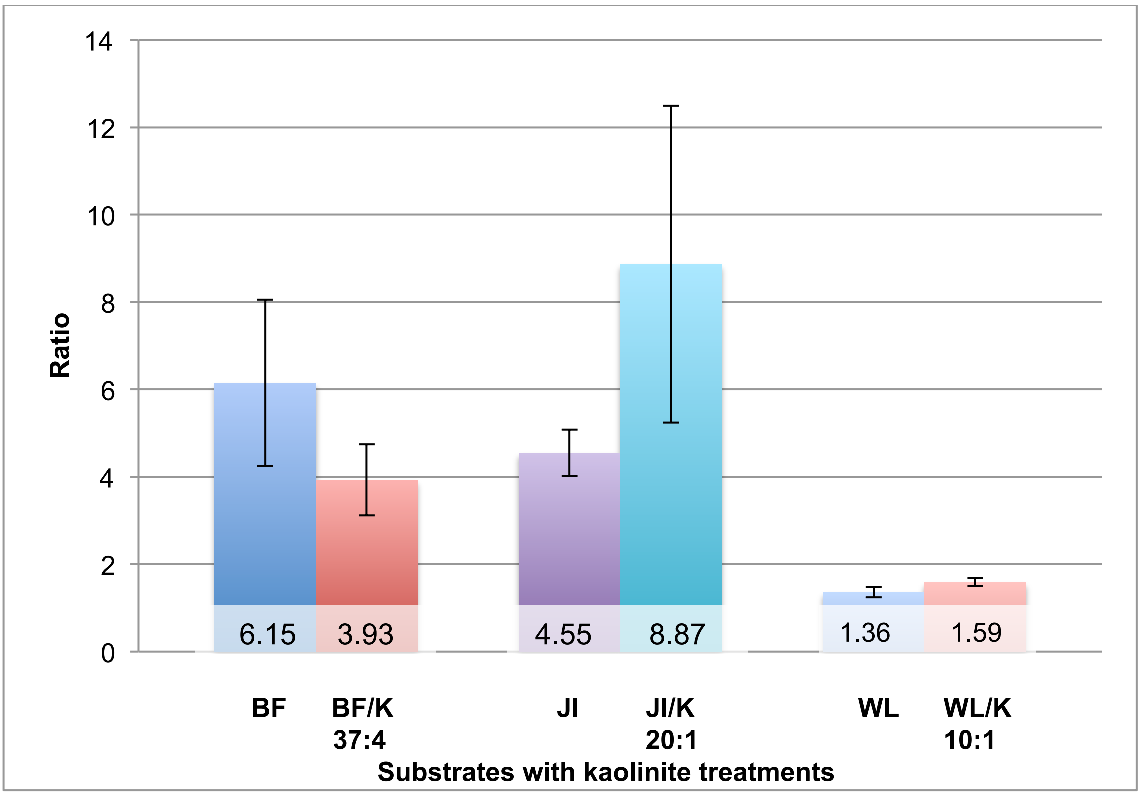


Figure 3.1.12 The aerial parts to roots ratio of *Brassica juncea* grown in three different substrates with two different treatments – kaolinite added by weight ratio. Mid-trial destructive harvest. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures (n = 3) ± 1 Standard Error (SE). P <0.001.

The Kruskal-Wallis test (Figure 3.1.13) found a P-value of <0.001. With the mean rank 12.68, John Innes no.2 was significantly different to the rest, ANOVA testing agreed with this finding.

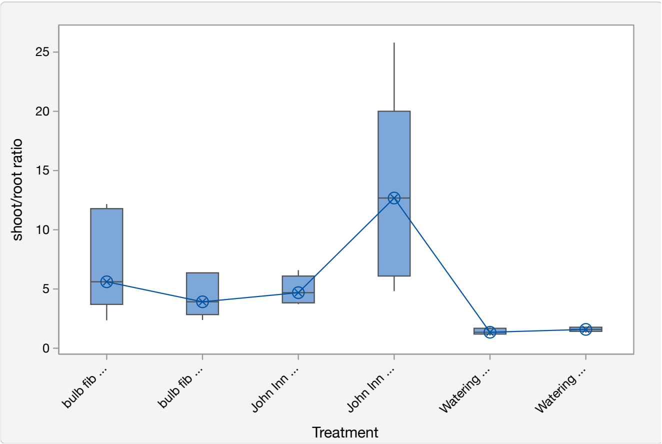


Figure 3.1.13 Box plot showing the Kruskal-Wallis test results, in the order: bulb fibre/bulb fibre with kaolinite/John Innes no.2/John Innes no.2 with kaolinite/Watering lane mix/Watering lane mix with kaolinite. Mid-term results. Data are mean (n = 5). Graph generated by Minitab®.

3.1.6 Full-term Destructive Harvest Result

The plant heights data (Table 3.1.2 and Figure 3.1.14) showed significance ($P < 0.001$) between the bulb fibre substrate without kaolinite added at the lowest mean value and the other treatments.

Table 3.1.2 The final growth data for *Brassica juncea* grown in three substrates with two kaolinite treatments added by weight ratio. Data are mean (n = 10) ± 1 Standard Error (SE), rounded to 3 significant figures.

Substrate and treatment		Plant height mm^{-1}	Leaf number	Leaf length mm^{-1}	Leaf width mm^{-1}
Bulb fibre	Mean value	214	11.7	265	100
	SE	±26.6	±0.491	±7.32	±2.38
Bulb fibre + kaolinite (37:4)	Mean value	860	38.6	245	88.8
	SE	±39.9	±8.59	±7.38	±1.75
John Innes no.2	Mean value	871	29.6	200	73.4
	SE	±16.6	±1.23	±17.1	±6.25
John Innes no.2 + kaolinite (20:1)	Mean value	822	26.3	223	82.2
	SE	±38.8	±1.62	±11.0	±3.89
Watering Lane mix	Mean value	900	21.3	152	54.8
	SE	±28.9	±1.07	±8.27	±4.48
Watering Lane mix + (10:1)	Mean value	875	21.3	152	54.8
	SE	±19.2	±0.530	±10.7	±4.69

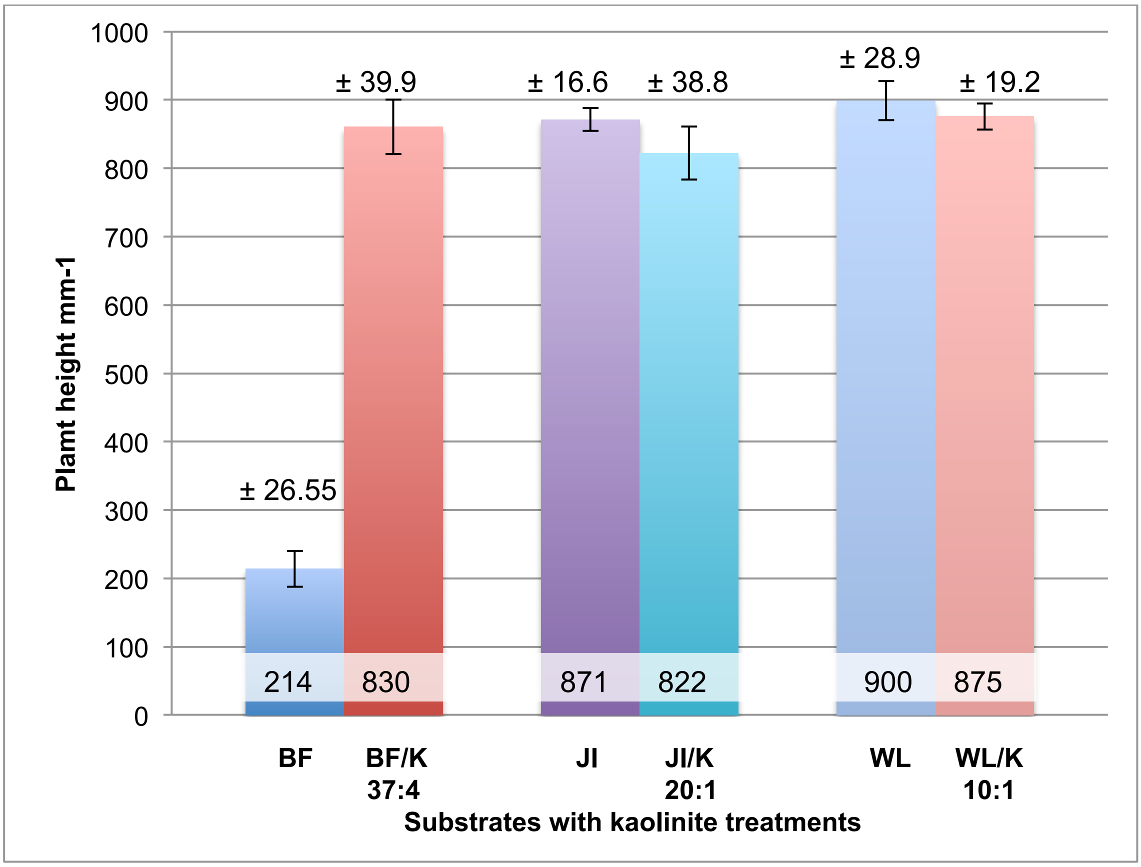


Figure 3.1.14 The plant heights of *Brassica juncea* grown in three substrates with two kaolinite treatments. Mean values are shown in the boxes at the bottom of the bars (n = 3) ± 1 Standard Error (SE values are shown above the bars).

The leaf count (<0.001) showed a significant difference in the two bulb fibre treatments of 26.9, with the bulb fibre without kaolinite having the lowest value (Table 3.1.3). Neither of the other substrates show significance between treatments. In the leaf sizes (e.g. Figure 3.1.15) only the Watering Lane mix treatments showed significant (P <0.001) difference, with the kaolinite treatment having the lowest value.

Table 3.1.3 LSD results for the leaf number of *B. juncea* at the full-term harvest grown in three substrates with two kaolinite treatments, added by weight ratio. Full-term harvest. Data are mean (n = 10), rounded to 3 significant figures.

Treatment and substrate	Mean leaf number	Grouping		
BF+K	38.6	A		
JI	29.6	A	B	
JI+K	26.3		B	
WL	25.6		B	
WL+K	21.3		B	C
BF	11.7			C

(Means that do not share a letter are significantly different)

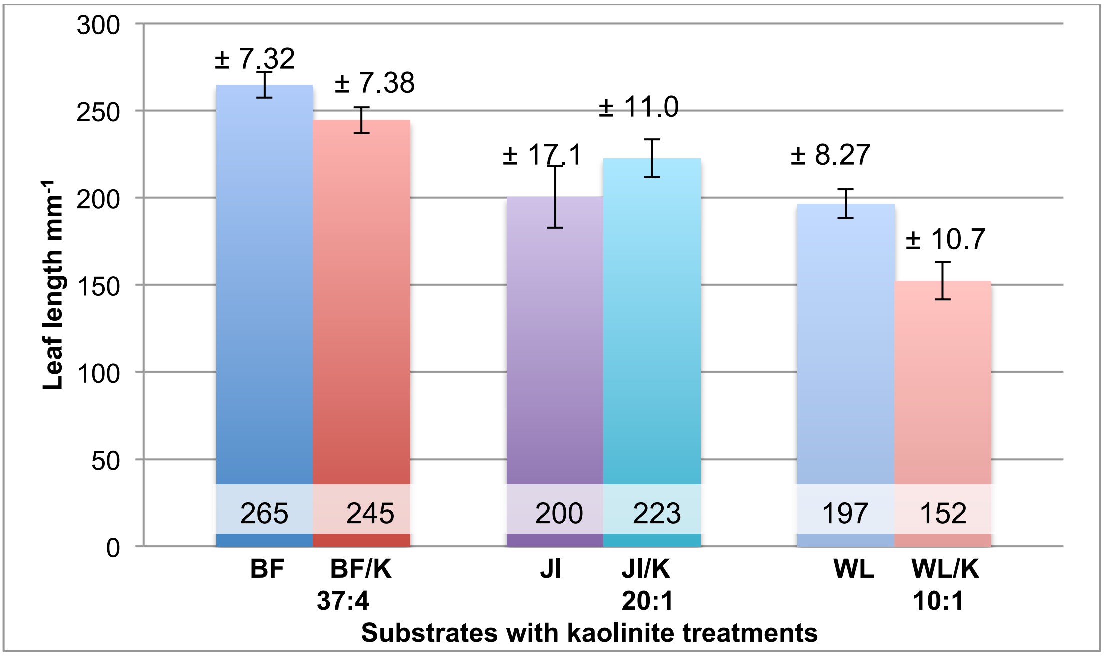


Figure 3.1.15 Leaf lengths of *B. juncea* grown in three substrates with two kaolinite treatments added by weight ratio. Mean values are shown at bottom of bars (n = 3) ± 1 Standard Error (SE values shown above bars).

Biomass

The mean results (Table 3.1.4) show that *Brassica juncea* grown in the bulb fibre with kaolinite developed greater biomass than without the mineral (18.45g rather than 5.45g in the total results), but this pattern was not continued with the other substrates.

Table 3.1.4 Biomass data from the destructive harvest of *B. juncea* grown in Bulb fibre, John Innes no.2 and Melcourt's Watering Lane mix. Data are mean (n = 10) ± 1 Standard Error (SE), rounded to 3 significant figures.

Treatment		Aerial parts			Roots			Total			Aerial parts/ roots ratio
		Wet weight g^{-1}	Dry weight g^{-1}	% change	Wet weight g^{-1}	Dry weight g^{-1}	% change	Wet weight g^{-1}	Dry weight g^{-1}	% change	
Bulb fibre	Mean value	41.7	4.37	90.3	6.21	1.08	83.6	48.0	5.45	89.5	4.07
	SE	6.19	±0.929	±0.748	±1.06	±0.255	±3.77	±6.93	±1.07	±0.955	
Bulb fibre + kaolinite (37:4)	Mean value	71.2	12.8	81.9	22.0	5.68	72.9	93.2	18.5	80.2	2.25
	SE	±4.62	±0.939	±0.834	±2.79	±0.670	±1.91	±6.30	±1.47	±0.734	
John Innes no.2	Mean value	62.8	12.8	80.3	17.6	4.03	76.2	80.4	16.3	79.7	3.04
	SE	±2.63	±0.361	±0.430	±.64	±0.427	±2.43	±2.81	±0.656	±0.554	
John Innes no.2 + kaolinite (20:1)	Mean value	58.8	10.08	82.7	11.9	2.86	74.3	70.7	12.9	81.5	3.53
	SE	±3.45	±0.635	±0.958	±1.38	±0.323	±3.48	±4.61	±0.893	±1.02	
Watering Lane mix	Mean value	42.9	7.55	82.3	14.8	3.16	78.5	57.7	10.7	81.4	2.39
	SE	±2.85	±0.655	±2.42	±1.22	±0.261	±1.06	±3.90	±0.828	±0.863	
Watering Lane mix + kaolinite	Mean value	30.6	6.37	79.0	12.4	2.55	74.9	43.0	8.91	78.9	2.5
	SE	±1.30	±0.225	±0.614	±1.69	±0.286	±4.74	±2.45	±0.472	±1.11	

Further analysis proved the data for the dried aerial parts and roots (Figure 3.1.16), separately and together to be significantly different (P <0.0001). The aerial parts to root ratio proved not to be significant (P >0.05). The above ground biomass and roots showed a similar pattern and results so only the total biomass data is displayed in Figure 3.1.16.

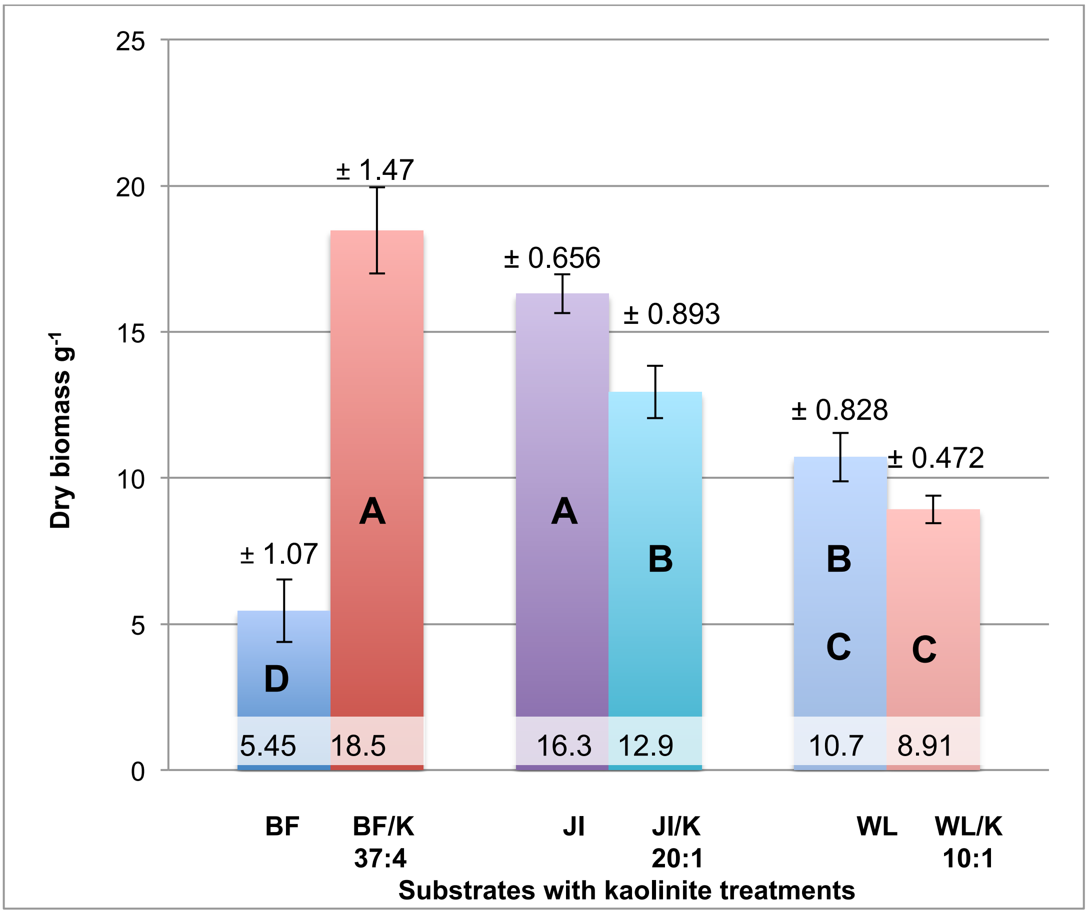


Figure 3.1.16 Total dried biomass of *Brassica juncea* from the different treatments of Experiment 1 at the full-term destructive harvest. Mean values are shown in the boxes at the bottom of the bars, to three significant figures, (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.0001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The bulb fibre substrates are significantly different, the bulb fibre being at the lowest end of the means and separate from all other values (Figure 3.1.16). The treatments in the John Innes no.2 are also significantly different from each other, with the kaolinite treatment having the lower of the two means. There was no significant difference between the Watering Lane mix treatments.

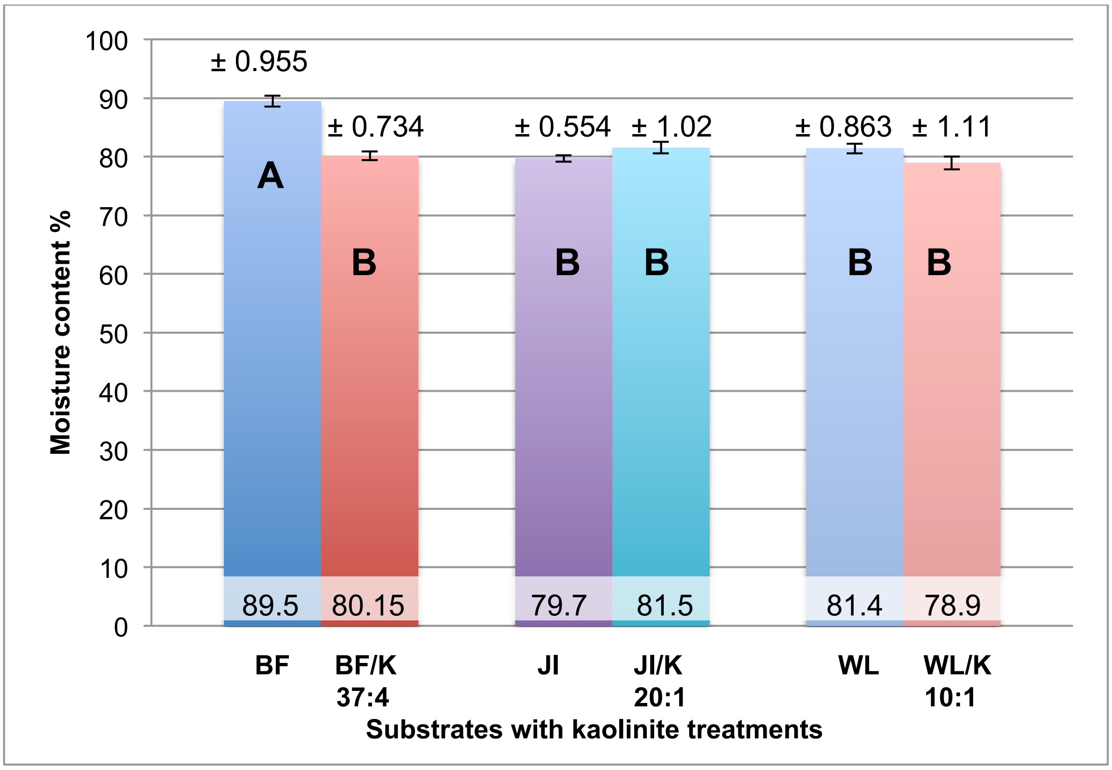


Figure 3.1.17 The total percentage moisture content of *Brassica juncea* grown during Experiment 1. Mean values are shown in the boxes at the bottom of the bars (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.001, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

LSD (Figure 3.1.17) results of the moisture content testing (Figure 3.1.17) showed significant difference (P <0.001) with the bulb fibre separate to the rest of the treatments, the BF having significantly more moisture content, despite the mean smaller size of the plants, than the rest of the treatments.

3.2 Experiment Two – the effectiveness of trace additions of kaolinite

3.2.1 Introduction

Since Experiment 1 demonstrated a positive reaction to the addition of kaolinite to bulb fibre an experiment was designed to investigate whether trace additions of kaolinite had an effect on *Brassica juncea* growth and biomass. As seen in Section 2.1, WDPT and capillary rise tests showed a reaction to 5%, but there was no information for amounts below that. Five treatments were chosen, 0%, 0.5%, 1%, 1.5% and 2%, in line with the work of McKissock, Gilkes and Walker (2002) on soil.

3.2.2 Method

Seeds were sown in module seed trays on the 22nd March 2016, then transplanted once the true leaves began to show on the 19th of April (28 days later). The pots were set up as described in Section 3.0, with ten repeats per treatment. They were watered freely by both the researcher and the staff of the Watering Lane nursery.

The experiment ended with a destructive harvest (the method described in Chapter 3.0) on the 31st of May 2016 (42 days after planting out). The plants had begun to bolt at this point.

3.2.3 Results

Environmental parameters

As can be seen from Figures 3.2.1 and 3.2.2 the temperature and light in the glasshouse were moving in into the higher summer ranges during this experiment. The means were not available for this experiment.

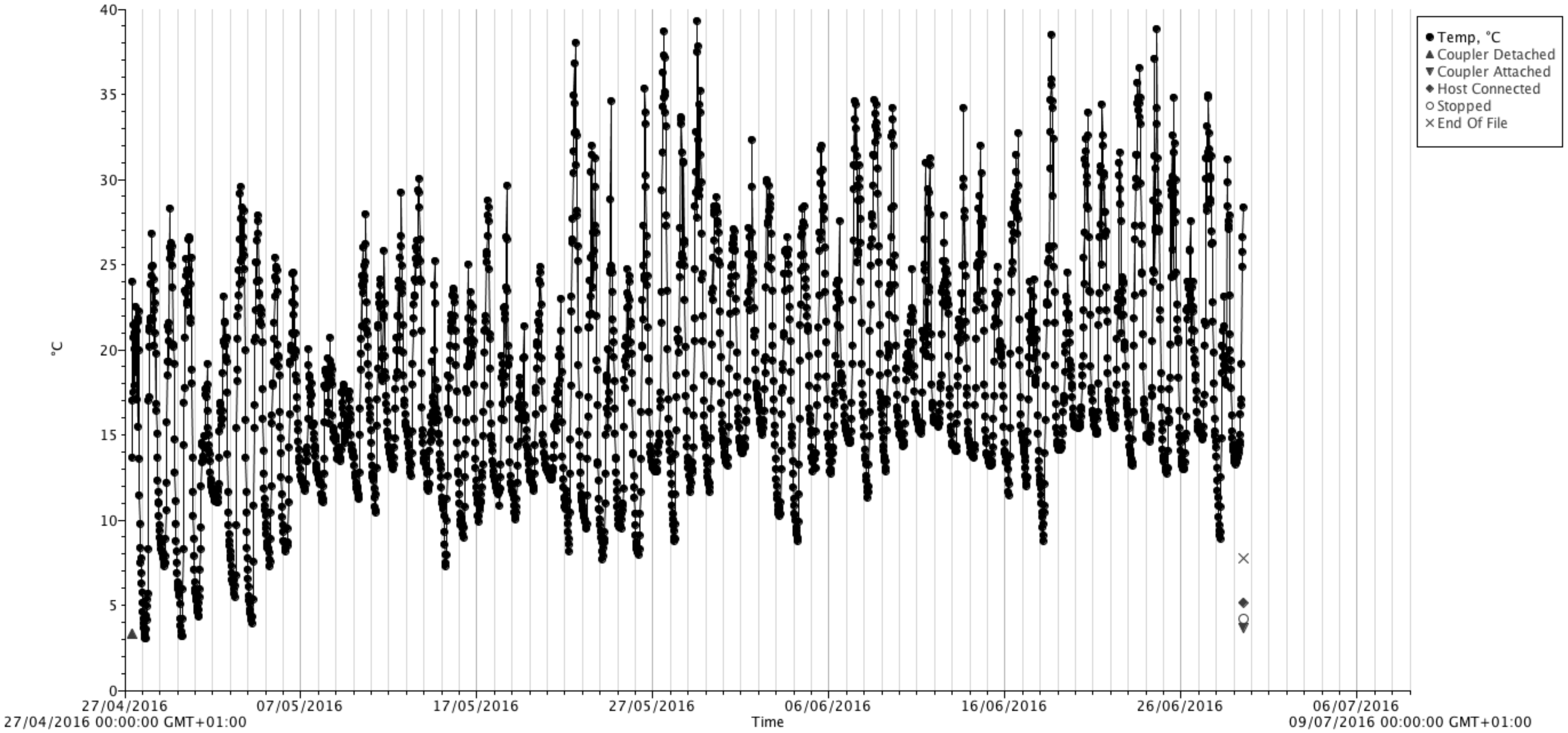


Figure 3.2.1 The temperature fluctuations (˚C) of the glasshouse during Experiment 2.

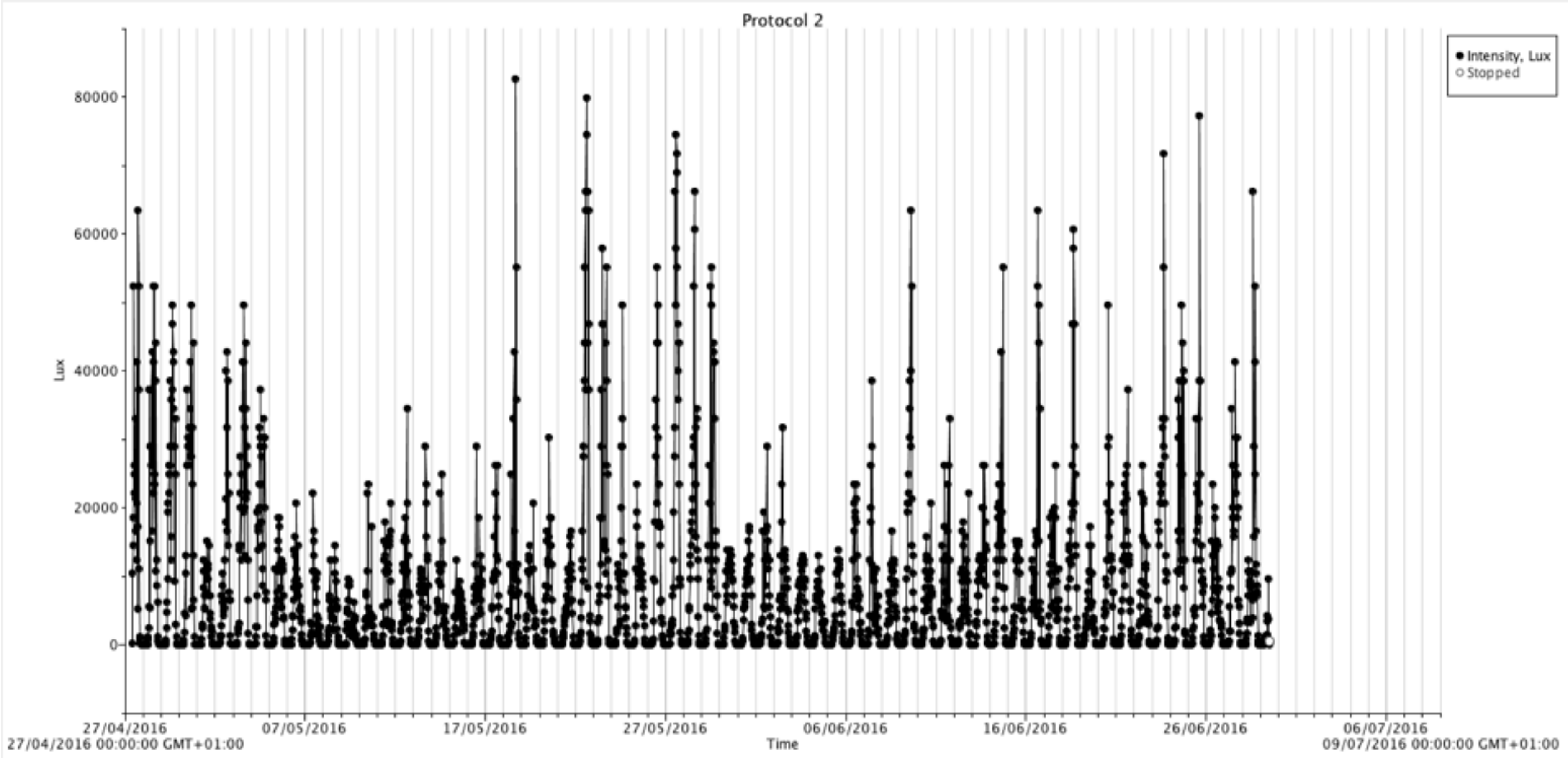


Figure 3.2.2 the light fluctuations in the glasshouse during Experiment 2.

All treatments showed a similar pattern of development (Figure 3.2.3) over the growing period. The plants remained quite close to each other in height for the first four weeks before beginning to extend away from each other. By the end of the experiment there were 200mm between the 0% kaolinite treatment and the 2% treatment.

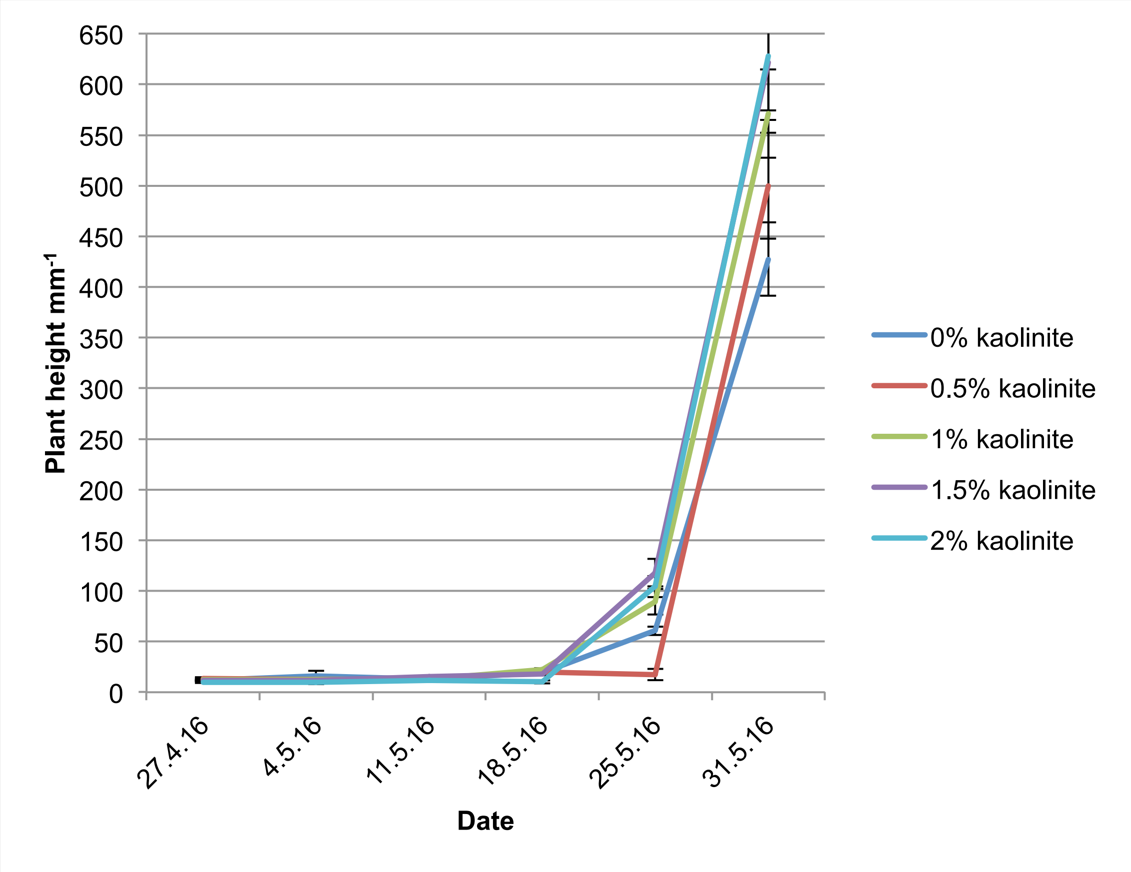


Figure 3.2.3 The progression of plant height from planting out to destructive harvest, measured from surface to growing tip, of *Brassica juncea* grown in peat-based bulb fibre substrate with five treatments of kaolinite mixed by percentage weight. Data are mean (n = 10), ±1 Standard Error.

The growing data for the leaves followed a similar trend, so only the leaf widths are shown here (Figure 3.2.4), the plants from all the treatments showed very little difference in number, length or width, all followed a similar growth patterns over the weeks. A faster growth up to the third week began to slow after May the 11th and began to reduce in width and length by the destructive harvest. Leaf numbers continued to increase, but remained very close in values.

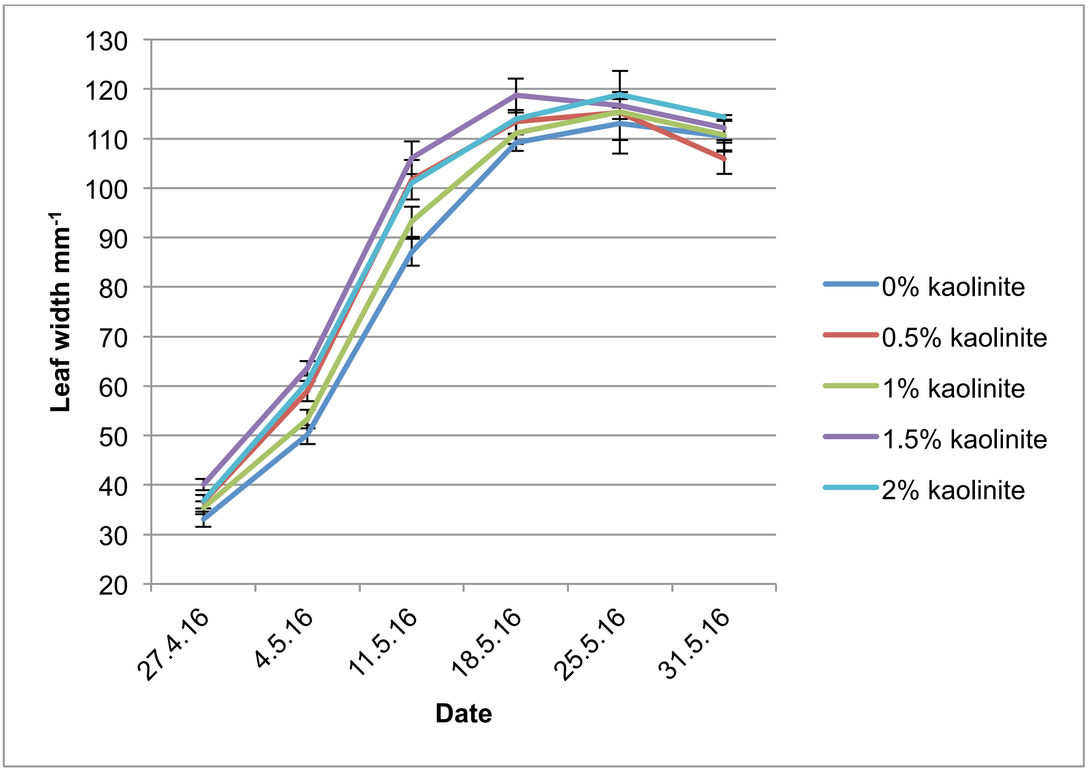


Figure 3.2.4 The progression of leaf width, from planting out to destructive harvest, of *Brassica juncea* grown in peat-based bulb fibre substrate with five kaolinite treatments mixed by percentage weight. Data are mean (n = 10) ±1 Standard Error.

Destructive harvest

The mean values (Table 3.2.1) showed a gradual rise in leaf number and plant height as the concentration of kaolinite increased, the leaf sizes were less clear.

Table 3.2.1 Growth data of *Brassica juncea* grown in peat-based bulb fibre with kaolinite treatments at the destructive harvest. Data are mean (n = 10) ± 1 Standard Error (SE), rounded to 3 significant figures.

Treatment %		Leaf no.	Height mm	Leaf length mm	Leaf width mm
0	mean	20.5	428	320	111
	SE	±0.791	±36.1	±4.45	±3.13
0.5	mean	21.3	500	307	106
	SE	±0.801	±52.5	±5.33	±2.09
1	mean	21.3	571	309	111
	SE	±0.401	±43.8	±8.11	±3.12
1.5	mean	22.3	622	307	112
	SE	±0.567	±56.8	±3.96	±3.33
2	mean	22.7	628	318	114
	SE	±0.425	±53.6	±6.06	±2.55

Only the plant heights (Figure 3.2.5) had a P-value of <0.05. Significance lay in two groups (Figure 3.2.5), with the 0% kaolinite present in only the B group (427.5mm), showing a significant difference from the 1.5% (22.3mm) and 2% (22.7mm) concentrations, present only in the A group.

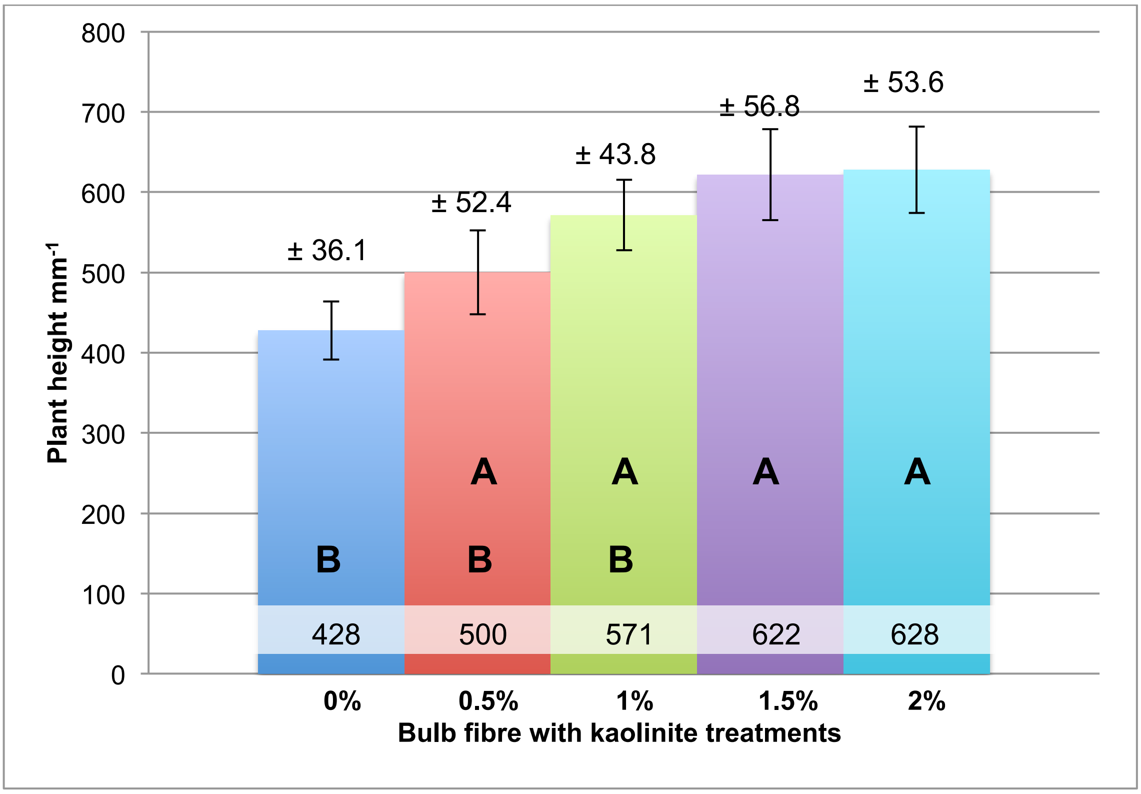


Figure 3.2.5 The plant heights of *Brassica juncea* grown in peat-based bulb fibre substrate with five treatments of kaolinite. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.05, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

Biomass

Not all the roots were harvestable due to researcher error and circumstances, the data is presented here, but the means are less reliable than the above ground plant matter so not analysed further.

Table 3.2.2 Descriptive statistics for the destructive harvest of Experiment Two, showing *Brassica juncea* grown in peat-based bulb fibre substrate with five treatments of kaolinite added by percentage weight. The data for the above ground plant matter is complete, but only partial data was collected for the roots, data are mean (n = 10) ± 1 Standard Error except the number of individuals in each root data set is marked by 'n', rounded to 3 significant figures.

Treatment %		Aerial parts			Roots		
		Wet weight g	Dry weight g	Moisture content %	Wet weight g	Dry weight g	Moisture content %
0	Mean	77.0	6.90	90.9	10.1 (n2)	2.15 (n2)	86.6 (n2)
	SE	±3.62	±0.389	±0.634	±1.04	±0.402	±3.00
0.5	Mean	86.3	8.78	89.6	17.1 (n3)	3.53 (n2)	79.2 (n2)
	SE	±3.95	±0.490	±0.712	±3.60	±0.237	±2.69
1	Mean	75.8	7.43	90.1	15.6 (n4)	2.49 (n2)	82.6 (n2)
	SE	±2.83	±0.295	±0.277	±2.55	±0.132	±1.50
1.5	Mean	80.9	9.09	88.6	13.5 (n5)	2.27 (n5)	83.5 (n5)
	SE	±3.46	±0.387	±0.591	±1.06	±0.230	±1.25
2	Mean	87.7	9.05	89.7	14.8 (n5)	12.0 (n5)	83.5 (n5)
	SE	±2.96	±0.454	±0.427	±1.63	±0.193	±0.873

Above ground plant material

The weights of the dried above ground biomass (Table 3.2.2 and Figure 3.2.6) showed significant difference ($P<0.05$) between the 0% and 1% kaolinite concentrations in one group and the rest in another group. The fact that aerial parts of the 1% treatment were of a lower weight than the 0.5%, meaning that it shared a LSD grouping with the 0% (Figure 3.2.6) could be explained by the fact that the data set had one missing datum and a single particularly small individual.

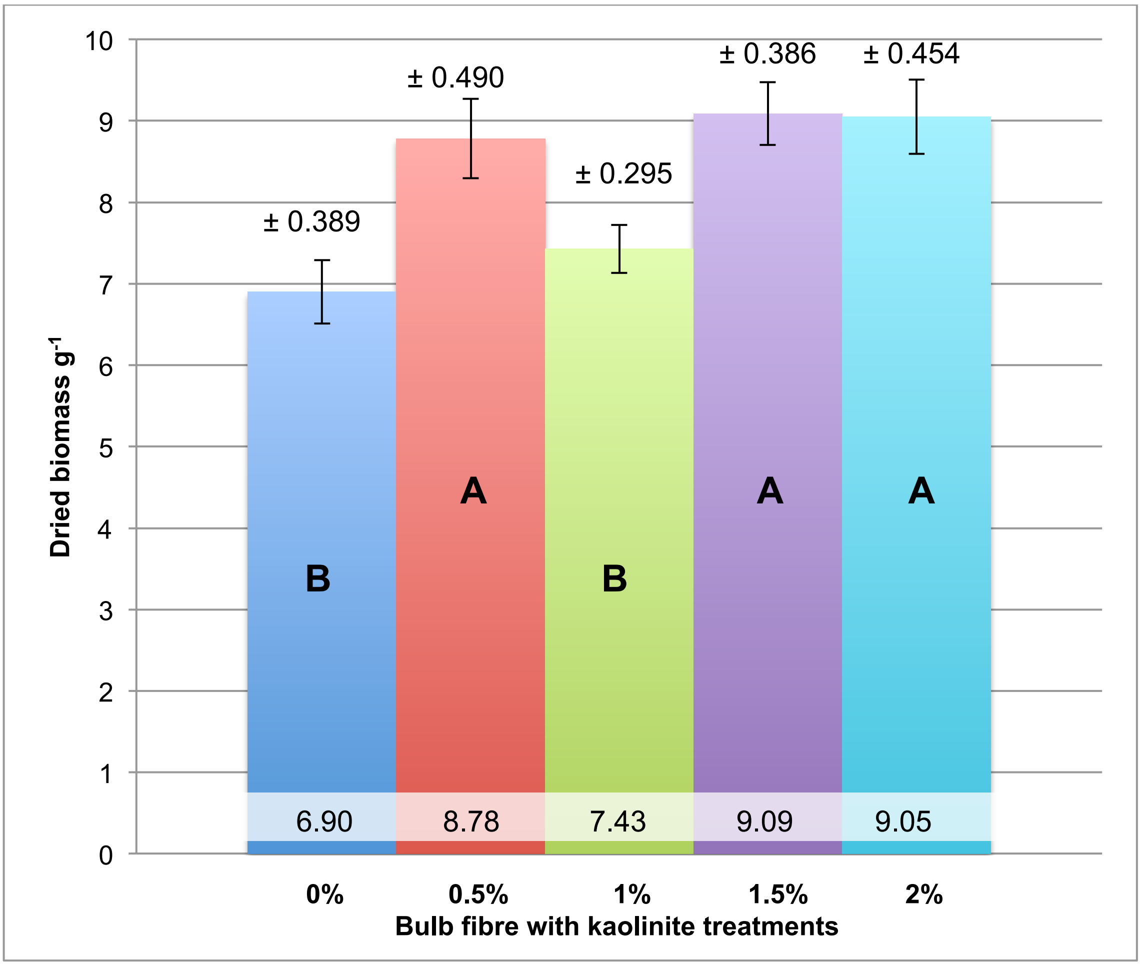


Figure 3.2.6 The dried above ground biomass of *Brassica juncea* plants, grown in peat-based bulb fibre substrate with five treatments of kaolinite added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars). $P < 0.05$, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

The moisture content was not normally distributed and had a P-value of >0.05.

3.3 Growing Experiment 3 – the effectiveness of high concentrations of kaolinite.

3.3.1 Introduction

Experiment 3 was a short experiment to investigate how *Brassica juncea* grew in high concentrations of kaolinite – 0%, 25%, 50% and 100%, with the peat-based bulb fibre making up the base where necessary. Only the biomass data was collected. It was expected that the higher the kaolinite presence the lower the biomass would be (H_1), due to less nutrient, WHC and AFP availability.

3.3.2 Method

With five repeats per treatment, 50ml pots were prepared and labeled. In regard to the 100% kaolinite the pot bases were lined with a sponge, trimmed down to prevent the loss of substrate without affecting the moisture retention. The seedlings were planted on the 19th of April 2016 and the destructive harvest was performed on the 19th of May (30 days).

They were watered freely, though water infiltration became increasingly hard with the higher kaolinite concentrations. Chlorosis was also apparent in the treatments with less substrate.

3.3.3 Results

Environmental Parameters

Due to software issues, mean values could not be calculated. The logger was not immediately stopped, so was kept in a dark place until it could be, which is why the graphs show low values without much fluctuation after the 19th of May. As can be seen from both Figures 3.3.1 and 3.3.2, the weather had changed over the month to become cooler and darker.

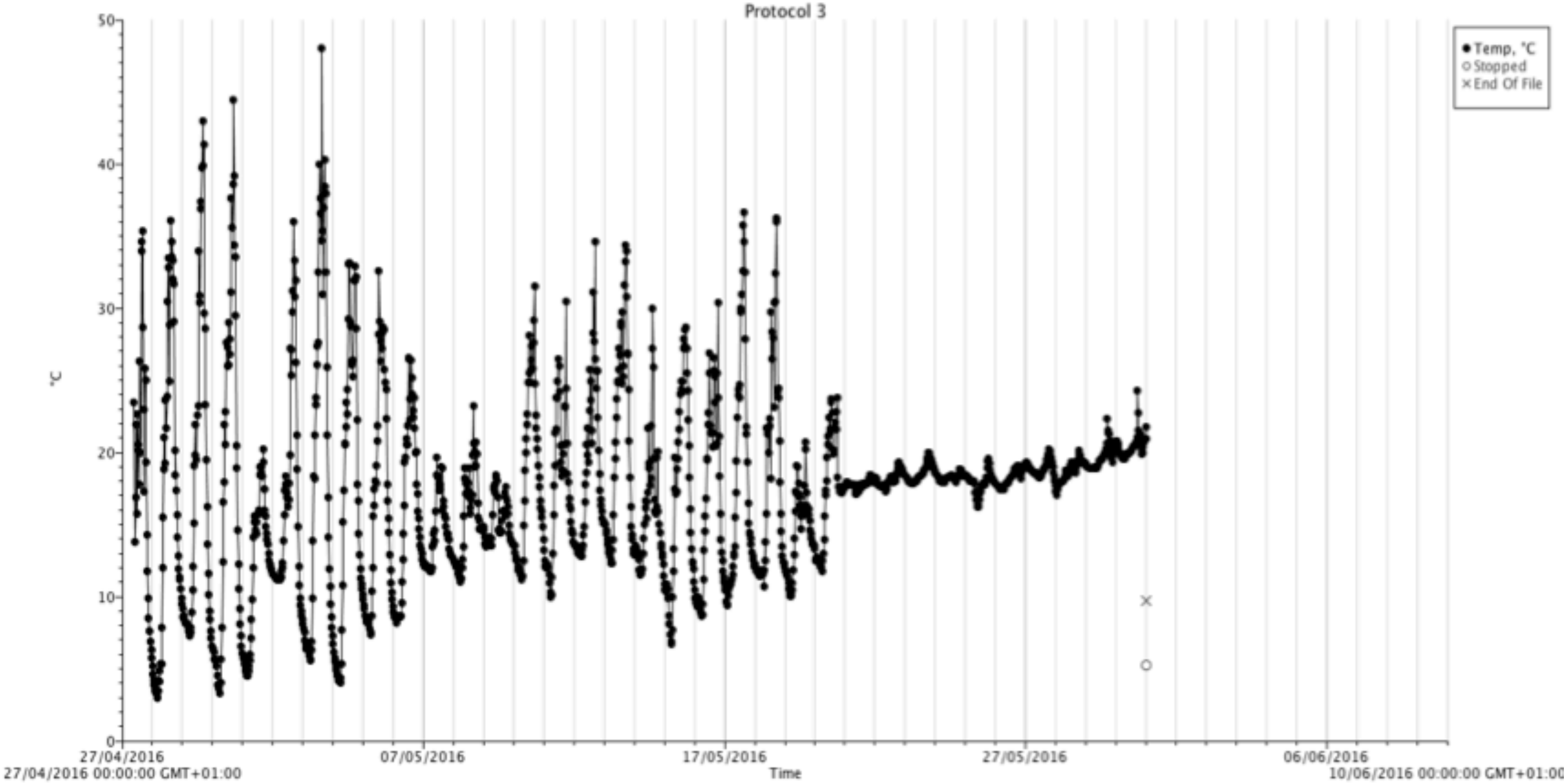


Figure 3.3.1 the temperature fluctuations (˚C) of the glasshouse during Experiment 3. The experiment was ended on the 19th of May.

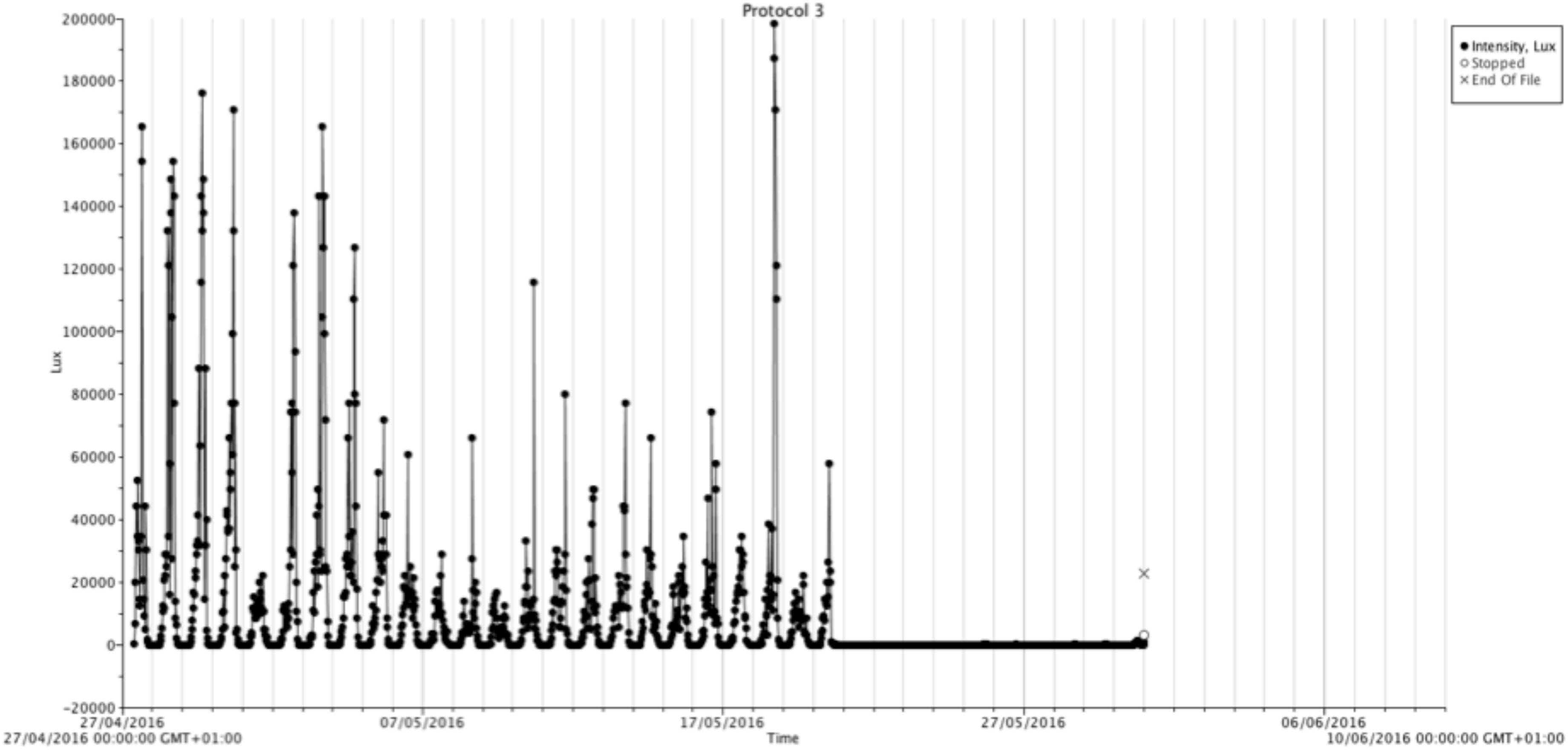


Figure 3.3.2 the light fluctuations (Lux) of the glasshouse during Experiment 3. The experiment was ended on the 19th of May.

Destructive Harvest

There were no significant results found in this experiment (Tables 3.3.1 and 3.3.2). Only basic results are presented, the raw data can be found in Appendix 4.3 (page 294).

Table 3.3.1 The end of growing period data for Experiment 3, *Brassica juncea* grown in treatments of peat-based bulb fibre and kaolinite. Data are mean (n = 10) ± 1 Standard Error (SE), rounded to 3 significant figures.

Treatment %		Height mm^{-1}	Leaf number	Leaf length mm^{-1}	Leaf width mm^{-1}
0	Mean	60.0	10.2	96.6	41.0
	SE	±20.1	±1.48	±12.6	±4.88
25	Mean	40.2	8.20	106	43.8
	SE	±9.34	±0.522	±4.63	±1.24
50	Mean	24.2	6.80	97.3	34.0
	SE	±1.37	±0.522	±3.06	±4.65
100	Mean	36.2	7.20	71.0	31.0
	SE	±11.1	±1.15	±9.27	±4.11

Treatment %		Aerial parts			Roots			Shoot to root ratio	Total		
		Wet weight g^{-1}	Dry weight g^{-1}	Moisture content %	Wet weight g^{-1}	Dry weight g^{-1}	Moisture content %		Wet weight g^{-1}	Dry weight g^{-1}	Moisture content %
0	Mean value	4.36	0.516	89.2	1.64	0.230	86.9	0.421	6.00	0.746	88.65
	SE	±0.851	±0.122	±1.24	±0.378	±0.610	±2.52	±0.0353	±1.20	±0.181	±1.56
25	Mean value	3.59	0.384	88.2	2.02	0.216	89.7	0.497	5.61	0.600	88.9
	SE	±0.742	±0.0642	±1.13	±0.481	±0.0529	±1.88	±0.0836	±1.21	±0.116	±0.657
50	Mean value	2.08	0.278	85.8	1.29	0.140	89.9	0.506	3.37	0.418	88.3
	SE	±0.415	±0.0615	±3.13	±0.161	±0.0359	±1.76	±0.0430	±0.449	±0.0963	±2.32
100	Mean value	2.11	0.196	91.1	0.840	0.0800	90.9	0.539	2.95	0.276	91.1
	SE	±0.442	±0.0534	±1.86	±0.117	±0.0157	±1.13	±0.107	±0.545	±0.0689	±1.63

Table 3.3.2 The biomass data for Experiment 3, *Brassica juncea* grown in treatments of peat-based bulb fibre and kaolinite. Data are mean (n = 10) ± 1 SE, rounded to 3 significant figures.

All the biomass data were very similar so only the total biomass results are shown here (Figure 3.3.3).

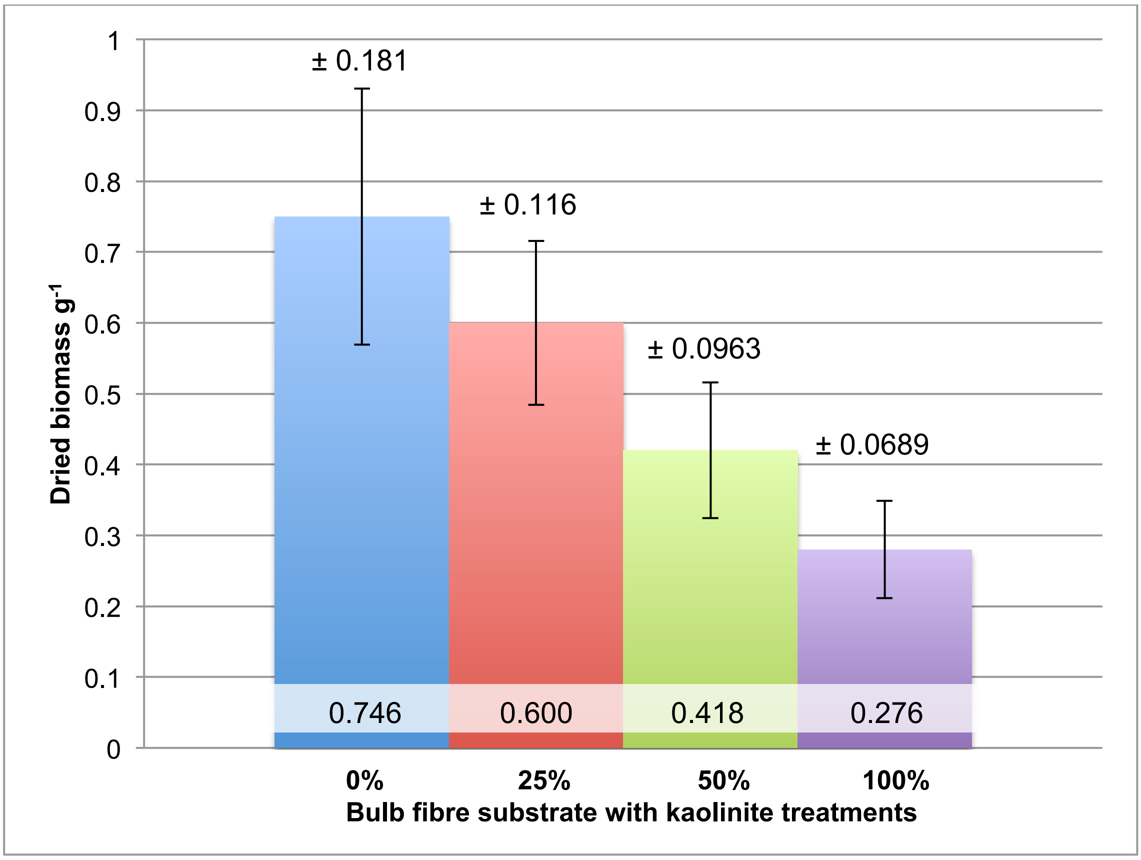


Figure 3.3.3 The total biomass of dried *Brassica juncea* grown in treatments of peat-based bulb fibre and kaolinite for Experiment 3. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars). P >0.05.

There is a trend in the mean dried biomass data showing that the higher the concentration of kaolinite the lower the biomass achieved, which was predicted in the hypothesis. However these differences, while somewhat regular (approximately 0.15g between each treatment) were P>0.05.

3.4 Growing Experiment 4 – optimum kaolinite in peat-based bulb fibre substrate

3.4.1 Introduction

The purpose of Experiment 4 was to find the optimum amount of kaolinite to add to the peat-based bulb fibre growing substrate to achieve increased plant biomass, by looking for a curve in the data. Five different treatments were chosen to this end: 0%, 5%, 10%, 20% and 40%. Laboratory work (Chapter 2.0) suggested that the top of the curve would be most likely found between the 10% and 20% amounts (H_1).

Following from the results of Experiment 3, it was expected that the plants growing in the 40% kaolinite would develop the least biomass, but the results of Experiments 1 and 2 suggested that increased kaolinite and biomass would be positively correlated.

This experiment was run twice after Cabbage White caterpillars (*Pieris brassicae*) destroyed a large amount of the plants' biomass in Experiment 4.0. As a result any data collected from the above ground plant matter could not be considered reliable. Seeds were sown as soon as possible, but Experiment 4.1 could not be started until October the 5th 2016 and was completed on January the 3rd 2017.

3.4.2 Method

Each treatment had five repeats. The number had been reduced from previous experiments after experience with the time required for data collection. The basic procedure was followed as described in Chapter 3.0 (Growing Experiments). All the bulb fibre came from the same batch – 153312L13.

3.4.3 Experiment 4.0 Results

Environmental Parameters

The average temperature over the period of the experiment was 19.96˚C (±0.263 SE) and the average light levels were 4028.14 Lux (±187.965 SE) (Figures 3.4.1 and 3.4.2).

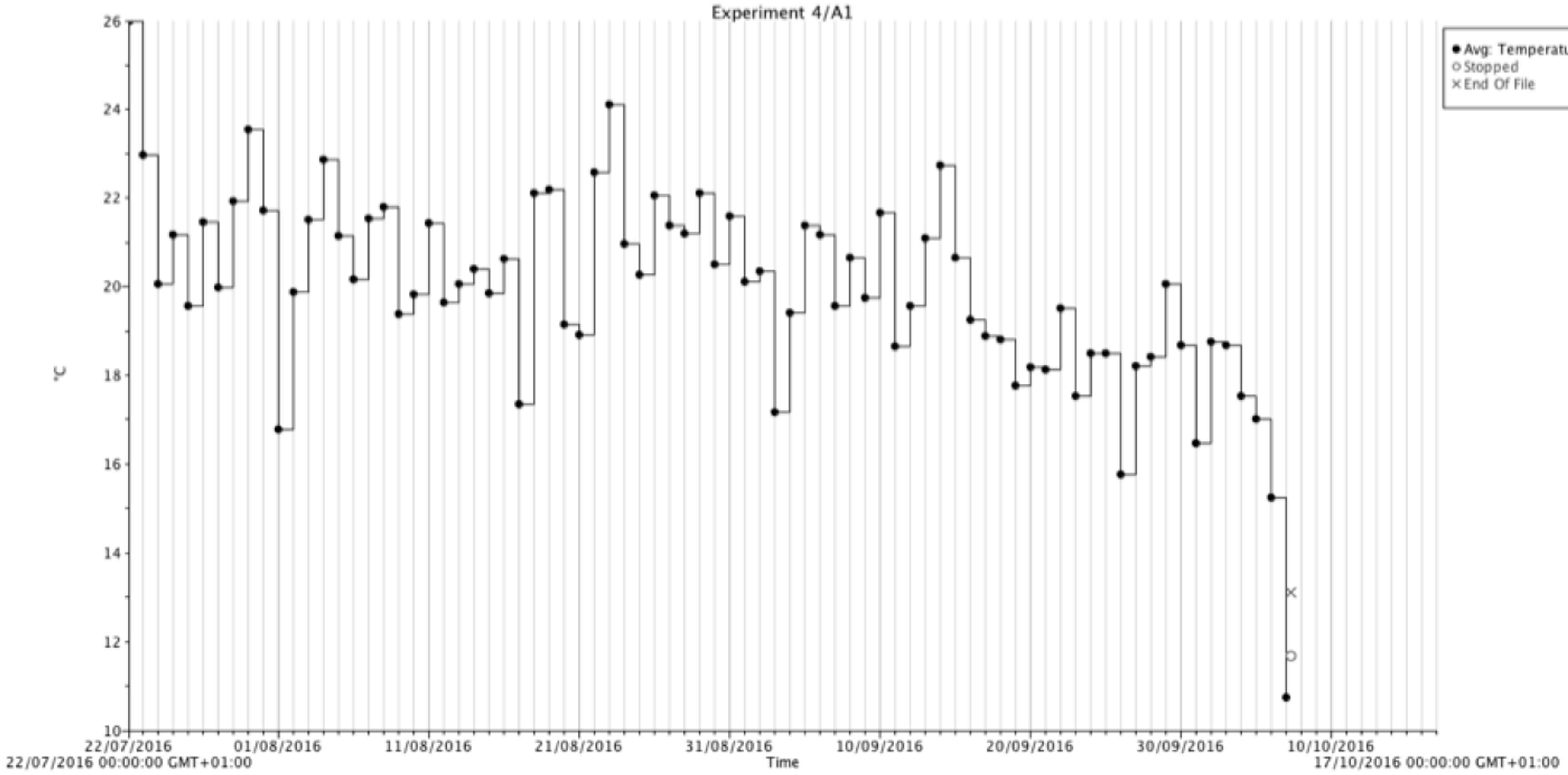


Figure 3.4.1 The temperature (˚C) in the glasshouse at Watering Lane Nursery during the period that Experiment 4.0 ran.

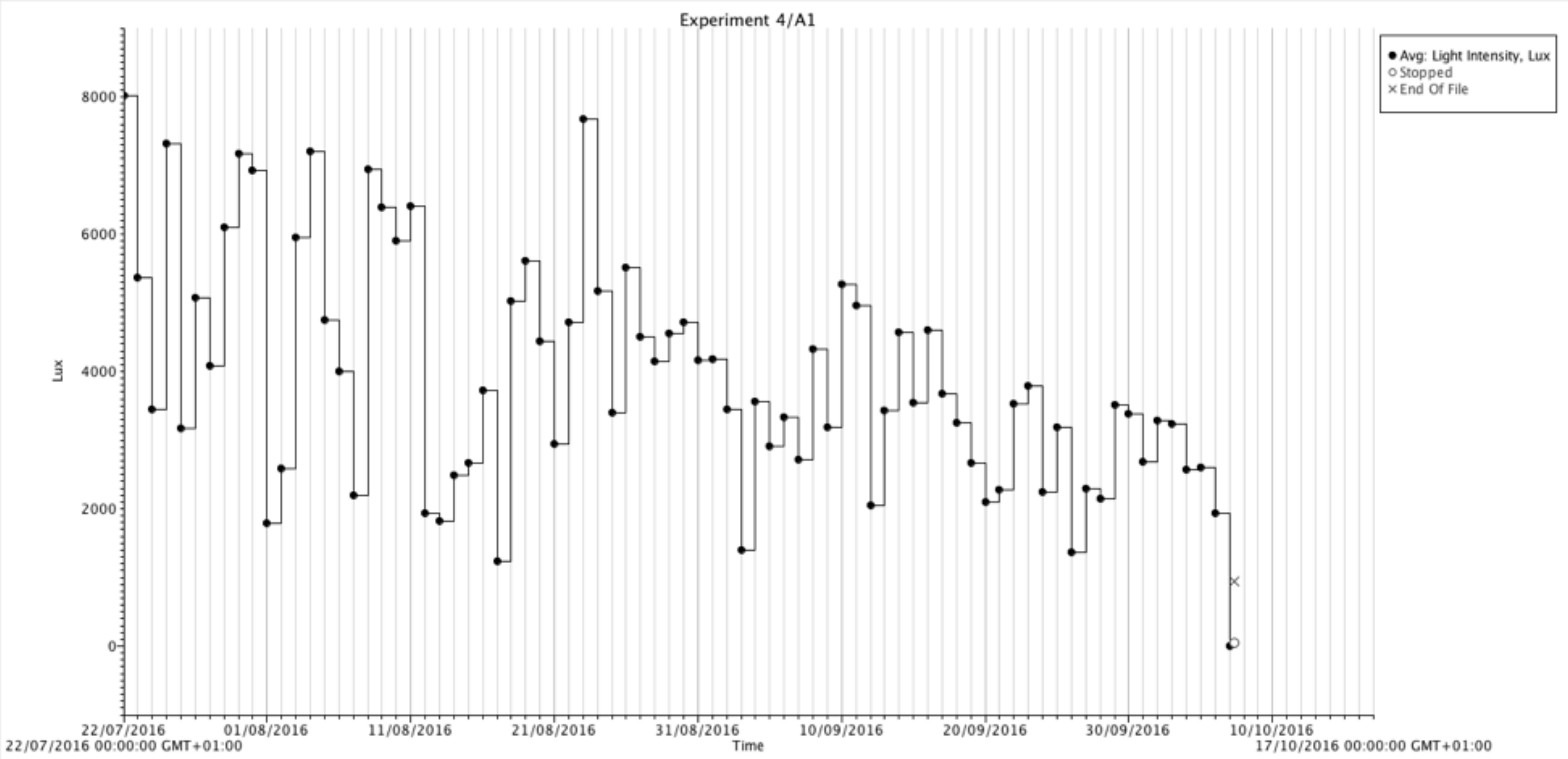


Figure 3.4.2 The light levels (Lux) in the glasshouse at Watering Lane Nursery during the period that Experiment 4.0 ran.

Growth data

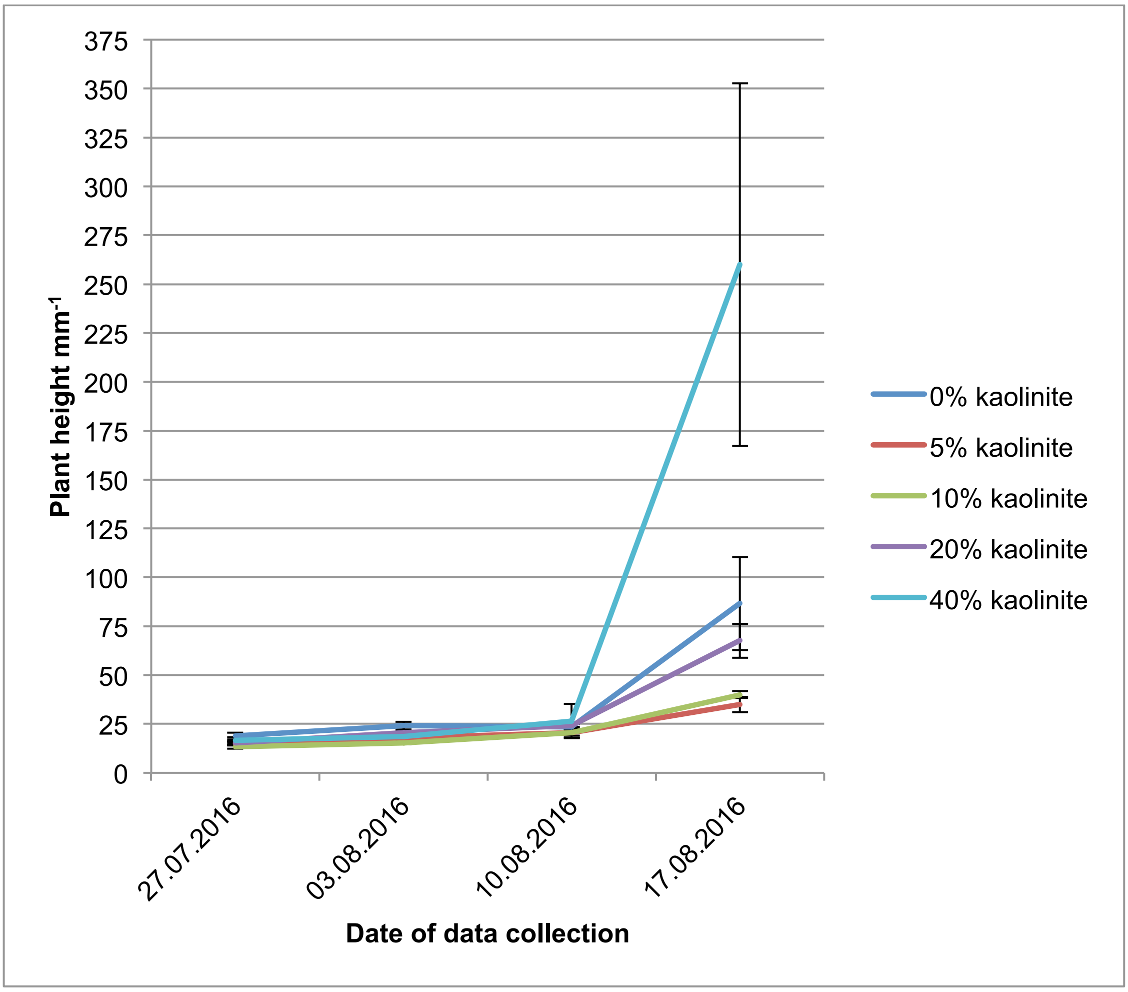


Figure 3.4.3 The height growth rate of *Brassica juncea* grown in peat-based bulb fibre substrate with different kaolinite treatments added by percentage weight. Data are mean (n = 5) ± 1 Standard Error (SE).

The extreme increase shown in the growth data (Figure 3.4.3 and Table 3.4.1) for the *B. juncea* grown in the 40% kaolinite treatment is due to the fact that three of the five plants had bolted – these were the only plants to do this. The plants grown in the 0% and 20% treatments have the greatest plant height by the end of the experiment.

Destructive Harvest

Due to the caterpillar damage, with the exception of stem length only the plant height and root data are published and discussed here.

The descriptive statistics (Table 3.4.1) for Experiment 4.0 show the plant heights of the *Brassica juncea* grown in 40% kaolinite were substantially taller than the other treatments (Figure 3.4.4), a difference of 173.4mm from the next tallest group, this is indicative of bolting. The data was not normally distributed, Kruskal-Wallis test gave the data a P-value of <0.05. A box-plot generated from the data (Figure 3.4.5) showed that it was the plants grown in the 40% kaolinite treatment that were significantly different from the other treatments, ANOVA was performed for clarity and confirmed these results.

Table 3.4.1 The descriptive statistics for the dry weight biomass of *Brassica juncea* roots grown in peat-based bulb fibre with treatments of kaolinite added by percentage weight. Data are mean (n=5) ± 1 Standard Error (SE), and rounded to 3 significant figures.

Treatment %		Plant height mm	Roots		
			Wet weight g	Dry weight g	% Moisture
0	mean value	86.6	8.18	0.716	91.3
	SE	±23.8	±0.670	±0.0721	±0.485
5	mean value	35.0	5.31	0.442	91.2
	SE	±3.95	±0.645	±0.0354	±1.06
10	mean value	40.0	6.75	0.626	90.2
	SE	±1.70	±0.668	±0.0362	±0.921
20	mean value	67.6	6.09	0.614	89.7
	SE	±8.80	±0.400	±0.0293	±0.784
40	mean value	260	5.03	0.434	4.59
	SE	±92.7	±0.499	±0.0565	±0.838

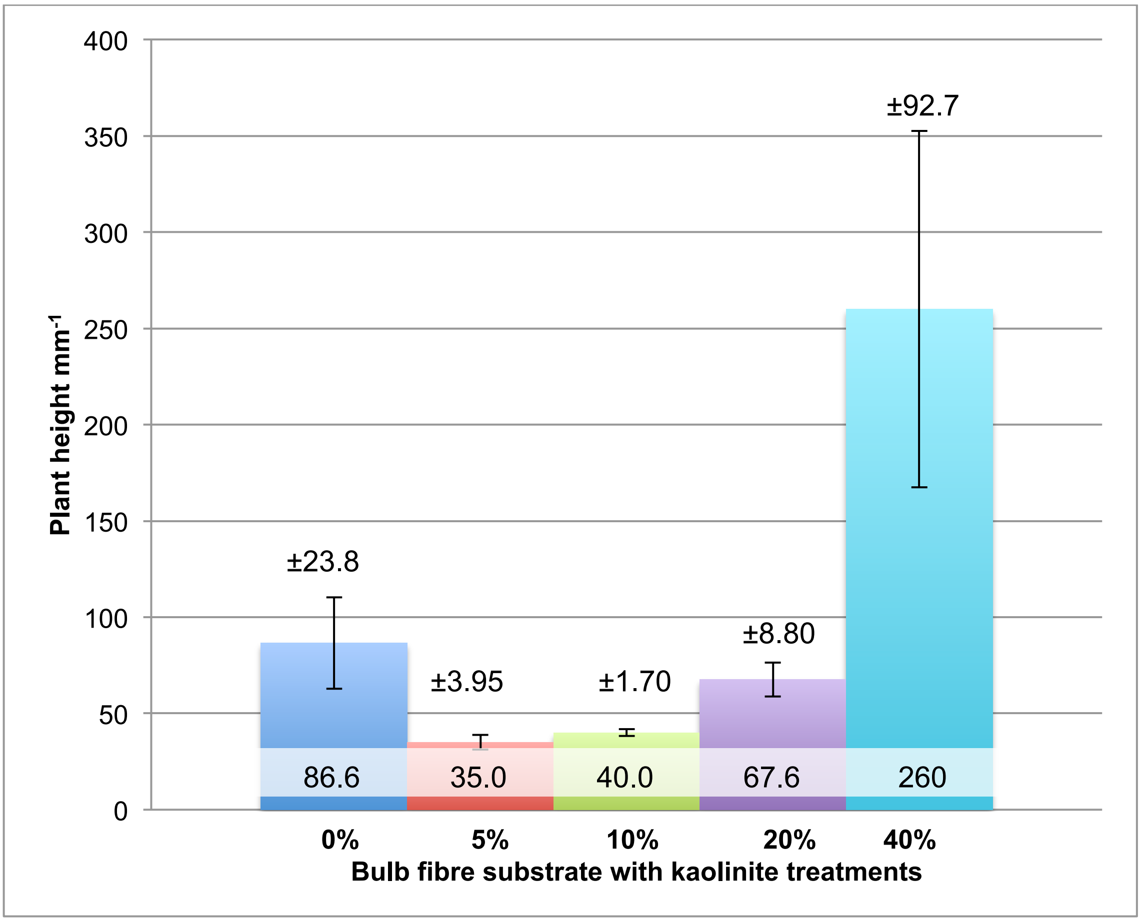


Figure 3.4.4 The final values for the heights of *Brassica juncea* grown in peat-based bulb fibre substrate with different kaolinite treatments added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.05.

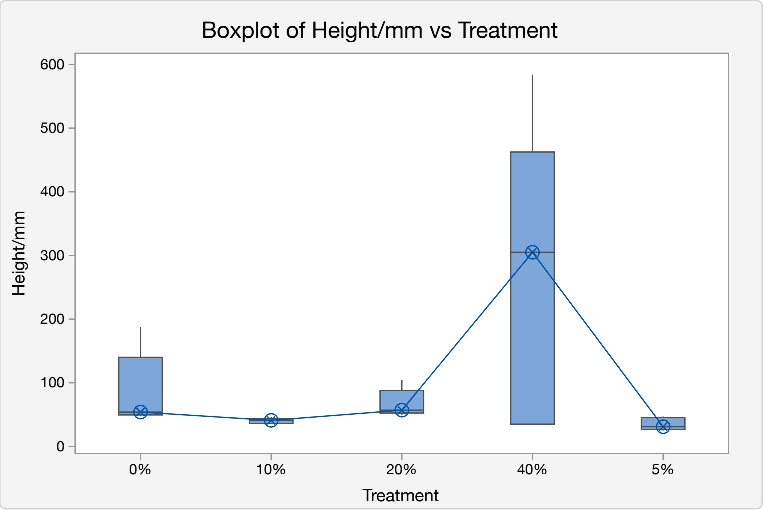


Figure 3.4.5 Boxplot showing the results of a Kruskal-Wallis test for heights of *Brassica juncea* grown in peat-based bulb fibre substrate (mean values) with different kaolinite treatments added by percentage weight. Data are mean (n=5) ± 1 Standard Error (SE). Graph generated by Minitab®.

The descriptive statistics (Table 3.4.1) showed greater root biomass in the 0% and 10% treatments than in the others (Figure 3.4.6), a P-value of <0.01 was found. The 0%, 10% and 20% treatments were not significantly different from each other (Table 3.4.2), but were different from the 5% and 40% treatments which were together in a second group.

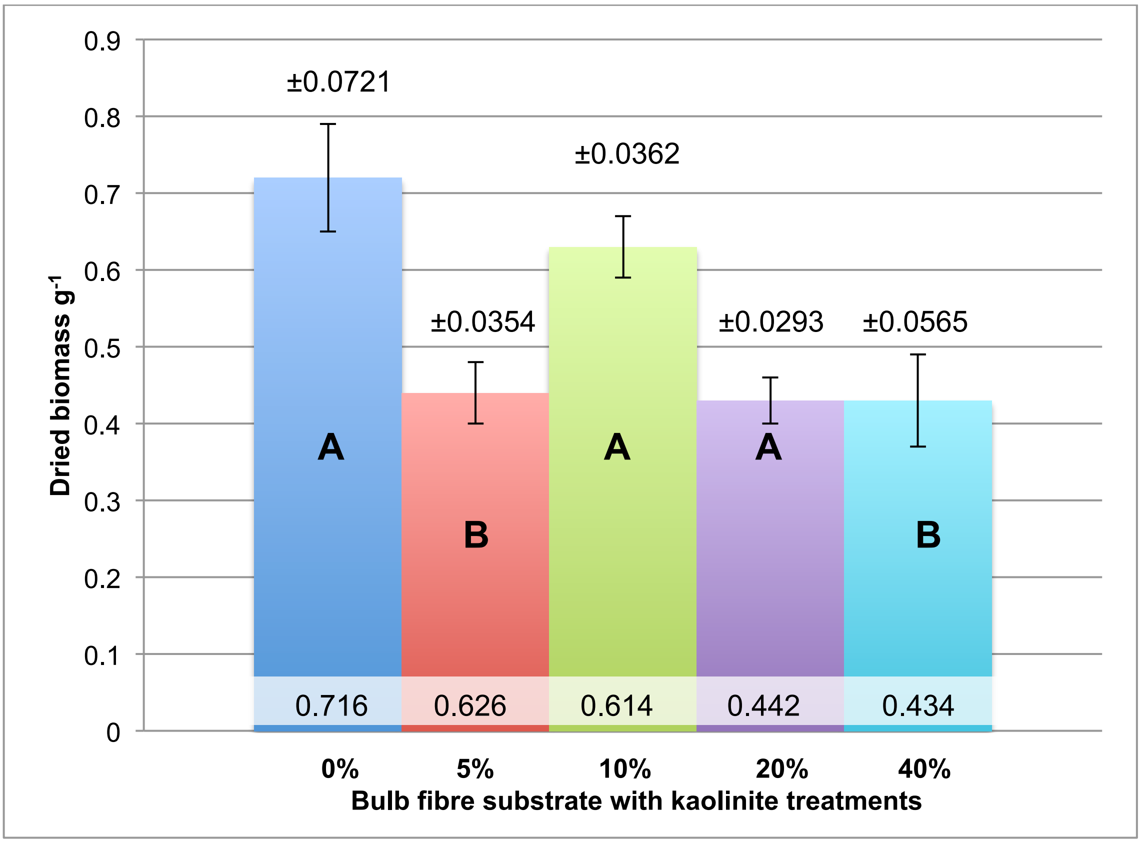


Figure 3.4.6 Experiment 4.0. The mean dry biomass weight of *Brassica juncea* roots grown in peat-based bulb fibre with treatments of kaolinite added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars). P <0.01, LSD groupings are indicated by letters, means that do not share a letter are significantly different.

3.4.4 Experiment 4.1 Results

This experiment ran from October the 5th 2016 to January the 3rd 2017.

Environmental Parameters

The mean temperature in the glasshouse during the course of Experiment 4.1 was 10.46˚C (±0.278 SE) (the fluctuations can be seen in Figure 3.4.7) and the average light intensity was 1811.65 (±114.62 SE) (Figure 3.4.8).

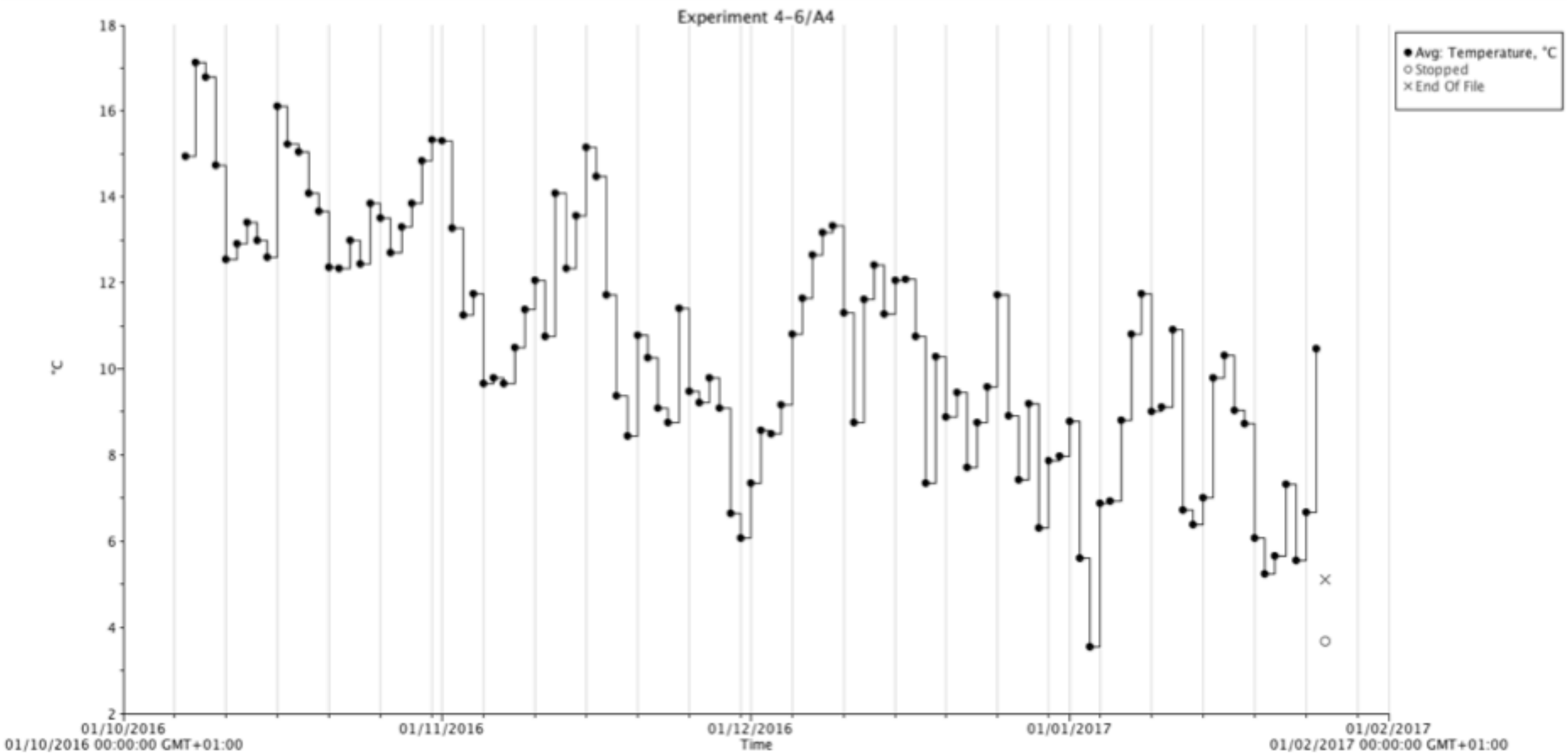


Figure 3.4.7 The temperature range in the glasshouse during Experiment 4.1.

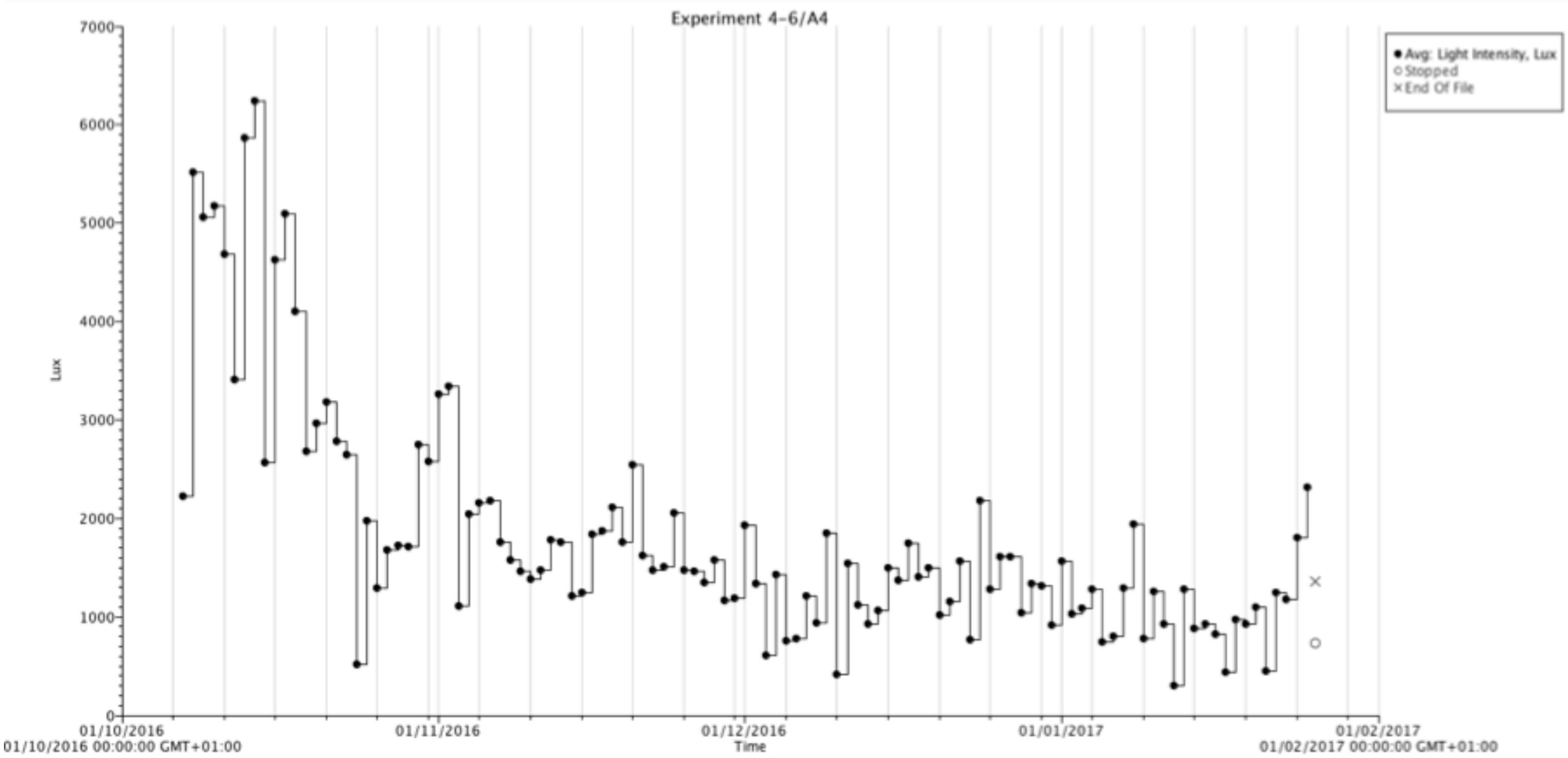


Figure 3.4.8 The light range in the glasshouse during Experiment 4.1

Growth data

Unlike in previous experiments, where the highest values for plant height were due to bolting, in this case none of the plants bolted, although considering the upward trend for all the plants (Figure 3.4.9), had the experiment run for much longer flowering would have begun. The plant height and leaf length values are similar to the other growth data, so only they are shown here (Figures 3.4.9 and 3.4.10). Where as the height of the plants grown in the 10% treatment showed an intermediate position for much of the growth period, the leaf length showed the plants in that treatment to have among the largest leaves according to their mean values. However, as with previous experiments, there was little variation through most of the experimental period.

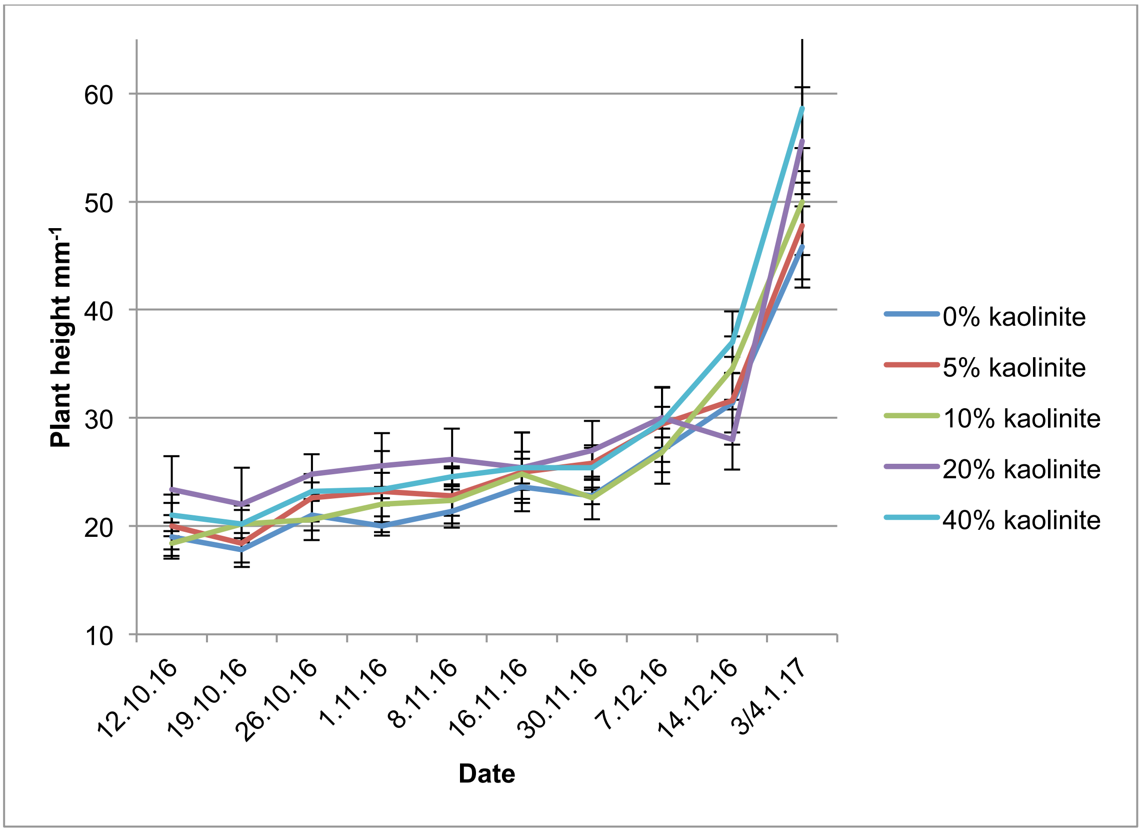


Figure 3.4.9 The growth of *Brassica juncea* grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight in Experiment 4.1. Data are mean (n = 5) ±1 Standard Error.

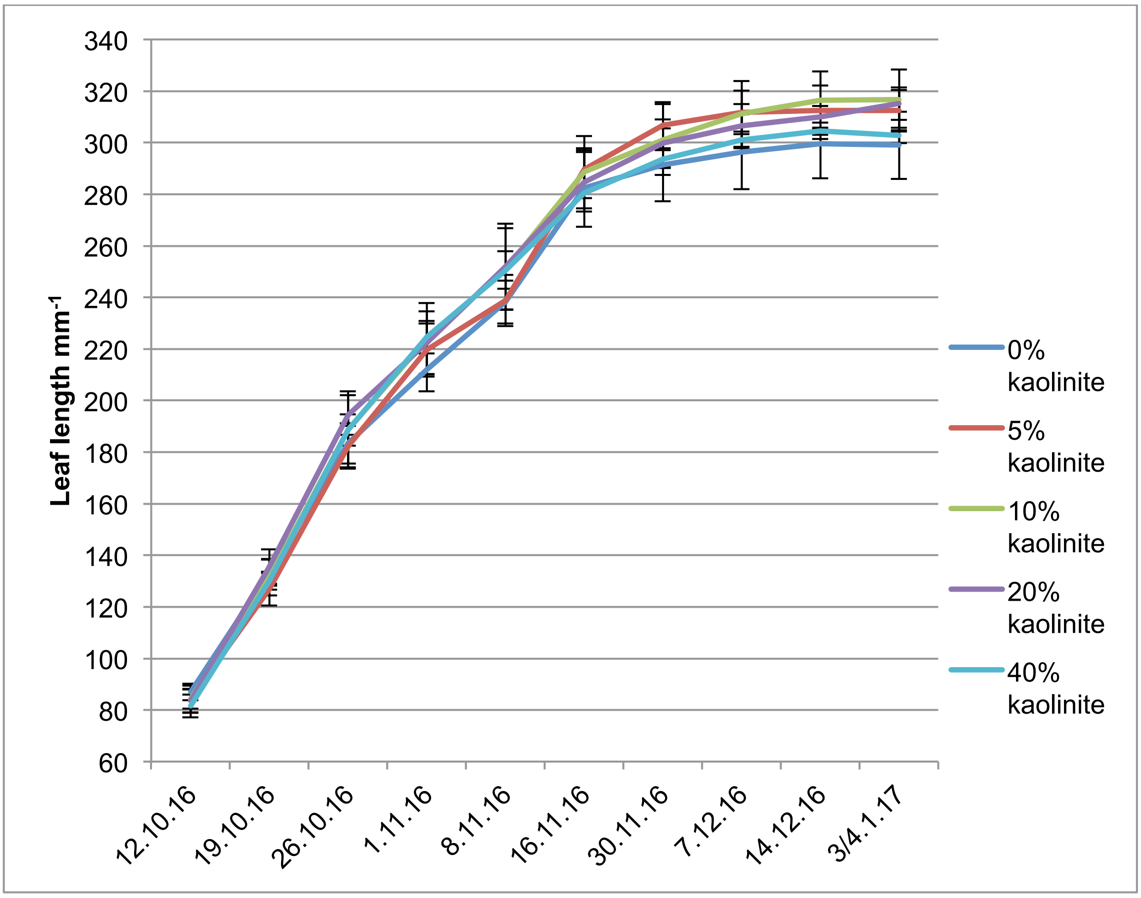


Figure 3.4.10 The leaf length of *Brassica juncea* over their period of growth, grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight. Data are mean (n = 5) ±1 Standard Error.

Destructive harvest

The mean values (Table 3.4.2) showed a slightly larger biomass for the 10% kaolinite treatment (>0.05), however in all cases no significant difference was found.

Table 3.4.2 The biomass data for *Brassica juncea* grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight, Experiment 4.1. Data are mean (n = 5) ± 1 Standard Error (SE) and rounded to 3 significant figures.

Treatment %		Aerial parts			Roots			Total			Aerial parts /roots ratio
		Wet weight g^{-1}	Dry weight g^{-1}	Moisture %	Wet weight g^{-1}	Dry weight g^{-1}	Moisture %	Wet weight g^{-1}	Dry weight g^{-1}	Moisture %	
0	Mean value	61.1	5.32	91.4	15.0	1.65	89.0	77.1	6.97	90.9	3.22
	SE	±5.23	±0.394	±0.249	±1.44	±0.195	±0.833	±5.43	±0.485	±0.348	
5	Mean value	60.8	5.35	91.2	16.7	1.69	90.2	77.5	7.04	91.0	3.17
	SE	±4.26	±0.547	±0.525	±2.58	±0.327	±0.388	±5.67	±0.779	±0.493	
10	Mean value	73.1	6.60	91.2	17.8	2.22	89.0	90.9	8.81	90.7	2.98
	SE	±4.50	±0.960	±0.920	±3.63	±0.695	±1.41	±7.52	±1.63	±1.08	
20	Mean value	70.8	6.18	91.4	20.3	2.36	89.5	91.1	8.53	90.9	2.62
	SE	±5.36	±0.683	±0.449	±4.28	±0.642	±1.26	±9.14	±1.30	±0.616	
40	Mean value	60.2	5.70	90.4	13.85	1.95	86.4	74.1	7.65	89.7	2.37
	SE	±2.57	±0.307	±0.772	±2.57	±0.373	±1.48	±2.73	±0.662	±0.814	

3.5 Experiment 5: investigating effects on *Triticum aestivum*

3.5.1 Introduction

The purpose of this experiment was to see how an alternate plant performed with the same kaolinite treatments in bulb fibre. *Triticum aestivum* (winter wheat) (Section 1.4.1) was chosen because being a monocotyledon its morphology was very different to *Brassica juncea*. The hypothesis was that the kaolinite treatments would improve growth and biomass production.

3.5.2 Method

50ml pots were used, with four plants (previously sown in a seed tray, as described in Chapter 3.0) planted in each. When collecting data, the plant height was measured from the surface of the substrate to the growing tip (emerging leaf) of the longest tiller. The leaf length was measured from the point where it leaves the sheath to the tip of the longest leaf on the plant.

The experiment was begun on October 5th 2016 (when the seedlings were transplanted), a mid-trial harvest was performed on November the 11th and the experiment was ended on January the 11th. Harvesting was performed by removing the above ground plant matter with a sharp knife - because there were four plants in a pot, the root data proved impossible to collect.

3.5.3 Results

Environmental parameters

Because Experiment 5 ran along side Experiment 4.1 they share the same environmental data. The mean temperature in the glasshouse during the course of Experiment 4.1 was 10.46˚C (±0.278 SE) and the average light intensity was 1811.65 (±114.62 SE) (The ranges are shown in figures 3.5.1 and 3.5.2).

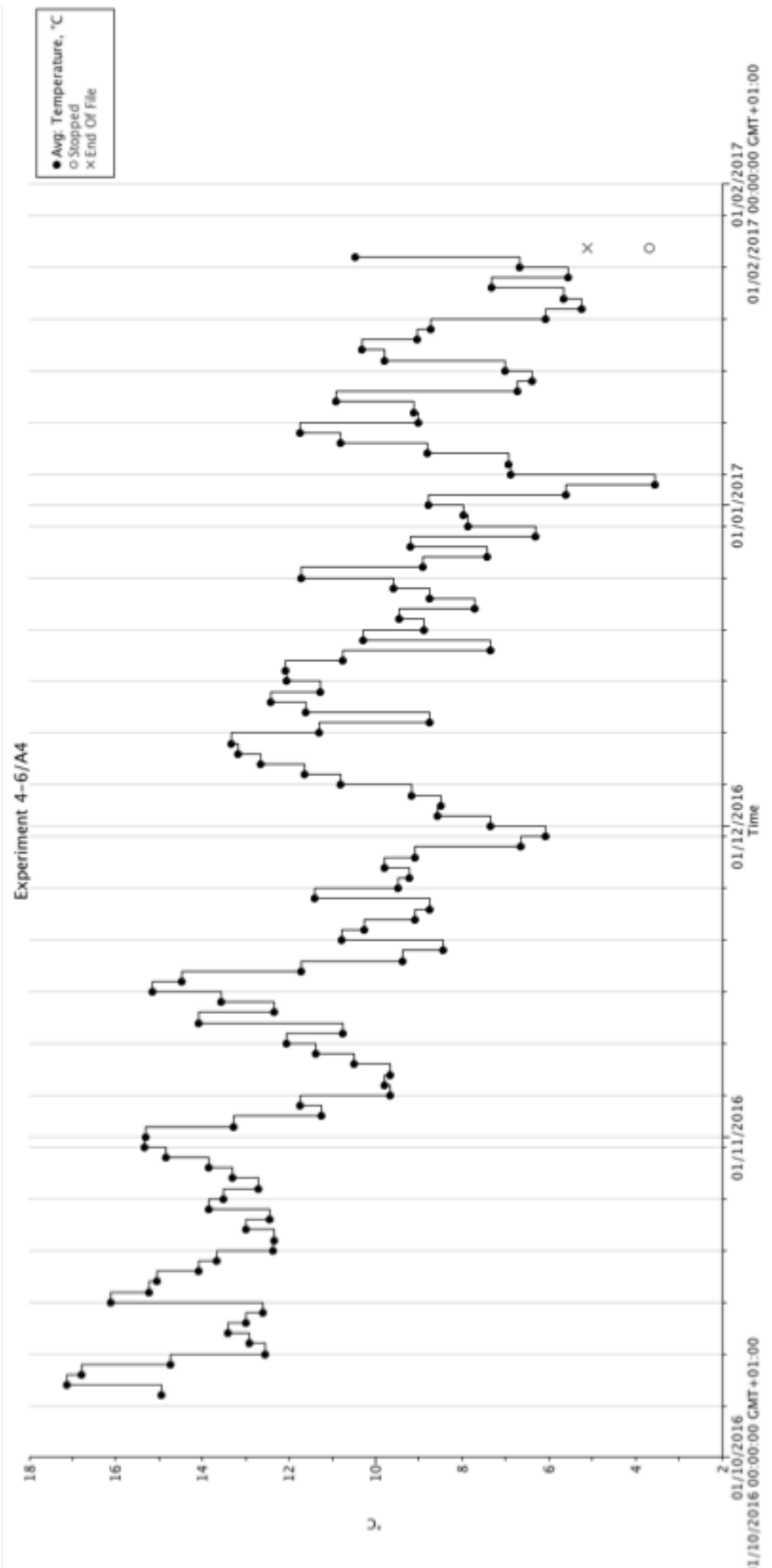


Figure 3.5.1 The temperature range in glasshouse during Experiment 5.

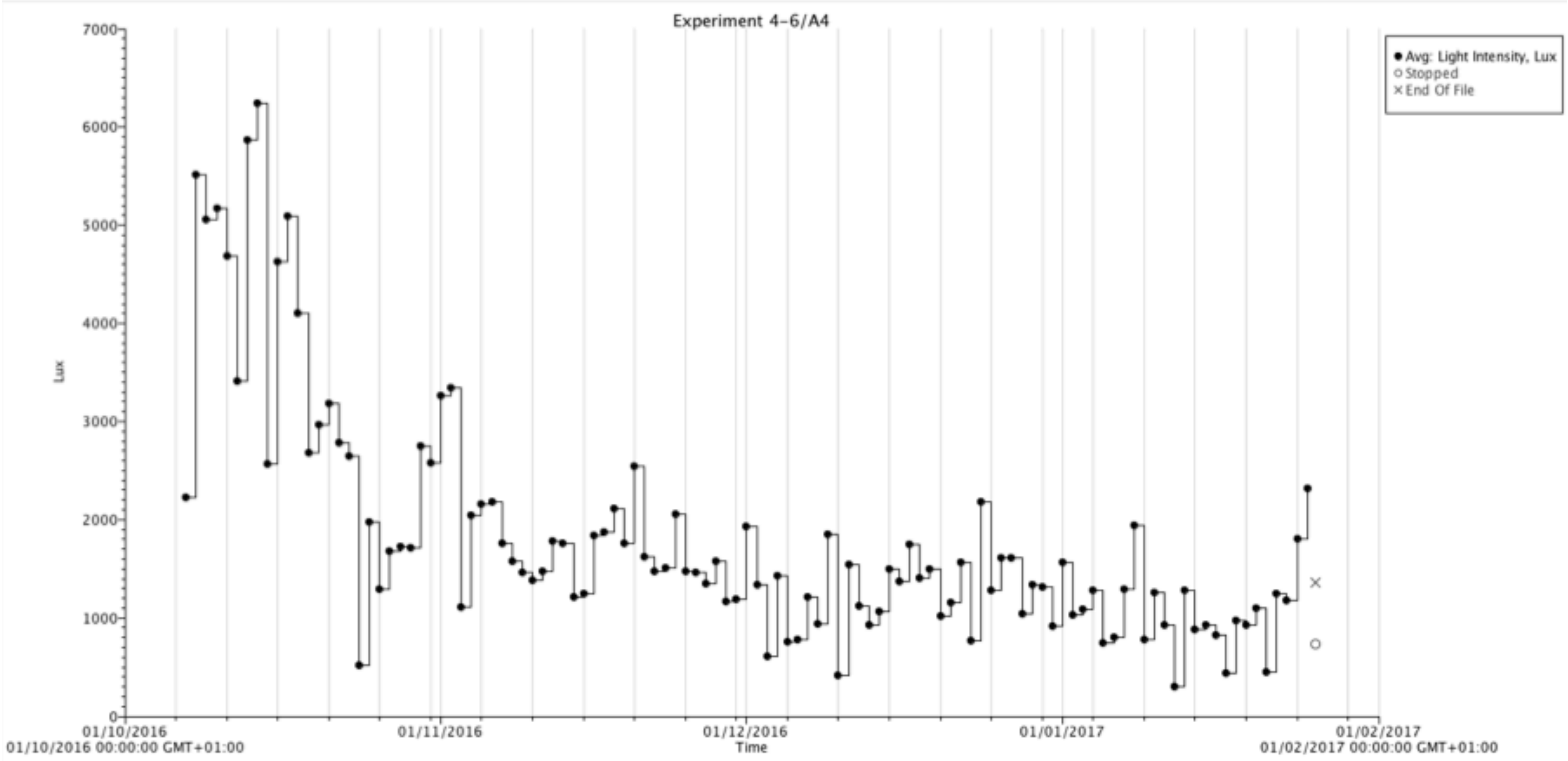


Figure 3.5.2 The light range in the glasshouse during Experiment 5.

Growing data

All results showed similar values, so only the plant height data (Figure 3.5.3) is shown here, along with the leaf count (Figure 3.5.4), which showed a different trend. The leaf height growing values showed the 0%, 5% and 10% kaolinite treatments to be the tallest plants (the 10% slightly above the rest) and the 20% and 40% treatments a little smaller, however there is unlikely to be any significance in these mean values since they are so tightly grouped.

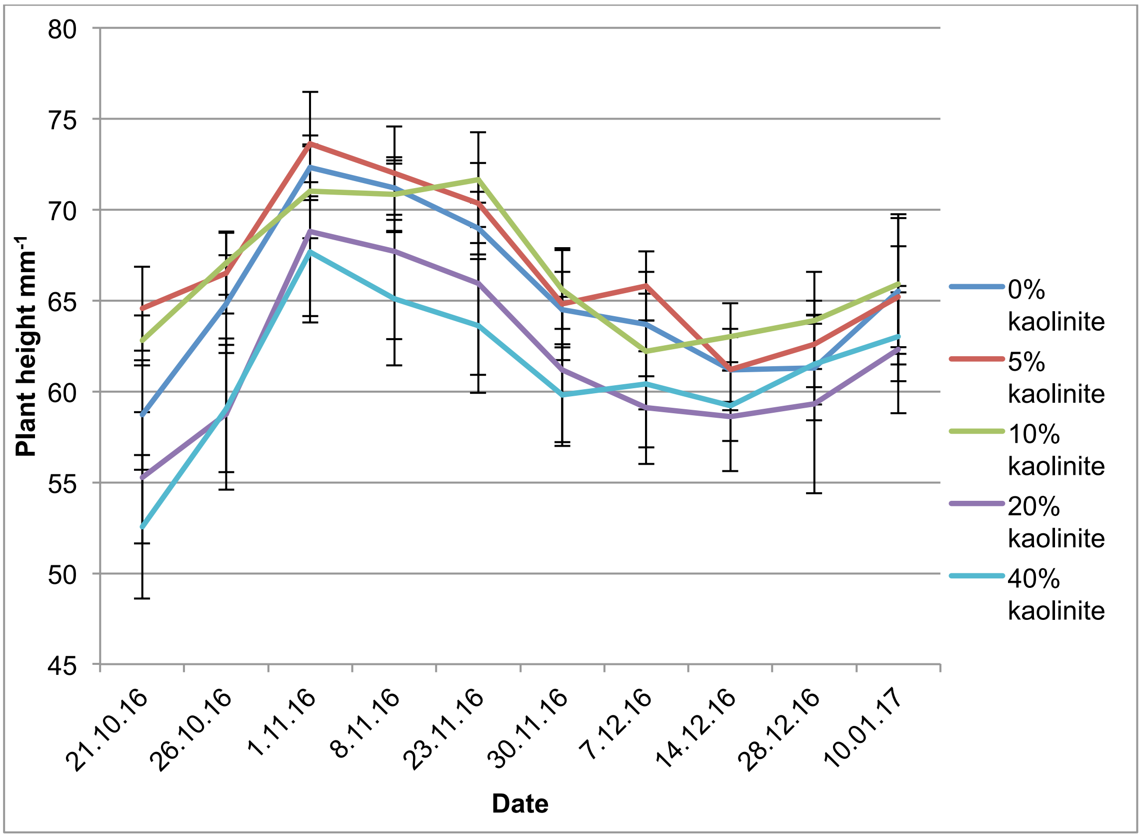


Figure 3.5.3 The mean height values of *Triticum aestivum* over the full growing period, grown in peat-based bulb fibre with kaolinite treatments added by percentage weight. Data are mean (n = 5) ±1 Standard error, P > 0.05 (last data point).

The development of leaves – leaf count – (Figure 3.5.4) is almost the reverse of the plant height data, with only the 0% treatment remaining in the higher values.

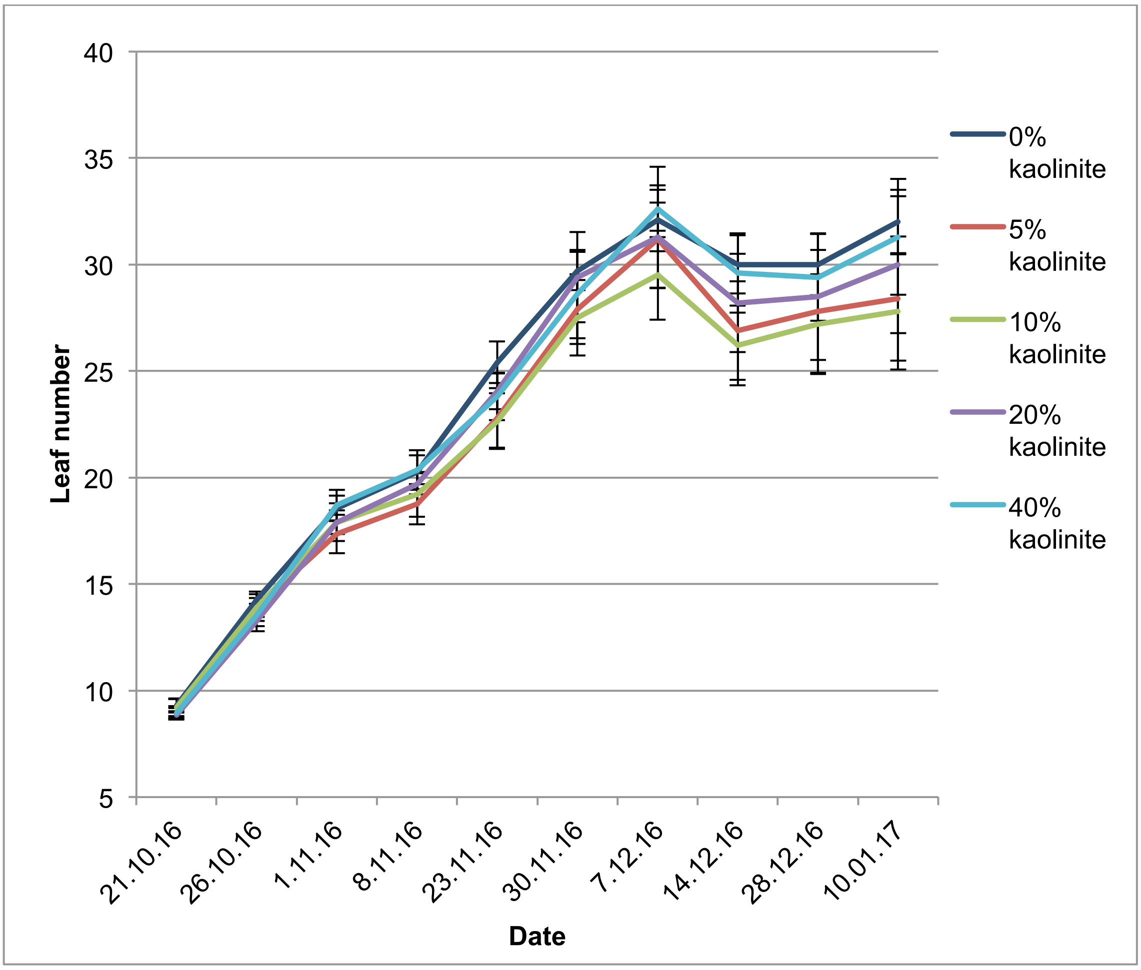


Figure 3.5.4 The mean leaf count of *Triticum aestivum* over the full growing period, grown in peat-based bulb fibre with kaolinite treatments added by percentage weight. Data are mean (n = 5) ±1 Standard error.

3.5.4 Mid-trial destructive harvest

A mid-term destructive harvest on the 11th of November of two plants per pot was performed, taking the second and fourth plants (this numbering was based on the plants' positions in a clockwise direction from the pot's front label). Table 3.5.1 displays the basic descriptive statistics, all results were P >0.05.

Table 3.5.1 The descriptive statistics for the mid-trial harvest of Experiment 5, showing the growth and biomass results for *Triticum aestivum* grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight. Data are mean (n = 5) ± 1 Standard Error (SE) and rounded to 3 significant figures.

Treatment %		Leaf count	Plant height mm	Leaf length mm	Leaf width mm	Dry weight g	% Moisture content
0	Mean	25.7	70.1	322	5.10	0.491	85.3
	SE	±1.38	±1.17	±9.77	±0.0894	±0.0461	±0.858
5	Mean	22.0	71.0	314	5.40	0.474	83.1
	SE	±1.49	±3.89	±9.51	±0.261	±0.025	±0.832
10	Mean	22	73	318.3	5.4	0.539	82.17
	SE	±1.288	±3.521	±10.009	±0.167	±0.0439	±1.29
20	Mean	23.7	67.1	299	5.30	0.467	83.4
	SE	±0.482	±5.37	±12.1	±0.268	±0.0296	±0.701
40	Mean	23.4	61.9	304	4.60	0.489	81.9
	SE	±1.43	±4.65	±12.3	±0.167	±0.0550	±0.266

3.5.5 Full-term destructive harvest

As can be seen in Table 3.5.2, no significant results were found from the full-term destructive harvest (P >0.05).

Table 3.5.2 The descriptive statistics for the full-term destructive harvest showing the growth and biomass results for *Triticum aestivum* grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight. Data are mean (n = 5) ± 1 Standard Error (SE) and rounded to 3 significant figures.

Treatment %		Leaf count	Plant height mm	Leaf length mm	Leaf Width mm	Dry Weight g	Moisture content %
0	Mean	32.0	65.5	312	4.70	0.509	83.5
	SE	±1.52	±4.02	±7.69	±0.110	±0.302	±0.901
5	Mean	28.4	65.2	289	4.40	0.491	82.2
	SE	±2.92	±2.77	±8.21	±0.219	±0.568	±1.07
10	Mean	27.8	65.9	307	4.70	0.531	80.7
	SE	±2.73	±3.84	±7.75	±0.110	±0.0447	±1.10
20	Mean	30.0	62.3	288	4.60	0.562	80.3
	SE	±3.22	±3.50	±11.6	±0.0894	±0.560	±1.09
40	Mean	31.3	63.0	297	4.60	0.571	80.1
	SE	±2.72	±2.44	±5.83	±0.0894	±0.121	±0.547

3.6. Experiment 6 – simulated revegetation scheme for semi-arid areas

3.6.1 Introduction

The intention of Experiment 6 was to simulate a re-vegetation scheme in a semi-arid environment.

Brassica juncea and *Triticum aestivum* were both used, grown in bulb fibre with two different treatments: 0% and 10% kaolinite. 10% kaolinite was closest to the original amount used in Experiment 1, and at the time of designing the experiment the final results of Experiments 4.1 and 5 were not available (in fact Experiment 6 ran concurrently), however mean values throughout seemed to suggest that the 10% kaolinite treatments were the most effective. The lab experiments also showed 10% kaolinite, along with 20% kaolinite to be the most effective movers of water against gravity (e.g. capillary rise and WDPT tests, Sections 2.1.6 and 2.1.7), and while the WDPT test showed the 40% treatment to be the most effective, the growing experiments and observations suggested that it was too dense for plants to grow comfortably in. Therefore 10% kaolinite appeared to be the best choice for Experiment 6.

3.6.2 Method

Twenty 50ml pots were prepared with bulb fibre, half with the 0% treatment and the other half with the 10% treatment. Five *Brassica juncea* and five *Triticum aestivum* were planted in each treatment and placed randomly in the group. Once they were well established they were planted out again into 2l pots of John Innes no.2 - chosen because it mimics soil better than other artificial substrates, soil was not chosen because it increases the amount of variables, including the possible introduction of pathogens.

Once they were transplanted into the John Innes no.2, on October the 18th 2016 they were watered to container capacity, and placed on upturned plastic vegetable boxes to encourage drainage. They were left until they were all wilting and then watered again. The intention was to repeat this cycle several times, but due to the time of year it took weeks to achieve significant wilting and there was no time to repeat a second cycle. When collecting data through the period any necrotic leaves were removed. The destructive harvest was performed on the 24th and 25th of January 2016 (98 days later).

3.6.3 Results

Environmental data

The mean temperature in the glasshouse during the course of Experiment 6 was 10.46˚C (±0.278 SE) and the average light intensity was 1811.65 (±114.62 SE). Figures 3.6.1 and 3.6.2 show the environmental fluctuations over the course of the experiment.

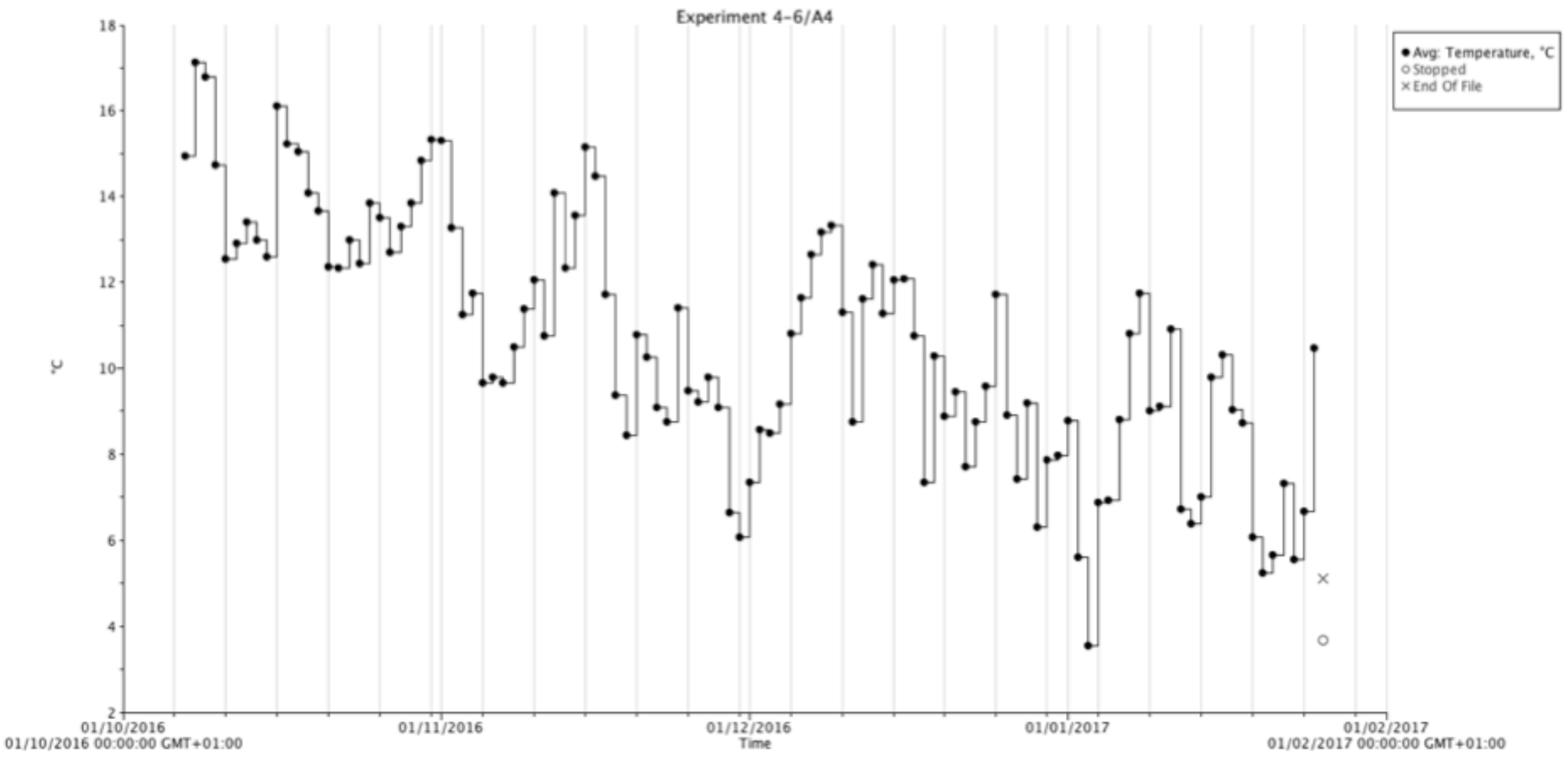


Figure 3.6.1 The temperature (˚C) in the glasshouse at Watering Lane Nursery during the period of experiment 6.

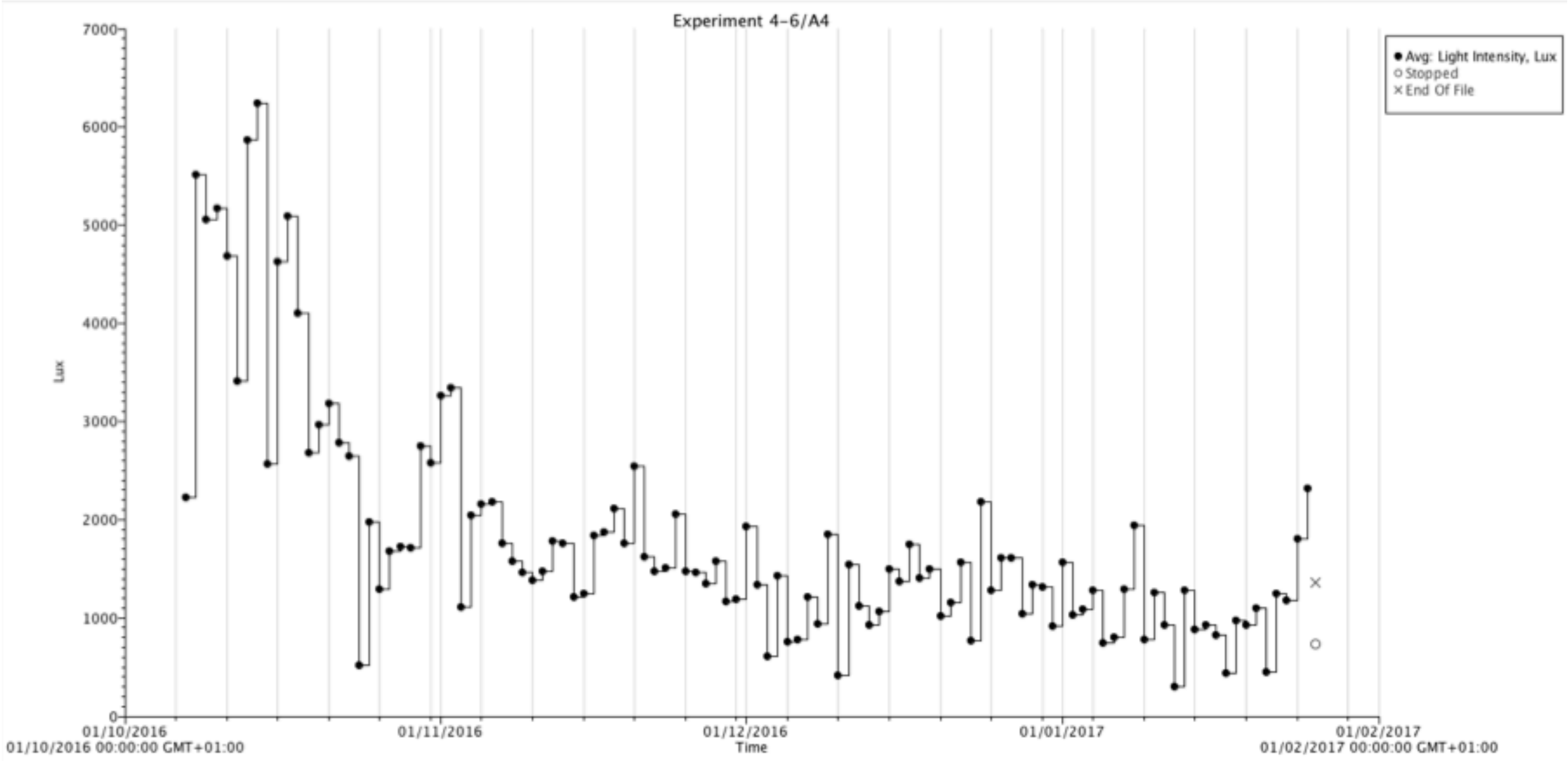


Figure 3.6.2 The light levels (Lux) in the glasshouse at Watering Lane

Growth data

The leaf data is similar to the plant heights, so only the plant heights are shown (Figure 3.6.3). In all cases the 10% treatment suggests greater growth, with the leaf count (Figure 3.6.4) showing a wider difference in the *T. aestivum* values, however the destructive harvest results showed no significant difference between treatments (Table 3.6.1).

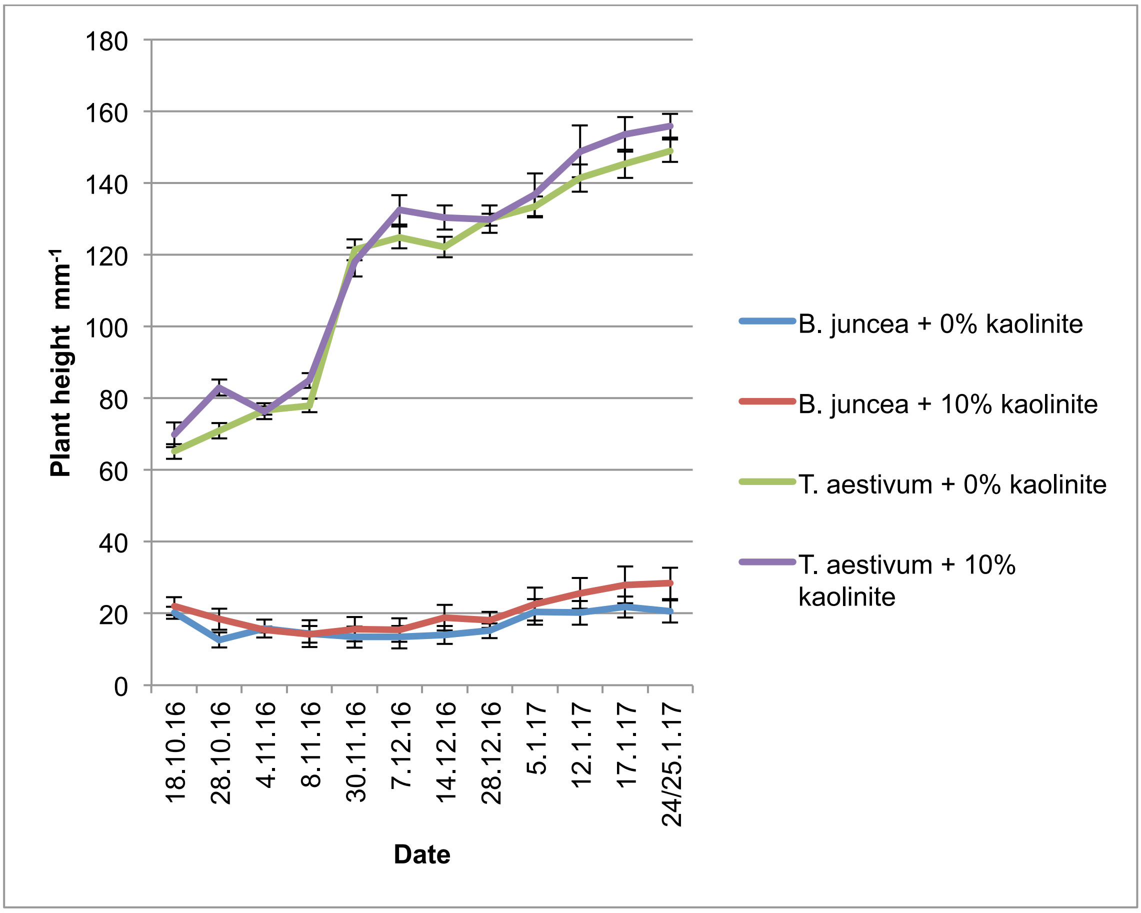


Figure 3.6.3 The plant heights of *Brassica juncea* and *Triticum aestivum* grown in peat-based bulb fibre substrate with two kaolinite treatments, under drought conditions. Data are mean (n = 5) ±1 Standard error.

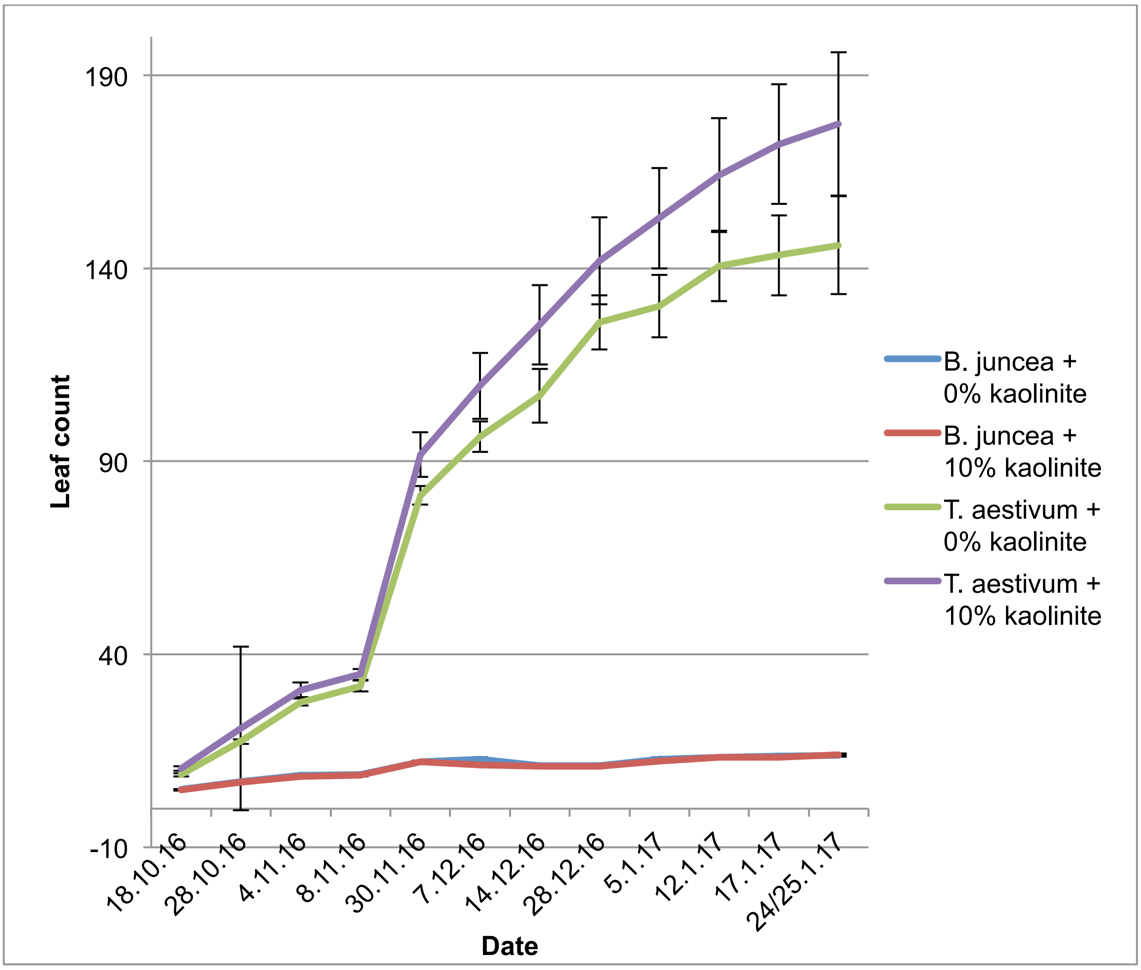


Figure 3.6.4 The leaf count of *Brassica juncea* and *Triticum aestivum* grown in peat-based bulb fibre substrate with two kaolinite treatments, under drought conditions. Data are mean (n = 5) ±1 Standard error.

Destructive harvest

The results for Experiment 6 (Table 3.6.1) all had a P value of >0.05.

Table 3.6.1 The descriptive statistics for the destructive harvest of Experiment 6, with *B. juncea* and *T. aestivum* grown in peat-based bulb fibre substrate with two kaolinite treatments. Data are mean (n = 5) ± 1 Standard Error (SE).

Substrate and Treatment %		Leaf count	Plant height mm	Leaf length mm	Leaf width mm	Above ground biomass		Root biomass		Total biomass		Above ground to root ratio
						Dried weight g	Moisture content %	Dried weight g	Moisture content %	Dried weight g	Moisture content %	
B. juncea + 0%	Mean	13.8	20.6	289	77.0	6.30	85.9	1.14	83.8	7.44	85.7	5.71
	SE	±0.335	±3.12	±7.31	±5.22	±0.214	±0.536	±0.103	±0.577	±0.298	±0.474	±0.382
B. juncea + 10%	Mean	14.0	28.4	309	85.6	6.77	87.6	1.25	83.6	8.02	87.1	5.66
	SE	±0.283	±4.40	±9.19	±3.18	±0.216	±0.421	±0.141	±1.79	±0.292	±0.444	±0.485
T. aestivum + 0%	Mean	146	149	396	5.20	4.00	86.3	0.576	89.9	4.57	86.9	7.15
	SE	±12.7	±3.14	±7.33	±0.335	±0.534	±0.250	±0.0918	±1.30	±0.613	±0.416	±0.670
T. aestivum + 10%	Mean	177	156	398	5.20	5.24	85.6	0.818	90.3	6.06	86.5	7.07
	SE	±18.6	±3.19	±6.91	±0.179	±0.628	±0.531	±0.120	±1.23	±0.718	±0.518	±1.13

3.7 Discussion of the Growing Experiments

Growing experiment 1 (confirming the BSc results)

At the mid-term point, the addition of kaolinite to the peat-based bulb fibre improved the plant growth significantly in comparison to the substrate without the addition, bringing its biomass to a similar level to both John Innes no.2 treatments, and significantly higher than the Watering Lane mix treatments. Adding kaolinite did not significantly affect the results from the Watering Lane mix. The bulb fibre with kaolinite had the largest leaf area ($P < 0.05$), making it potentially useful to the growth of leaf vegetables and ornamentals.

However by the time of the full-term destructive harvest the leaf sizes are largest for BF since only the plants grown in the bulb fibre without kaolinite did not begin to bolt (flower), they were also the smallest in height to a significantly different degree ($P < 0.001$) and had the fewest leaves.

Visually the John Innes seedlings were small but sturdy, with thick stems, and plants grown without kaolinite were longer. It was noticed that seedlings that ‘lodged’ (toppled over) when watered - even though the water did not touch them - were always grown in substrate without kaolinite, which suggested a stronger or more extensive root system with kaolinite . While the biomass of the roots grown in John Innes no.2 with kaolinite was low in comparison to the John Innes no. 2 without addition, the ratio of above ground plant matter to roots showed a significantly higher value for the John Innes no.2 with kaolinite, suggesting that the presence of the mineral may have encouraged more energy to be allocated to root production in that substrate. This may prove useful for the production of root crops.

There was significant difference in the biomass data between the two bulb fibre treatments (Figure 3.1.16), with the addition of kaolinite increasing the biomass in the full-term destructive harvest. There was a great deal of change between the mid-trial and full-term harvest, where the treatments were divided by Fisher's LSD into two groups, in the full-term there were four divisions. There was no significant difference between BF/K and JI but they were significantly and positively different to all other treatments. JI/K and WL/K were significantly different from each other, and BF was in its own grouping at the lowest end of the table.

The results of the first experiment upholds the hypothesis that adding kaolinite to the peat-based bulb fibre substrate does significantly improve the growth of *Brassica juncea* and increase its biomass, the value of which was significantly different to all other treatments except the John Innes no.2. The investigation also showed that significantly more of the fresh weight of the *Brassica juncea* grown in bulb fibre without kaolinite added was water compared to the other treatments.

However its effects on the other substrates were not so clear, and indeed it had a significant negative effect on the John Innes no.2 by the time of the full term harvest.

The Watering Lane mix did not uphold the hypothesis (although it should be remembered that Melcourt add a wetting agent to the mix, which may have skewed the results), kaolinite did not improve growth, but it also did not impede it to a significant degree, although in all cases the mean values for WL/K was lower than WL. The Watering Lane mix is very open, with a high AFP (see Table 2.3.1), it may be that the kaolinite did not stay homogenously mixed after potting and the first irrigation, or that the larger pores resulted in the clay aggregating preferentially in the pores. It was noted by the researcher during the growth period that substrates with added kaolinite took longer for water to drain through, showing that the clay had a clear effect on water movement when present. This work is similar to that of Fields, Fonteno and Jackson (2014), who, when investigating wetting agents, found significant results working with peat, but not with other substrates.

Experiment 1 confirmed the original experiment, and allowed the overall investigation into kaolinite and substrate to move on.

Experiment 2 (lower kaolinite concentrations)

ANOVA results for the final growth data (taken at the time of the harvest) showed that the difference in plant height was significant for the heaviest concentrations. Leaf size did not alter significantly, this either showed that leaf sizes without the kaolinite present were generally smaller, or that the presence of kaolinite alters the plant’s habit of developing much smaller leaves as it bolts.

The results from the dried biomass of the leaves and stem showed a significant positive reaction to the increased addition of kaolinite, despite the small additions. The environmental data indicated that the plants may have been heat stressed on a number of occasions, and were certainly water stressed, having wilted several times. It may be that the addition of kaolinite, which has been shown to improve heat conductivity (Sakaguchi *et al.*, 2007) and water infiltration (Diamantis *et al.*, 2017) increased the plants' ability to develop despite these events.

In hindsight a range between 0% and 5% or 10% would have been better, although McKissock, Gilkes and Walker (2002), investigated hydrophobicity in soils and using kaolin additions of 0%, 0.2%, 0.4%, 0.8% and 1.6%, and found significant positive results. However the hypothesis was upheld, the addition of kaolinite to positively affect growth in regard to height and biomass production.

Experiment 3 (heavy kaolinite concentrations)

There is a trend in the means that was aesthetic in the reduction of biomass with an increase in kaolinite, and it is tempting to draw significance, however, ANOVA is very clear that there was no significant difference.

This lack of significant difference was unexpected, plants grown in bulb fibre generally do well, at least with in the first few weeks, it was predicted that the biomass in the 0% kaolinite would be significantly greater, in particular than the 50% and 100%. Being in small 50ml pots the plants were very vulnerable to water stress, and did wilt on two occasions. This may have been enough to have reduced plant growth. Further work will need to be carried out in order to more fully understand these results.

Never-the-less the results uphold the hypothesis, showing that there was no benefit to using high concentrations of kaolinite. When dry the higher concentrations (in particular the 100% treatment) became very dense and water pooled on the surface rather than infiltrating the substrate.

Experiment 4 (discovering the optimum kaolinite concentration)

Experiment 4 was affected by caterpillar damage. The results for dried root biomass in Experiment 4.0 included the 0% treatment with the 10% and 20% treatments. Why the 5% treatment was significantly smaller than these three treatments is not evident, it is possible that running the experiment with more repeats might clear this issue up. Experiment 4.1 showed no significant difference between the treatments, however the plants were not stressed in the way Experiment 4.0 was, the highest temperature recorded was 26˚C, whereas Experiment 4.1 ran under a cooler regime with less evapotranspiration reducing the possibility of the substrate drying out between irrigations. The null hypothesis was upheld in the 4.1 experiment, never-the-less, the results do suggest that there are no detrimental effects to adding kaolinite to a substrate in order to protect plants from a possible drying event. A repeat of the experiment under the warmer conditions experienced during the running of Experiment 4.0 might show more significant difference in biomass production.

Experiment 5 (*Triticum aestivum*)

In hindsight this was a poorly designed experiment that tested the limits of the researcher’s abilities to collect data – until the mid-trial harvest there were one hundred individuals to collect data from, as well as two other experiments (Experiments 4.1 and 6) running concurrently. The plants should have either been planted in larger pots or individually in the 50ml pots so that root data could have been collected, other workers have used 1 litre pots or larger for a single plant (Evans, 1983; Keeling, McCallum and Beckwith, 2003; Miransari *et al.*, 2008).

Unlike the *Brassica juncea* the leaf heights seemed to diverge and converge over time. The greater difference seen in plant height in different treatments at the beginning is unlikely to have any significance, since they were all seedlings grown and selected from seed trays. Perhaps unconscious selection by the researcher had some effect, but it seems unlikely and inconsequential.

All the plants showed a reduction over time of height, which might be explained by temperature and light changes, or by increased resource shortage. There was a slight increase in plant height at the end, environmental data showed a slight increase in warmth, however this might also be researcher error, the final data was collected after the plants were cut from the pot, at the time it was considered that this would not affect data collection. There appeared to be a slight trend that the plants grown in 5% and 10% kaolinite treatments were slightly larger, but not significantly.

The null hypothesis was upheld, though as with previous experiments there was relevance in the fact that there was also no negative effect to the addition of kaolinite.

Experiment 6 (re-vegetation in arid climate simulation)

The hypothesis that adding kaolinite to the peat-based substrate would decrease the vulnerability of plants to drought was clearly not proved, despite earlier findings. This goes against the findings of researchers working with kaolinite in soils, such as McKissock, Gilkes and Walker (2002) and Lichner *et al.* (2006), also Michel (2009) found that 2:1 clay increased wettability. Although there was no significant data, as with other experiments in this study there seems to be a trend where plants grown with kaolinite (in particular 10% or 20%) have slightly higher means than those grown without. Therefore it would be worth repeating the experiment in the summer months where the plants could be more easily stressed with water and heat. It was unfortunate that the experiment was run during cold months with little evapotranspiration.

While only Experiments 1 and 2 upheld their hypotheses, the results show that in substrate with organic matter, such as bulb fibre or a bark-based substrate, kaolinite does not negatively affect growth. The positive results of the first two experiments suggest that further investigation into kaolinite as a way to reduce the effects of hydrophobicity would be worth while.

4.0 Discussion

In what appears to be, from reviewing the literature, the first study of its kind, this work sought to investigate a possible relationship between the addition of kaolinite to a peat-based potting compost and increased growth of biomass in the plants grown in that substrate.

Experiment 1 showed a significant positive result in the *Brassica juncea* grown in the bulb fibre substrate, but these results were not repeated in the subsequent growing experiments with the same potting media, although the 10% kaolinite concentration frequently had the greatest means (see Figures 4.1 – 4.4). Despite finding insignificant values in all but the first growing experiment, the results do show that the addition of kaolinite does not detrimentally affect the growth of plants in peat-based media to a significant degree.

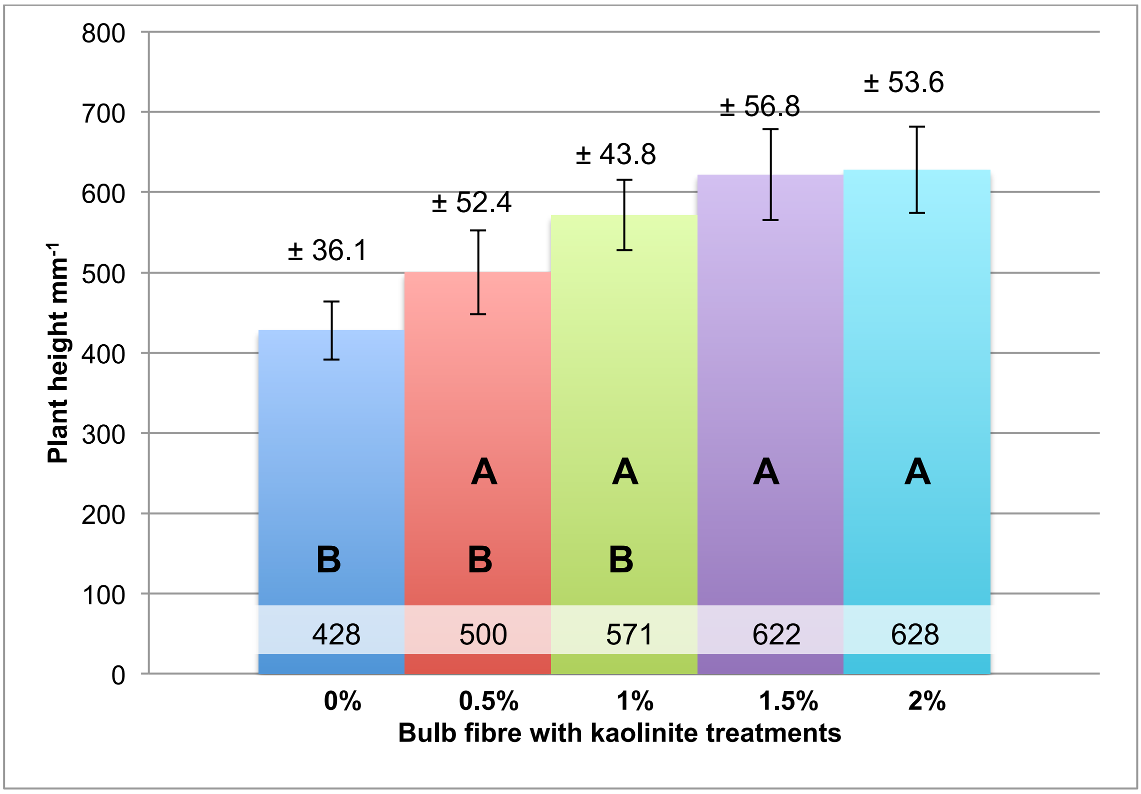


Figure 4.1 Plant heights of *Brassica juncea* grown in peat-based bulb fibre substrate with five treatments of kaolinite (Experiment 2). Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars), P >0.05. LSD groupings are indicated by letters, means that do not share a letter are significantly different.

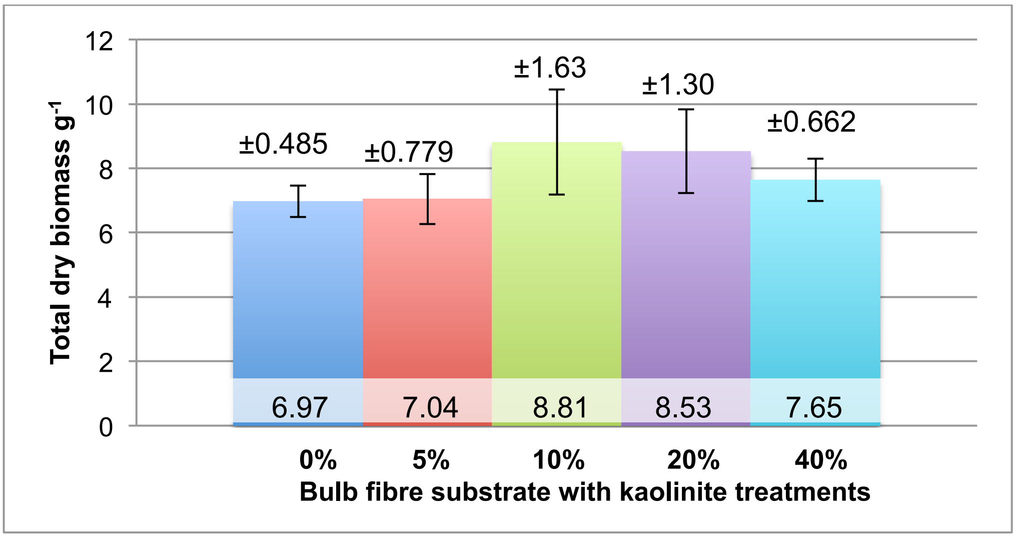


Figure 4.2 Experiment 4.1 - the total dried biomass of *Brassica* juncea grown in peat-based bulb fibre with kaolinite treatments added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the bars), P >0.05.

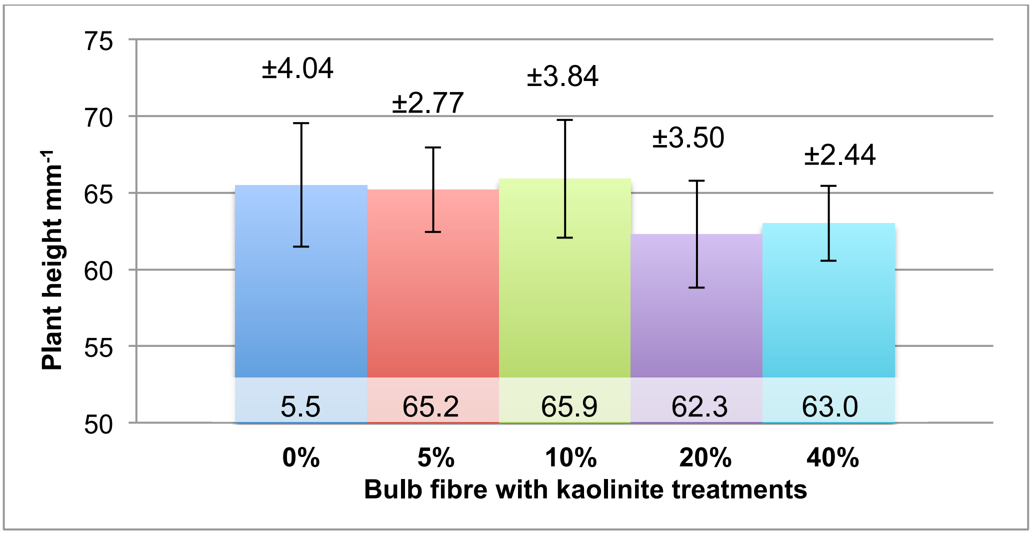


Figure 4.3 Experiment 5 plant height results (full-term destructive harvest) of *Triticum aestivum* grown in peat-based bulb fibre substrate with kaolinite treatments added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the the bars), P >0.05.

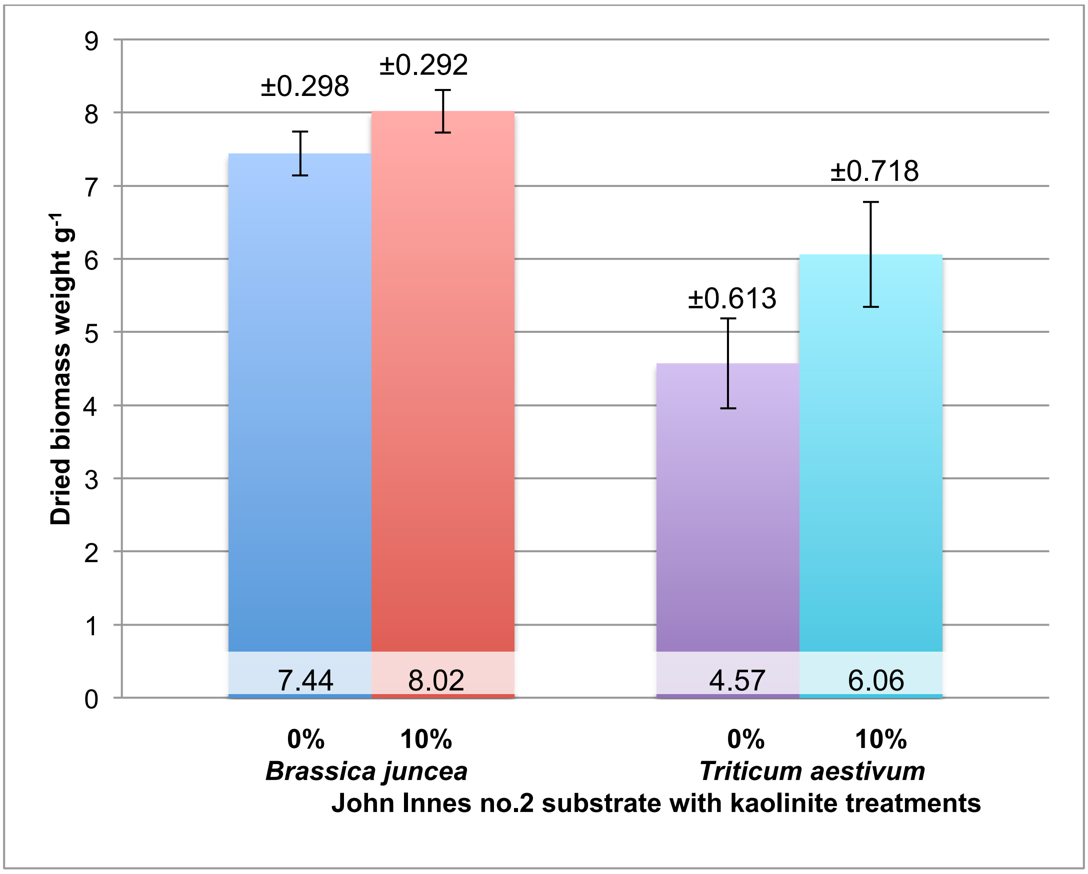


Figure 4.4 Experiment 6 total dried biomass results of *Brassica juncea* and *Triticum aestivum* grown in peat-based bulb fibre with kaolinite treatments added by percentage weight. Mean values are shown in the boxes at the bottom of the bars, rounded to three significant figures. (n = 3) ± 1 Standard Error (SE values are shown above the the bars), P >0.05.

The experiments performed in the laboratory showed that the presence of kaolinite counteracted the natural hydrophobicity of the dried substrates tested, the work of Lin *et al.* (2006), among other researchers, have shown that there is a link between organic matter and hydrophobicity. The results suggest that the mechanism is not simply a reduction of organic content in the samples as the kaolinite concentrations increased, since capillary rise results showed a bell curve, with greatest movement against gravity at 10% for bulb fibre (Figure 2.1.7) although the results were less clear with the peat, the peak mean being

20% and lowering at 40%, but not significantly (Figures 2.2.6 and 2.2.7). In the glasshouse when the plants were most stressed by heat and lack of water – in particular during Experiment 1 – the plants in kaolinite and the bulb fibre substrate did perform better, although not always significantly. *Triticum aestivum* was used to investigate how an alternate species would respond to the presence of kaolinite. Again, the results from Experiments 5 and 6 (Sections 3.5 and 3.6) offered no significant results, despite the means suggesting 6an increased growth in the 10% treatment in the better designed Experiment 6, which specifically investigated water stress.

The WDPT tests suggested that continued increase in kaolinite concentration would increase the speed of water infiltration, at least to 40% concentration (which had a faster rate than 100% kaolinite). However in the capillary rise experiments the 10% kaolinite concentration showed the highest mean for the bulb fibre (P <0.0001), for the peat there was no difference between the 10%, 20% and 40% treatments, but significant difference (P <0.05) between those and the 0% and 5% treatments. The Watering Lane mix, at a value of 10% (10:1 ratio) also showed a significant and positive difference from the 0g treatment. The growing experiments, while not showing significant results suggested that the plants would not thrive in a heavy kaolinite presence (Section 3.3 – Experiment 3). It can therefore be tentatively suggested that for peat-based potting composts a 10% addition of kaolinite would be the optimum treatment.

However until testing can be performed with repeatable significant results this can only offer limited confidence. When considering the high organic content of peat-based potting composts such as bulb fibre (75.2%, Table 2.1.6) and peat (88.3%, Table 2.2.4) this addition is in line with the advice offered to farmers by the Australian government, who suggest that for soils with organic carbon above 1% an addition of 5 – 7% kaolin rich soil (typically 30 – 40% kaolinite) is needed to overcome hydrophobicity (Government of Western Australia, 2017).

One of the tasks in this study was to isolate the cause of improved growth with kaolinite treatments. Of the possible causes considered in Section 1.2 (texture, pH, biofilms, heat exchange, water repellency), pH has been shown to cause little alteration to the substrates, with only the bulb fibre showing a significant difference in two of the treatments (all values were still between pH 5.09 and 5.37).

According to the research of Richards, Lane and Beardsell (1986, abstract) increased plant growth can be obtained by altering the particle density of bark-based substrate to make it denser (by removing particles greater than 2mm and introducing mineral additions). With this in mind, if the changes to the texture were the cause of the increased biomass then it could reasonably be expected that the addition of kaolinite to the Watering Lane mix, having an open texture (Melcourt Industries, n.d.), would have shown significant increased growth in Experiment 1 by making the substrate mix more dense (Figure 2.3.1 shows that adding kaolinite reduced the number of larger particles present) but in fact no significant difference between the two treatments, or a reduction in growth was found (Chapter 3.1).

Biofilms begin to form within 15 minutes of bacteria cells making contact with a surface, when the production of alginate is upregulated (Stoodley *et al.*, 2002), therefore it is likely that biofilms would have formed in the substrates tested in Experiment 1. If the strengthening of biofilms was the cause of the improved growth then it would be reasonable to assume that all the substrates would have shown improved growth in Experiment 1 (Section 2.1), which was not the case.

Only heat exchange and water repellency then remain as possible causes of the effects of kaolinite on plant growth evidenced in the first two growing experiments. The suite of experiments performed in the current work did not allow these two possibilities to be separated, further tests would be needed. Never-the-less, the wettability tests performed (capillary rise and WDPT tests) clearly showed that kaolinite reduced hydrophobicity, as was predicted following previous soil research (e.g. Mataix-Solera *et al.* 2008; Cann, 2000; McKissock, Gilkes and Walker, 2002).

The function appears to be mechanical, either allowing water to move more freely through the soil matrix, or, as suggested by Dlapa *et al.* (2004; also McKissock, Gilkes and Walker, 2002) by spreading out over the particles or humic acid crystals and creating a hydrophilic barrier between the water and the hydrophobic elements of the media.

It has been suggested that for kaolinite to effectively reduce hydrophobicity it needs to go through a wetting/drying cycle (Ward and Oades, 1993, abstract; McKissock, Gilkes and Walker, 2002) – this was not found to be the case in this study, possibly due to the method of mixing and the substrate type. Manual mixing in the light organic media allowed thorough integration, whereas mixing kaolin clay evenly into soil is far more difficult to accomplish.

This behaviour of increased biomass production in *Brassica juncea* was not observed in the other substrates tested in Experiment 1 (Section 3.1). In the physical testing (Section 2.3) the John Innes no.2 proved to overcome hydrophobicity quickly even without the kaolinite (Table 2.3.9), but the Watering Lane mix was hydrophobic, as shown in the laboratory work and in the literature (Warren and Bilderback, 2005; Olszewski, Danan and Boerth, 2008) and yet did not show significant increased growth with the mineral added despite, at a ratio of 10:1, the addition being 10%. The structure, here, may be very important. As seen in the particle distribution (Figure 2.3.1) bark has a very open structure (Melcourt Industries, n.d.), that a fine mineral such as kaolinite could be either washed through or unevenly distributed by water during irrigation. It was not possible to test accurately for turbidity, to see if more kaolinite was lost in the Watering Lane mix.

Because of the inconsistencies in most of the growing experiments, work is required to develop experiments with repeatable results, however there are reasons to accept that kaolinite would be a useful addition to potting substrates. The capillary rise and water drop penetration time tests clearly show a reduction in water repellency with the increased addition of the mineral, a result that was in line with previous research, as already noted. Experiment 1 showed a significant growth and biomass increase in the *Brassica juncea* when grown in the bulb fibre with the kaolinite added, and Experiment 2, while offering no significant results, did show a regular increase in the mean results of dried biomass as kaolinite concentration was increased to 2% (Figure 4.1). It is therefore suggested that kaolinite could be a useful addition to peat-based potting composts to protect plants from water stress, both before and after a plant is purchased by a member of the public, or planted in revegetation schemes in arid and semi-arid areas.

5.0 Conclusion

This research set out to investigate the possibility that adding kaolinite to growing media would improve plant growth, and if so to find out how. In doing so there was also the intention of making a practical contribution to science, industry and the preservation of soils through the prevention of erosion.

In this work experiments have shown that the addition of kaolinite will reduce hydrophobicity in the potting substrates tested, those substrates representing three major types of commercial growing media – peat-based (bulb fibre), bark/wood based (Melcourt's Watering Lane nursery mix), and mineral based (John Innes no.2). It has also shown, in one experiment, that it can significantly improve the growth of *Brassica juncea* when grown in a peat-based substrate, and in most of the growing experiments that it will not negatively affect the growth of *B. juncea* or *Triticum aestivum*. Although a lot of the results were not significant, further study is justified considering the results of Experiments 1 and 2 as well as the flaws in the late experiments that could be improved upon, including the seasons the experiments were run in. Improved experiment design could attain repeatable results to find the optimum concentration of the mineral, tentatively put forward here as being 10%. A repeat of the final experiment (Section 3.6) under hotter conditions to achieve several drying cycles might also show useful results.

The study of hydrophobicity has, understandably, been focused on the existence, causes and ways to treat the phenomenon in soils. Very little work has been undertaken on potting substrates (Gautam and Ashwath, 2012). Equally, while some researchers have identified kaolin as a factor in reducing hydrophobicity (e.g. Cann, 2000; Mataix-Solera *et al.*, 2008) no work appears to have specifically looked at the use of kaolinite to overcome the identified issue of wettability in organic substrate (Kukkonen and Vestberg, 2007; Edwards, 2017). Michel (2009) looked at one clay and found significant positive results, but that clay was 65% smectite and 25% illite – both having a 2:1 structure, with only 8% kaolinite. This study has shown, as laid out in the Discussion (Chapter 4.0), that it is not always necessary to put a potting substrate through a wetting/drying cycle to achieve full effectiveness of kaolinite (Ward and Oades, 1993, abstract; McKissock, Gilkes and Walker, 2002).

Commercial nurseries are aware of the problems with hydrophobicity (Edwards, 2017) and take steps to ensure there is rarely a problem. However when plants are sent to stores that are often not prepared for live plants, without trained staff to care for them, such as supermarkets and discount stores then stock is often lost. Plants are often regularly forgotten about until they are wilting at which point an attempt may be made at watering only to find that the water runs straight through and plants are generally discarded (Hicken, 2017; Thompson, 2017). The addition of kaolinite could, according to the results of this study - in particular the capillary rise and WDPT tests - improve the longevity of a plant under such conditions and prevent their loss.

Further study could include collaborations with potting compost manufacturers, nurseries and supermarkets to investigate the viability of using kaolinite to prolong the shelf life of plants, in particular assessing the cost/loss ratio.

In the work to prevent further erosion by undertaking revegetation schemes losses are noted in both matured plants (Gautam and Ashwath, 2012) and seeds (Muños-Rojas *et al.*, 2017) due to arid environments, in particular Gautam and Ashwath (2012) point out that the substrate the plants are raised in dry out and become water repellent before the rains come. Trialing a revegetation scheme using kaolinite as an addition to the potting substrate used might reveal interesting results that could potentially improve the success rate of these efforts, allowing the plants and seeds to take advantage of any moisture whenever it should come.

APPENDICES

Appendix 1: Hydrophobicity – a review of the literature

Appendix 2: Referenced email correspondence

Appendix 3: Raw data from the laboratory experiments

Appendix 4: Raw data from the growing experiments

Appendix 1 Hydrophobicity

Hydrophobicity - soil water repellency - is defined as the condition when a drop of water does not immediately infiltrate the substrate (Doerr, Shakesby and Walsh, 2000).

In reality all solid surfaces attract water (van Oss and Giesse, 1995), some simply attract water more than others. Practically, however, if a surface such as a growing substrate, allows a drop of water to bead for more than a few seconds it is considered hydrophobic to one degree or another and in extremis, water may evaporate before being taken up by the substrate (Hallett, 2007). It is now accepted that most soils exhibit hydrophobic behaviour when dry (Doerr *et al.*, 2009; Vogelmann *et al.*, 2013), as do most artificial organic growing media (Michel *et al.*, 2001; Blodgett *et al.*, 1993). Hydrophilic substrate allow water to spread across the surface and be quickly taken up (Woche *et al.*,2005).

Hydrophobicity leads to poor root structure and plant growth (Cisar *et al.*, 2000; Naasz, Michel and Charpentier 2008; Gautam and Ashwath 2012) since water cannot be made available to the plants. Under hydrophobic conditions water does not easily get taken up by the substrate, nor is it readily retained since it can often display preferential flow where water moves down paths of least resistance (often due to larger porosity). ‘Fingers’ of moisture – also referred to as ‘fingered flow’ - move downwards in the substrate column, away from the root structures, and potentially contaminating the water table with solutes while leaving most of the substrate dry (Ritsema *et al.*, 1998; Dekker *et al.*, 2000; Doerr *et al.*, 2000; Ferreira *et al.* 2000; Naasz, Michel and Charpentier, 2008). Ritsema *et al.* (1993, cited by Ferreira *et al.*, 2000) found that due to preferential flow the water table was recharged quicker, albeit with solutes that might otherwise have been intercepted by the soil or its biota. Hydrophobicity also leads to hysteretic behaviour, where the pattern of wetting a media does not match the pattern of rewetting (Naasz, Michel and Charpentier, 2008). Over time, due to hysteresis and the washing away of hydrophobic solutes, these fingers of wettability become established routes through the soil (Ritsema *et al.*, 1998).

Hydrophobicity in Soil

Since hydrophobicity can affect soil degradation, for better or for worse (depending on the individual circumstances), it is hardly surprising that most work on the matter of hydrophobicity has been focused on soils. The FAO (2015) have divided the planet's land mass to 12.6% for crop lands, 13% grasslands and 27.7% tree-covered areas (25% of the world's surface is uncovered by vegetation – or sparsely – due to abiotic factors), they calculated that cultivated land use per capita is only 0.2 ha in Europe, and even lower than that in less developed countries and expect this to have reduced to 0.1ha in 2050. They conclude that 33% of all land is degraded to a moderate to high degree.

Hydrophobicity has been documented around the world, from Australia (Blackwell, 2000; Cann, 2000; Franco *et al.*, 2000; Rillig, 2005) where seven million hectares are estimated to be affected or under risk (Beckett, Fourie and Toll, 2016) to Norfolk (Doerr *et al.*, 2006), but most commonly in arid areas, especially Mediterranean Biomes. In fact the only continent where it hasn't been reported is in Antarctica (Jordán *et al.* 2013; Natural Environment Research

Council and British Antarctic Survey, 2017) however most of the surface of the Antarctic is covered with regolith, rather than true soil, and no soil repellency has been observed by researchers in the outlying islands where ‘brown soil’ can be found (Conway, 2017). It has been reported in many soil types, with differing amounts of organic matter, at different climate temperature levels, different agricultural systems (or none), wildfire affected and non-affected areas, texture, aggregation, chemical composition, pollution, pH, clay content, microorganism content and mycorrhizal content (Jordán *et al.* 2013). Panina (2010) perhaps puts it most succinctly: ‘Water repellency is an unstable and non-predictable property of the soil’.

In soils hydrophobicity can lead to reduced moisture up take caused by greater run-off (Imeson *et al.*,1992; Badía *et al.*, 2013; Jeyakumar *et al.*, 2014), less soil water storage (Badía *et al.*, 2013; Panina, 2010), erosion (Osborn *et al.*, 1964; Badía *et al.*, 2013; Chau *et al.*, 2014), poor seed germination (Moody and Schlossberg, 2010), reduced plant growth (Doerr *et al.*, 1996; Naasz *et al.*, 2007; Panina, 2010; Gautam and Ashwath, 2012), patchy plant growth (DeBano, 1981; Panina, 2010; Lozano *et al.*, 2013), increased erosion through run-off and rain-splash detachment (Doerr *et al.*, 1996; Jeyakumar *et al.*, 2014), chemical treatments and other solutes are removed from the surface quickly (Vogelmann *et al.*, 2010; Jeyakumar, 2014) and pollute the water table through preferential flow (Chau *et al.*, 2014).

On a more positive note it can cause water to move more quickly beneath the surface through preferential flow and so reduce evaporation from the soil by preventing upward movement of moisture via capillary action (Imeson *et al.*, 1992; Rye and Smetton, 2017). Aggregation influences water and air movement in the soil structure, as well as soil biota and plant growth (Denef and Six, 2005), and hydrophobicity can improve their stability (Piccolo and Mbagwu, 1999; Mataix-Solera and Doerr, 2004) although Roy and McGill (1998) disagree (except at the level of microaggregates), as well as carbon sequestration (Piccolo and Mbagwu, 1999). In their 2017 abstract, Zheng *et al.* suggested that water repellent soils can be used to stabilise slopes, although Beckett, Fourie and Toll, in their 2016 conference presentation, suggested that hydrophobic soils have a lower sheer strength and would therefore decrease slope stability.

The causes, such as organic matter, plant exudates and fire events, are far more diverse and harder to isolate. Hydrophobicity in soils can be caused by anthropogenic pollution (Roy and McGill, 1997; Chau *et al.*, 2014), organic matter (Jordán *et al.*, 2009; Martínez-Zavala and Jordán-López, 2009; Badía *et al.*, 2013; Mirbabaei *et al.*, 2013), such as plant exudates and debris containing mucilage (Zickenrott *et al.*, 2016) or plant oils and waxes (Doerr *et al.*, 1996; Doerr *et al.*, 2000; Ferreira *et al.*, 2000), through burning (Mataix-Solera *et al.*, 2008), substrate texture (Doerr *et al.*, 1981; Badía *et al.*, 2013; Mirbabaei *et al.*, 2013), clay presence (Badía *et al.*, 2013), pH (Hurraß and Schaumann, 2006); microorganism activity (Roy and McGill, 1998) or land use (Doerr *et al.*, 2006).

The particle distribution of soils has long been thought of as being one of the main causes of soil water repellency, with coarser (sandier) soils being considered more hydrophobic (De Bano, 1981, Panina, 2010; Zontek and Kostka, 2012). However, as research continues it has become apparent that this is not necessarily the case (Doerr *et al.*, 2000; Vogelmann *et al.*, 2010;

Badía *et al.*, 2013). Inorganic particles have a low surface tension (Woche *et al.*, 2005) but are easily coated by organic materials because their smooth surfaces give them a lower specific surface area compared to other particles (Wallis and Horne, 1992, cited by Panina, 2010; Robichaud and Hungerford, 2000). Zisman (1964, cited by Moody and Schlossberg, 2010) point out that while mineral surfaces usually exhibit hydrophilia, solid organic particles display free energy at the boundaries shared with water and are hydrophobic, when these organic particles coat the larger particles of sand, they render those grains hydrophobic.

Mataix-Solera and Doerr (2004, also Arcenegui *et al*., 2007) postulated that the hydrophobic material they found in the smallest fractions of their samples (even from samples otherwise found to be hydrophilic) were due to fine hydrophobic materials rather than coated particles, this was the case no matter whether the samples came from a site that was burnt or unburned, yet one would expect fewer organic compounds in a burnt site where presumably most organic matter, in particular oils and waxes, had been destroyed. Arcenegui *et al.* (2007) sieved their soil samples after subjecting them to burning and found that even in the hydrophilic *terra rosa* soils from Spain the finest fraction was always the most hydrophobic. Clearly this doesn’t match with the more common understanding that the larger sand particles being more hydrophobic, but perhaps the burning is the antagonist, with volatile organic compounds not being destroyed but condensing around the smaller particles after being temporarily volatilised. Mataix-Solera and Doerr (2004) postulated that the hydrophobia of the finest fraction – which is important for nutrient exchange – may be the cause of the slow recovery from burning that has been noted in their region of Spain (citing Abad *et al*., 1996), so that even though the site as a whole might be hydrophilic, it may still suffer from low cation exchange.

It is also possible that the aggregate size influences soil water repellency, as suggested by Vogelmann *et al.* (2010), they cite Jasínska *et al.* (2006) who showed that hydrophobicity is usually apparent on the surface rather than inside aggregates and concluded that the soil clay minerals play an important role in this, kaolinite has certainly been found to be influential in the formation of macroaggregates (Denef and Six, 2005). Eynard *et al.* (2006), looking at grassland on clay-rich (smectite clay, which is high in CECs with a tendency to clump together) soils, found that wettability in aggregates (made more stable by the presence of hydrophilic polysaccharides) was positively correlated with organic carbon content. They state that some of the hydrophobicity witnessed was due to changes in the aggregates caused by water infiltration, and cited Podwojewski *et al.* (2002), who showed that over-grazing in the Andes decreased aggregate size and consequently wettability.

Blankinship *et al.* (2016) found that aggregate stability was dependent on the action of microorganisms. From what is known of soil biofilms (ref.), it seems likely that it would be these alginate-based microenvironments that enable microorganisms to affect aggregate size. Tadayonnejad, Mosaddeghi and Dashtaki (2017) suggested that hydrophobic organic compounds would coat aggregates and not absorb into them, however Bisdom, Dekker and Schoute (1993) considered it more likely that it was the interstitial fine matter (combinations of silt, clay, organic matter and other substances which acts as the cement for the aggregates) that causes the hydrophobic behaviour. To check their hypothesis they washed these fines away and found that wettability improved, they also treated fresh samples with hydrogen peroxide to destroy all organic matter and aggregates, and found that, yet again, wettability was restored. From this they concluded that organic material was the chief cause of hydrophobicity, but not due to coatings around other particles.

Many studies have found a correlation between hydrophobicity and organic content. Imeson *et al.* (1992) found that in their sites water repellent material was mostly found in the organic layer – the plant debris from the forests above, as well at the top 5 – 15cm of the mineral soil below it. Mirbabaei *et al.* (2013) found the greatest degrees of hydrophobicity in sandy soils with organic matter present between 5% and 12%, but across all the samples there was a positive correlation between organic matter content and hydrophobicity (also found in Spanish calcareous soils by Mataix-Solera and Doerr, 2004), they concluded that water repellence was not caused solely because of the high sand fraction, but because of the presence of organic substances with hydrophobic behaviour. This agrees with several other researchers (Robinson, 1999; Eynard *et al.*, 2006; Jordán *et al.*, 2009; Martínez-Zavala and Jordán-López, 2009), but not with Harper *et al.* (2000), Dekker and Ritsema (1994, cited by Mirbabaei *et al.*, 2013) or Ritsema and Dekker (1994, cited by Mirbabaei *et al.*, 2013).

Humic substances are broadly divided into three main categories based on their solubility under different pH: humin, humic acid and fulvic acid, with most investigations focusing on the acids for ease of use (Pettit, n.d.; Lin *et al.*, 2006). They are all hydrophobic (Lin *et al.*, 2006) with humic acid proved hydrophobic at the atomic level (Cheng *et al.*, 2009). Humic acid has a tendency to aggregate on glass surfaces rather than spreading across it, creating an uneven spread of weak capillary formation, hydrophobic soil was found to achieve similar results (Cheng *et al.*, 2009). Kaolin, which is generally hydrophilic, can be rendered hydrophobic, simply by forcing adsorbtion of humic acid at a high pH (Chen *et al.*, 2017).

Using a SEM Roy and McGills (1998) were unable to observe organic coatings around particles, but attributed this to the patchiness of the polluting crude oil they were investigating. In their search for a quicker and cheaper method for assessing hydrophobicity by using near infra-red spectroscopy, Knadel *et al.* (2016) outlined in their abstract that they found a connection between water repellency and organic matter, but not between water repellency and total organic carbon, this agrees with the findings of an international study looking at soils from many different countries (Doerr *et al.*, 2005) where organic compounds associated with hydrophobicity were extracted using alcohols. The extractions rendered 13 of 15 samples hydrophilic, however these extractions, including controls from non-hydrophobic soils were then added to wettable sand, and all samples rendered the sand non-wetting, suggesting that the presence or absence of one or more compounds is not enough to predict hydrophobicity. The researchers suggested that hydration, or intermolecular arrangement may also be important (Doerr *et al.*, 2005). According to Doerr, Shakesby and Walsh (2000) by the time of their review attempts to view these hydrophobic layers by microscopic viewing have been inconclusive, and to date, this reviewer has not found anything either.

Several researchers have concluded that the amount of organic matter is not as important as the composition (Mataix-Solera *et al*., 2007; Vogelmann *et al.*, 2010; Lozano *et al.*, 2013). Mirbabaei *et al.* (2013) cite Kaiser *et al.* (date) and Wahl *et al.* (2008) when they suggest that some of the seasonality noted in hydrophobicity is due to changes in the nature of the organic content. The species of plants growing in a sampled soil has been found by some researchers to have a direct and positive influence on the wettability of soil (Dekker *et al.*, 2000; Mirbabaei *et al.*, 2013). This could be due to plant exudates, water repellence is associated with the presence of fatty acids and short-chain hydrocarbons (Muñoz-Rojas *et al.*, 2016a). Waxes and volatile oils, from plants such as pines and eucalyptus species, are often associated with soil hydrophobicity (Lozano *et al.*, 2013; Vogelmann *et al.*, 2013).

Lozano *et al.* (2013) found the highest number of hydrophobic samples in their research came from underneath lipid-rich *Pinus halepensis* (Aleppo pine) and after investigating the lipid content of the soil suggested it was this that caused the degree of non-wettability, however, they also noted that the persistence of that repellency was greatest under *Quercus ilex* (evergreen/ holm oak) (also high in lipids), but offer no suggestion as to why that might be, however de Blas *et al.* (2010) found similar results, and simply commented that hydrophobicity was a complex emergent issue. Badía *et al.* (2013) found hydrophobicity in both pine forest and evergreen oak forests – both on alkaline soils – but the oak forest soil was only hydrophobic on the surface, they do not mention if they removed the plant litter before testing, though this is a common practice in sampling. The results of tests on ash, performed by Dlapa *et al.* (2013, cited by

Jordán *et al.* 2013) suggested that the chemistry of the ash was central to its water repellent nature.

Miller *et al.* (2017) conclude in their abstract that specific aromatic compounds (in their case found in wood chips) contributed greatly to water repellency in the clay loam soil they were studying. Horne and McIntosh (2000), on the other hand, found no clear link between hydrophobic behaviour and lipids or even organic carbon content, however, the soils were different since they were studying their native sandy soils in New Zealand. They believed that hydrophobicity was being caused by the way the amphipathic molecules were orientating (Lozano *et al.*, 2013).

Work on mucilage (a polymeric root exudate (Reeder *et al.*, 2015) exuded by *Zea mays* (Maize) has shown it to be hydrophobic once dried, and that this behaviour persisted for some time after irrigation (Ahmed *et al.*, 2016, abstract; Reeder *et al.*, 2015). The mucilage of *Lupinus albus* (Field beans), *Vicia faba* (Broad bean), *Triticum aestivum* (Wheat) (Zickenrott *et al.*, 2016) and *Salvia hispanica* (Chia) (Reeder *et al.*, 2015) have also been researched and found to exhibit hydrophobic properties, though there may be some difference in degree, perhaps depending on viscosity (Zickenrott *et al.*, 2016).

Not all workers have found this association between hydrophobicity and organic exudates, Bodí *et al.* (2009) found significance only in whether there was any plant cover or not. As with other causes of hydrophobicity, it appears that there is no clear answer, only generalities, and the behaviour, and therefore treatment of soils must be considered individually.

Mycchorizal fungi adopts a patchy habit (Young *et al.*, 2012), which is reminiscent of the patchy behaviour observed in some non-wettable soils. Some researchers have put forward arbuscular mycorrhizal fungi as a cause of hydrophobic soils (Lin *et al.*, 2006; Mataix-Solera *et al.*, 2006; Rillig *et al.*, 2010; Young *et al.*, 2012), in a study of golf greens, York and Canaway (2000) noted the similarity of non-wettable spots to 'fairy rings' caused by basidiomycete fungi. Young *et al.* (2012), investigating fungal-caused hydrophobicity at Rothampsted Research Station, found a significant positive correlation between fungal presence and hydrophobicity, although they made it clear that their method of testing was not very accurate, and they may have inadvertently measured non-fungal proteins as well, Rillig *et al.* (2005) also highlighted this problem. Fungal growth has been shown to increase in the presence of added nitrogen, and to a lesser extent added nitrogen and potassium, and yet not when a balanced NPK fertiliser (nitrogen, potassium and phosphorus) was added (Young *et al.*, 2012).

Hydrophobicity will continue sometimes even after the fungi cease to colonise an area (York and Canaway, 2000). Lin *et al.* (2006) looked at the relationship between the hydrophobicity noted in Taiwanese coastal windbreaks of *Casuarina equisetifolia* and fungi; all their fungal isolates proved to be hydrophobic, but some (two in particular) showed hydrophobic metabolites as well. Curiously Dorostkar *et al.* (2015) found that the fungi they studied did not show non-wetting capabilities if grown in isolation.

Hallett and Young (1999) noted an increase in fungal activity on the surface of aggregates, however it is unclear whether they distinguish between fungal activity and microbial activity, not all researchers do, but arbuscular mycchorizal fungi can cause hydrophobicity and aggregation alone (Rillig *et al.*, 2010). Lozano *et al.* (2013) looked for a causal link as they investigated S.E. Spanish soils, using several different processes, but found none, although they only investigated the top 1cm of the surface. They suggested that the link between fungal activity and water repellency is indirect, and that any increased presence was due to the plant species present (the plant species being the direct cause of hydrophobicity).

In 1991 a new class of fungal proteins were identified called Hydrophobins (Rillig, 2005), which appear to have universal occurrence. Hydrophobins appear to have a property similar to humic substances, in that they are hydrophilic in a moist environment, but become hydrophobic in a dry one, their crystalline structure alters between the two conditions (Rillig, 2005).

In a study investigating soil water repellency after a prescribed fire in Australia (Muñoz-Rojas *et al.*, 2016b) it was noted that microbial biomass increased with the release of nutrients into the soil, and the researchers suggested that this was a likely contributing factor to the loss of hydrophobicity observed. Bárcenas *et al.* (2011) found that while microbial activity increased in the Mediterranean forest they were studying after a fire, the fungal mass decreased and was slow to recover. A follow up study by Muños-Rojas *et al.* (2017) confirmed a strong correlation between soil hydrophobicity and microbial activity, as well as pH and electrical conductivity.

Hallett and Young (1999) looked at soils from two Scottish sites (both with organic content of >5%) and found that the soils became hydrophobic with the addition of nitrogen fertiliser, they noted that the biological activity of the microorganisms increased with the addition, and considered that it was their activity that produced hydrophobic materials, however in Australia Franco *et al.* (2000) found that microbial activity was only a small, but admittedly important, aspect of the hydrophobic wax component. Perhaps the microorganisms encourage fungal presence with their nitrogen-rich byproducts, which causes the hydrophobicity. Roy and McGill (1998) found no links to nitrogen presence in their investigation into hydrophobic soils in Alberta, Canada, however they were focusing on soils polluted by crude oil. They found hydrophobic bacteria present in non-wettable soils, although overall bacterial diversity was found to be as high as in wettable soils.

pH has been put forward as a possible cause of hydrophobicity (Mataix-Solera *et al.*, 2006), Bodí *et al.* (2013) discuss the work of Mataix-Solera *et al.* (2008) on *terra rossa* soils, looking at the higher pH of the calcareous soils leading to a lower incidence of soil water repellency, however they ignore the researchers' own conclusions that it was the presence of kaolin in the soil that caused the lack of hydrophobicity. Never-the-less there does seem to be less occurrence of hydrophobicity in alkaline soils, and liming acidic soil to raise the pH has been shown to reduce water repellency (Gerke *et al.*, 2001). Mataix-Solera and Doerr (2004) postulated that humic acids causing the hydrophobic effect were dissolved in the alkaline environment (an idea put forward by Arcenegui *et al.* (2007) as well), or that fungal causes of hydrophobicity were fewer since the mycorrhizae prefer a more acidic environment.

Karnok *et al.* (1993) found that treating a soil of 85% sand and 15% peat with the alkaline sodium hydroxide removed all traces of humic acid, and therefore hydrophobicity, after a number of treatments. They concluded that the alkaline was neutralising the humic acid, and so it seems likely, when looking at the evidence, that it isn’t the pH that’s important in hydrophobicity, but the presence of humic acid, a supposition supported by the work of Lozano *et al.* (2013). However the Karnok *et al.* (1993) experiment was flawed, since their sample site where only water was added also showed a similar lowering in hydrophobicity in their first study, but while (for their second study) their comparative sites were treated nine days consecutively, the water-only sites were treated only two days consecutively. Contrary to the supposition that the low pH of a substrate is a by-product of the cause of hydrophobicity, Mataix-Solera *et al.* (2006) suggested that pH could be directly affecting wettability by altering surface charge. However other researchers have found that pH may have a correlation, but not causality (Roy and McGill, 1998; Muñoz-Rojas *et al.*, 2016a) and Mirbabaei *et al*. (2013) found no clarity on the matter one way or the other.

It is widely acknowledged that burning can trigger water repellency (e.g. Roy and McGill, 1997; Tessler *et al.*, 2008; Zavala *et al.*, 2009; Robichaud, 2016), indeed the United States Department of Agriculture (USDA) uses the presence and degree of hydrophobicity as an indicator of fire severity (Natural Resources Conservation Service/ United States Department of Agriculture, n.d.). The work of Doerr *et al.* (1996) contradicts this, finding, as they did, no change in the already hydrophobic soils under *Eucalyptus globulus* (tasmanian bluegum) and *Pinus pinaster* (maritime pine) forests; the lead researcher went on to show that soils under conifer forests in temperate regions could display non-wetting habits without fire (Doerr *et al.*, 2009b), in fact only 25% of their 81 sites showed hydrophilic behaviour. This research was performed on the soil once the surface organic matter had been removed, both *in situ* and air-dried in the lab.

Hydrophobicity through fire is thought to be triggered or increased through one or more of several mechanisms, as laid out by Doerr *et al.* (2006): 1) organic compounds in the leaf litter are volatilised on the surface and condense around soil particles (DeBano and Krammes, 1966; Arcenegui *et al.*, 2007), 2) organic compounds are polymerised, becoming more hydrophobic in the process (Giovanni and Lucchesi, 1983, cited by Doerr *et al.*, 2006), 3) hydrophobic compounds already present in the soil are bound even tighter to the particles (Savage, 1974, cited by Doerr *et al.*, 2006), or 4) waxes present in soil organic matter are melted and redistributed (Franco *et al.*, 2000).

Some evidence suggests that hydrophobicity is triggered in weak or non-repellent soils (DeBano, 2000a; Tessler *et al.*, 2008; Zavala *et al.*, 2009) and reduced in repellent ones (Doerr *et al.*, 2006). Doerr *et al.* (2000a) states that while burning sometimes caused hydrophobicity it was not always a certainty, and that there was something else at work, DeBano (1991, cited by Doerr *et al.*, 2006) suggested that any soil with 2 – 3% organic matter would have hydrophobicity induced under fire conditions and the work of Arcenegui *et al.* (2007) agrees with this, finding that plant species high in volatile organic compounds (VOCs) is more likely to induce repellency than a plant that is not, temporarily induced repellency has been found to be lost at five cm depth, and begin to dissipate after six weeks. Savage (1974) outlines in his abstract his experiment where he burned litter over columns of sand then immediately removed the litter layer from one column but waited until the other had cooled before removing the layer, it was this second layer that exhibited hydrophobic behaviour, this suggests that the hydrophobic organic molecules from vegetation are translocated beneath the soil surface during a burning event (Doerr *et al.*, 2009a), further, the amount of litter present before burning was found by Arcenegui *et al.* (2007) to have a direct relation to the degree of hydrophobicity exhibited afterwards.

However Doerr *et al.* (2006) found that repellence could be lost in previously highly hydrophobic, sandstone-based Eucalyptus forest soils (in Australia) if the temperature of the burn was high enough, several research groups (Robichaud, 2000; Robichaud and Hungerford, 2000; Doerr *et al.*, 2006; Arcenegui *et al.*, 2007) have confirmed this temperature to be between 250˚C and 400˚C. DeBano and Krammes (1966) subjected already hydrophobic mountain soil (San Gabriel Mountains, U.S.A., under mixed chaparrel brush) to a range of temperatures from five to twenty minutes, and found that the highest temperatures (800˚F/427˚C and 900˚F/482˚C) eliminated hydrophobicity entirely, while lower temperatures (100˚F/38˚C – 300˚F/149˚C) increased the severity. Robichaud and Hungerford (2000) noted that most experimenters burned their samples in ovens – which is not what happens in forest fires - and heated theirs from above on dry and moist samples. They found that originally dry samples displayed more hydrophobicity than the wet, and the most hydrophobic behaviour was from the dry samples that were heated to a lower temperature (100˚C – 150˚C).

It can take more than two years to restore natural water repellency (Giovannini and Lucchesi (abstract),1983; Doerr *et al.*, 2006), which is cause for concern since the ecosystem is evolved for a water repellent soil there was a chance that the increased hydrophilic behaviour could lead to the loss of top soil under heavy storm conditions. This research calls into question the conclusions of Robichaud (2000) when he investigated the effects of rainfall on soils in the Rocky Mountains (U.S.A.) after a prescribed fire, he assumed that because there was significant erosion the soils must have been rendered hydrophobic, without directly testing the burnt soils. Mataix-Solera *et al.* (2013, cited by Jordán *et al.*, 2013) found that fire temperature had less to do with water-repellency and concluded that the soil properties were a significant factor in explaining why some soils became hydrophobic under fire conditions and others didn't, for example macropores caused by roots and animals can increase water infiltration even in a burned landscape (Imeson *et al.*, 1992).

When Mataix-Solera *et al.* (2008) investigated *terra rossa* soils in Spain, they found that some exhibited hydrophobicity after a fire event while others didn't. The difference was the clay content - soils with a higher kaolin content were more wettable, Arcenegui *et al.* (2007) achieved similar results, but suggested that while it might be the kaolin, more research should be conducted into the rôle of iron oxides in counteracting hydrophobicity.

Hydrophobicity is often lost with depth (Dekker *et al.*, 2000; Doerr *et al.*, 2006; Panina, 2010; Badiá *et al.*, 2013), Wijewardana *et al.* (2016) finding SWR only in the top 20cm. However other researchers have found, especially after fire events, that a layer of hydrophobicity can establish below the soil surface from plant-sourced volatile vapours that move down through the soil until they condense again, as outlined in Letey's abstract (2001), effectively capping water movement above and below that layer (Robichaud and Hungerford, 2000). Imeson *et al.* (1992) found the same behaviour, but noted that macropores allowed water infiltration to continue through the non-wetting layer, they believed that the hydrophobic layer protected the ground from evaporation in the Mediterranean climate. While Gerke *et al.* (2001) found that hydrophobicity increased with depth, this was almost certainly, as they pointed out, due to the fact that the rehabilitated land was the site of an abandoned lignite coal mine that had been limed to the first 40cm.

Roy and McGill (1997) investigated soils contaminated over decades with crude oil in Alberta, Canada, among their findings (reported elsewhere in this review) they found that WHC was generally higher in their uncontaminated controls with one exception, which they attributed to the high percentage of organic matter. They found that oven-heating at 105°C over 24 hours slightly increased hydrophobicity, whereas over 21 days the effect was slightly decreased, but heating to 200°C for 24 hours removed hydrophobicity entirely, presumably destroying volatile fractions of the pollutant. Chau *et al.* (2014) also investigated soils in Alberta, Canada, to evaluate the role of hydrophobicity in reclamation projects in Alberta tar sands sites, which happen to be located under peat lands, given a triumvirate of hydrophobic elements – hydrocarbons, sands and peat. In their abstract, Marín-García, Adams and Hernández-Barajas (2016), outline how they found hydrophobicity in clayey soil increased with the kind of crude oil (light, medium and heavy) it was contaminated with. Gerke *et al.* (2001) investigated a German reclaimed lignin mine, the land had previously been limed and planted with *Pinus nigra* (Black Pine), their extensive work (9660 Water Drop penetration Time tests on 322 samples taken horizontally and vertically to a depth of 1.5m) found patchy hydrophobic behaviour spaced horizontally only 1 cm apart, and hydrophobicity increasing passed the depth of the lime amelioration, which they attributed to the lignite particles. Cerdá, Jordán and Doerr (2017) found that pesticide use in a Mediterranean field could trigger patchy hydrophobicity.

Hydrophobicity is often triggered by dryness (Robinson, 1999; Mataix-Solera and Doerr, 2004), counteracted by moisture – the wetter a soil/substrate is the less hydrophobic (Dekker *et al.*, 2000; Tessler *et al.*, 2008; Panina, 2010; Mirbabaei *et al.*, 2013), and re-established by hot weather (Ferreira *et al.*, 2000; Doerr, Shakesby and Walsh, 2000; Michel *et al.*, 2001; Naasz, Michel and Charpentier, 2008). Bodí *et al.*, (2013) found that it was the most common variable in devising a prediction model for water repellency. Imeson *et al.* (1992) found that infiltration of water in a test site displaying hydrophobia was increased in a second simulated rainfall event an hour after a first one, once the soil was more moist. This tendency is not universal, possibly depending on the organic compounds present in the dominant colonising plant species (Doerr *et al.*, 2009b) although Marín-García, Adams and Hernández-Barajas (2016) stated in their abstract that even their soil samples most heavily contaminated with crude oil lost the hydrophobicity evident when dry once 14.6% moisture was attained. Cycles of wetting and drying have been found to naturally reduce hydrophobicity in fine sand, less so in coarser sands, possibly due to the changes in organic molecules caused by the cycles (McKissock, Gilkes and Walker, 2002).

Mirbabaei *et al.* (2013) discovered that for their ten Iranian soil sample sites 'actual' water repellency was entirely seasonal, only manifesting in the summer, but most of their samples exhibited SWR after being heated and dried at 25ºC for several days, this work is borne out by Bodí *et al*. (2013) who found seasonal differences in Mediterranean rangelands depending on moisture availability, soil water repellency has often been found to be transient based on precipitation (Müller, Deurer and Newton, 2010). Dekker *et al.* (2000), working with Dutch sand dune systems, found that actual water repellent soils exhibited greater potential water repellence than those soils that were not hydrophobic before heating to 65˚C, unlike Mirbabaei *et al.* (2013) they did not test in the field, but brought their samples to the lab.

However in some cases irrigation can cause water repellency since the water always contain mineral salts (Leelamanie and Karube, 2013). If the presence of these salts is high enough that irrigation will result in soil salinisation (Leelamanie and Karube, 2013; Tadayonnejad, Mosaddeghi and Dashtaki, 2017). Dorostkar *et al.* (2016) ran an experiment with increasing levels of saline irrigation water and showed a correlated rise in SWR, which might have been expected since electrolytes do the opposite of surfactants, increasing the surface tension of the water (Leelamanie and Karube, 2013), however dissolved sodium can cause hydrophobic clays to flocculate, decreasing water repellency (Quirk and Schofield, 2013).

Mirbabaei *et al.* (2013) found that their Iranian soil samples containing 30% clay exhibited hydrophobicity, Doerr *et al.* (2006) agree with this, however they do not state what kind of clay was present either in that study or a later study of conifer forests (Doerr *et al*., 2009b), where he noted that soils with >4% clay did not display hydrophobicity. Roy and McGill (1998) found the opposite in their Canadian samples, where hydrophobicity was associated with a lack of clay-sized particles. Vogelmann *et al.* (2010) found hydrophobicity increased with expanding clays such as Montmorrilonite (with a 2:1 structure, see section on kaolinite) but not in soils with dispersing (1:1) structures such as kaolin-rich soils (Arcenegui *et al*., 2007; Mataix-Solera *et al*., 2008).

Most studies have been focused on soils from the Mediterranean biome, with little investigation into lands with a temperate humid climate (Doerr *et al*., 2006), indeed, only three studies to date, including the results of one questionnaire on golf courses, have looked at hydrophobicity in the U.K.. Doerr *et al.* (2006) ran an excellent study, following a transect running from Norfolk in the east to the Welsh coast in the west and surveyed 41 sites under five categories: ‘shrubs and rough pasture’, ‘permanent pasture’, ‘conifer forest’, ‘broadleafed forest’ and ‘agricultural land’. However most of this work was done in June 1999, the coolest June since 1991, with rainfall 27% higher than the average (Doerr *et al.*, 2006; Perry, 2006), this must have had some effect on the results which were unexpected when compared to other studies. While the researchers found hydrophobicity to match the highest results anywhere else in the world, they found that the usual indicators of repellency – texture, organic content, specific water content (the ratio of the mass of water to the mass of dry soil) – were not very effective as indicators, land use and critical moisture content (the point at which plants can no longer easily take up water), proved to be far better predictors. Doerr *et al.* (2006) studied soil both *in situ* and in the lab (air-dried samples) and found water repellency in all but two of the 27 ’permanently vegetated' sites, with 22 sites showing some degree of hydrophobicity at all three depths they tested at, though only five (woodland) sites showed no reduction in that repellency, the sycamore woodland proved hydrophilic. Strangely, they found that in 13 samples hydrophobicity was reduced when air-dried.

No water repellency was found in 13 of the 14 cultivated lands by Doerr *et al.* (2006), McKissock, Gilkes and Walker (2002) found the same thing in Western Australia, where uncultivated soils were less wettable than their ploughed sites, as did Woche *et al.* (2005) in Germany who suggest texture as the predictor for repellency. In the Doerr *et al.* (2006) research, the site that exhibited water repellency was an organic potato field, which agrees with the findings of Cerdá, Jordán and Doerr (2017) investigating citrus plantations and Robinson (1999), who found hydrophobicity in potato fields in a sandy soil in Suffolk. Robinson (1999) investigated a potato field under two different management systems, ridge and furrow (potatoes are grown on a ridge of soil to make use of early year solar gain, and reduce potato scab) in an early crop and flat bed in the later one. He found hydrophobicity in both systems (this was class two in a system of five classes, meaning infiltration took less than a minute), but the ridge and furrow method did not allow water to remain on the surface long enough for it to infiltrate. Robinson suggested that hydrophobicity was present because of the intensive use of the field, and the regular ploughing in of plant residue, however without more data from other sites in that locale it is hard to gauge if that is a valid assumption in the light of the work of Doerr *et al.* (2006). It might be possible that the hydrophobicity came from microorganisms which predate on potatoes. Müller *et al.* (2016) also found a causal link between land management, specifically tillage, and, in their case, subcritical water repellency (water infiltration is slow, but repellency is not immediately obvious). Eynard *et al.* (2006), however, found the opposite – grassland that had never been tilled showed less hydrophobia than cropland that had been tilled for more than 80 years, and suggest a positive relation between hydrophobicity and organic carbon. It is possible that what has been measured is not the direct result of cultivation, but selection by farmers of the most productive sites.

In the face of climate change a greater reliance on rain-fed systems can be expected as fresh water reserves are depleted (Hallett, 2007) and the U.K. is not immune to this, the winter and spring of 2017 has been particularly dry, public and on-farm reservoirs were reported low and rivers unable to meet farmers' needs before May was finished (Barkham, 2017). British soils are not immune to hydrophobicity once dried (Robinson, 1999; Doerr *et al.*, 2006). It is expected that the planet will experience more extreme weather events (Chartered Institution of Water and Environmental Management, 2007) due, in part, to changes in the upper atmosphere (Mann *et al.*, 2017). Newton, Carran and Lawrence (2003) found that hydrophobicity was reduced in New Zealand black loamy sand when CO_2 was increased over a five year period, they suggest this change may be due to alterations in the biodiversity in and above the soil and the changes in the natural processes caused by that biodiversity, such as nutrient and organic matter recycling, or changes in plant life. However a study of the same site after ten years (Müller, Deurer and Newton, 2010) offered a different result – there was no observed difference between ambient and higher CO_2 sample sites – they suggest this could be down to there being no significant alteration in SOM, but also whereas the 2003 sampling took place after a drought had just been broken, the sampling for the later study took place, deliberately, after a rainfall event.

From this review, it seems clear that there is no clear answer to the cause of soil hydrophobicity, and that each plot of land must be examined and treated individually. There do seem to be a few indicators: a high sand content can often cause hydrophobicity, despite it's use for good drainage, since it offers a larger area for hydrophobic materials, either waxes and oils or humic and fulvic acids; fire can induce or remove hydrophobicity depending on the plants growing in it and the temperature the fire reaches; plant litter and exudates, depending on the species, can cause hydrophobicity, as can arbuscular mycorrhizal fungi within the soil; land use, more often a ploughed field will show more wettability than untouched land and water content. However, even research must be read and understood carefully, as Doerr *et al.* (2006) warns:

> 'in this paper, as in most previous studies, spatial variability of water repellency could be interpreted as being either great or small, depending on: i) whether samples of similar moisture contents are compared; ii) the spatial scale; and iii) the level of discrimination used for different water repellency levels' (p. 749)

Diehl (2013) acknowledged that 'SWR is subject to numerous antagonistically and synergistically interacting environmental factors' (p. 15). He found that the arrangement of amphiphillic molecules altered when dry and argued that the higher degree of moisture, the less energy it took to alter their alignment, but that the presence of ionic solutions could also allow the necessary alteration. Vogelmann *et al.* (2013) agrees with this assessment, pointing out that the different factors affect an individual site in three dimensions, in the light of the effect of seasons on hydrophobicity, one might extend that to include the fourth dimension.

Hydrophobicity in artificial organic substrate

In the matter of hydrophobicity in artificial organic substrate there is much less research, possibly because the commercial industry is careful to keep their stock well watered and so it may not become an issue for them (Gautam and Ashwath, 2012) although Kukkonen and Vestberg (2007) found in a questionnaire study that most professional Finnish growers (who overwhelmingly used peat either by itself or mixed) considered hydrophobicity to be the main problem in their substrate that they would alter if they could. Depending on the irrigation method of a glasshouse, plants can be closer to or further away from drip nozzles, and zones of dryness can trigger hydrophobic behaviour (Michel, 2009).

Most organic potting composts become hydrophobic when allowed to dry out (Michel, Rivière and Bellon-Fontaine, 2001; Gautam and Ashwath, 2012), which significantly alters the water retention properties of potting substrate (Naasz, Michel and Charpentier, 2008) and preferential flow can be observed, even in a plant pot, when one attempts to water a dried out pot (Heiskanen, 1995; Michel and Kerloch, 2017), as has been observed in hydrophobic soils. Hydrophobicity in potting compost poses an extra problem for growers compared to soil-based growing, as often nutrients are provided dissolved in water (Urrestarazu *et al.*, 2000). Plants, carefully raised on a nursery, are often not so well cared for in a shop environment (Hicken 2017; Perrin, 2017) leading to loss of stock, and revegetation schemes for arid, or semi-arid areas that rely on rain for moisture

(Gautam and Ashwath, 2012). Plants raised in organic substrates - often peat-based growing media - can dry out and then be unable to take up water when the rains come, causing plants to die from lack of water even though there is now water available (Gautam and Ashwath, 2012).

Peat is still the most popular media for developing artificial organic substrates (Michel, Rivière and Bellon-Fontaine, 2001; Kukkonen and Vestberg, 2007; Agriculture and Horticulture Development Board, 2015), generally it also shows the strongest water repellency (Heiskanen, 1995; Di Benedetto, 2007), in particular dark peat – that is the most decomposed peat (Michel, Rivière and Bellon-Fontaine, 2001), which has the greatest amount of humic acid – a compound, as we have already seen, which is linked to hydrophobic behaviour in soils (Lin *et al.*, 2006; Cheng *et al.*, 2009). As peats dry their surfaces move from bipolar (hydrophilic) through monopolar to non-polar (hydrophobic) positions (Michel, Rivière and Bellon-Fontaine, 2001). Rhezanezhad *et al.* (2016) point out that peat's organic functional groups are able to adsorb both hydrophilic and hydrophobic compounds, their interest is in phytoremediation, rather than hydrophobic behaviour of peat, but this seems very similar to how surfactants work (Fields, Fonteno and Jackson, 2014).

A relationship between the degree of decomposition in peat and the hydrophobicity displayed (the higher the decomposition, the greater the degree of hydrophobicity) has been noted (Doerr *et al.*, 2000; Michel, Rivière and Bellon-Fontaine, 2001), as has the pronounced hysteresis during wetting and drying shown by peat, especially in comparison to composted pine bark (Naasz, Michel and Charpentier, 2008). Michel and Kerloch (2017) did find coir to be more hydrophobic, but there is a great deal of variability in coir composts (Abad *et al.*, 2005), so this may not be dependable.

The patchiness of water repellency as seen in soils (Mataix-Solera and Doerr, 2004; Lozano *et al.*, 2013) does not appear to be a symptom of water repellency in organic substrates, they either exhibit the behaviour or they do not.

Imeson *et al.* (1992) considered that pore space increased infiltration, even in hydrophobic soils with a high organic content (35% with 50% total porosity), however this doesn't appear to happen with artificial organic substrates, with a far higher percentage of organic material (and correspondingly higher total porosity) (Michel and Kerloch, 2017). Their main interest was macropores, which general speaking are not found in potting compost – bark-based compost does have an open structure, but even with this substrate Beardsell and Nicholls (1982, cited by Argo, 1998) found that when water content was reduced below 35% hydrophobicity was evident. Texture in soils is usually considered to be one of the influencing factors in hydrophobicity, increasing the likelihood of a soil to be hydrophobic (Doerr *et al.* 2000), however not all researchers agree (Chau *et al.*, 2014).

It is not yet known for certain why organic growing media exhibits hydrophobicity (Naasz, Michel and Charpentier, 2008; Matthews *et al.*, 2017), below at least a 15% moisture content (Gautam and Ashwath, 2012). In 1976, Bunt hypothesised that it was due to 'a film of air adsorbed on the surface of the peat and to the iron humates that were present'. Today it is considered more likely that the humic acid present crystalises when dry, and these crystals are water repellent (Puustjavi and Robertson, cited by Argo, 1998), although it could be supposed that in regard to bark compost, which is usually from pines, that organic compounds found to be hydrophobic in soil studies are also influential here. Gautam and Ashwath (2012), in their study of 43 different growing media found that, similarly to soils, the hydrophobicity increased as the pH decreased, which fits with the theory that humic acids play an important role in potting media hydrophobicity.

Kerloch and Michel (2015, cited by Michel and Kerloch, 2017) found wettability to effect the degradation of growing media over time, the first wetting/drying cycle apparently having the greatest effect (Qi *et al.*, 2011). Wettability decreases over time with repeated wetting/drying cycles, and yet despite this water retention increases, as does the reduction in pore tortuosity (Michel and Kerloch, 2017).

Hallet (2007) puts forward the credible theory, for soils, that organic materials from plants, which are very hydrophilic in nature when wet, bond strongly with each other and soil particles when dry, resulting in hydrophobic surfaces. This could explain hydrophobia in organic substrate, since artificial substrates are mostly decomposed plant matter, and the most hydrophobic substrate – dark peat – also displays one of the highest water holding capacities.

The wettability of a substrate can be affected by some species of algae and bacteria (Doerr *et al.*, 2000), though Gautam and Ashwath (2012) found that the population size of wax degrading bacteria had no significant difference between non-hydrophobic and hydrophobic media, although they concluded that this was due to bacterial inactivity in low pH environments. It is also known that peat offers a conducive environment for some algae (Cronberg, 1991; Tinus and McDonald, 1979, cited by Heiskanen,1995; Di Benedetto, 2007) and pathogenic fungi (Bonanomi *et al.*, 2007; Cotxarrera *et al.*, 2002), it is known that fungi produce hydrophobins (Wessels, 1996), so it is possible that this may be related to hydrophobicity, indeed Hallett (2007) suggests it is the main cause of this phenomenon. This is less likely to be observed with bark-based substrates which possess, according to some researchers, antimicrobial properties (Tunlid *et al.*, 1989; Kai, Ueda and Sakaguchi, 1990).

Fields, Fonteno and Jackson (2014) found that even when wetting agents were added to a sphagnum peatmoss wetted to 25% moisture by weight (at low, medium and high rates) hydrophobicity was only overcome after ten irrigation events. It is not made clear what grade of peat moss was used (light, medium or dark) and the test used to ascertain container capacity was the funnel method, which is perhaps not the most thorough method (the substrate is submerged for 15 minutes, not one or two days). Their results are a not significant for the other substrates they evaluated.

Wettability can be restored, ironically, through the reintroduction of moisture (Doerr *et al.*, 2000), though the more hydrophobic the substrate, the harder it is, and more water is needed, to achieve this (Bettany, 2017). Doerr *et al.* (2000) discuss how repeated wetting and drying restores hydrophobicity in soils, but not at the same level as originally observed, this has not been observed during the suite of tests described in this current work (Bettany, 2017) where hydrophobicity has been easily restored to the same high degree, with oven- and even air-drying. Cycles of wetting and drying have been found to naturally reduce hydrophobicity in fine sand, less so in coarser sands, possibly due to the changes in organic molecules caused by the cycles (McKissock, Gilkes and Walker, 2002). However little is known about the mechanisms involved in the wetting/drying and rewetting cycles, or the threshold conditions – known as the critical water content (CWC) (Chau *et al.*, 2014).

In the future, it would be interesting to see research removing the humic acid from substrate, perhaps using the method developed by Fukushima *et al.* (2009) in order to investigate the wettability of substrate without the acid present.

1.4.4 Amelioration

Bunt (1976) only offers surfactants as an answer to hydrophobicity in container-held organic substrate (specifically peat), mentioning that some were too toxic to use with seedlings – in the 21st century we now have more options.

Keeping potting substrate permanently moist is a general method of husbandry in commercial nurseries, however it is not usually possible, even for golfing greens to do the same for soil (Cisar *et al.*, 2000).

Mechanical Methods

Mechanical methods, as outlined by Bear (1973, cited by Panina, 2010), are regularly used in golfing greens (a common site for SWR and resulting patchy growth), slitting and spiking the soil to encourage water infiltration (passing by the most hydrophobic layer at the surface), and controlling the 'thatch' – the tangle of living and dead grass matter at the O zone (the level between the plants and the soil, where plant debris is to be found) – by coring and regular mowing. Wallis and Horne (1992, cited by Panina, 2010) found that SWR was not necessarily caused by thatching, since removing it did not significantly decrease repellency.

Wetting Agents

Wetting agents, which are not always surfactants (Zontek and Kostka, 2012) reduce the surface tension of the water by enabling some of the hydrogen bonds to be broken allowing increased infiltration, they consist of a hydrophilic 'tail' and a hydrophobic 'head', the head will adhere to a particle, allowing the hydrophilic tail to create a new 'surface' (Fields, Fonteno and Jackson, 2014), temporarily reducing hydrophobicity.

There are several different types of wetting agents: 1) Anionics (and blends including anionics) are negatively charged and can allow fast wetting, they also have a tendency to disperse clays (whether this is desired or not depends on the land use). Tadayonnejad, Mosaddeghi and Dashtaki (2017) investigated the ability of Polyacrylamide (PAM) to reduce or prevent saline irrigation water inducing water repellency in a pomegranate orchard through drip irrigation and found a positive correlation. Unfortunately, depending on the application, they can also be phytotoxic (Zontek and Kostka, 2012); 2) Polyoxyethylene (POE) surfactants, as with Anionics, Zontek and Kostka (2012) have labeled these 'old chemistry' being introduced in the 1950s. They were intended to treated localised dry spots (LDS) in golfing greens and do reduce hydrophobicity, but can also be phytotoxic; 3) Block Co-Polymer Surfactants, these are ‘new chemistry’ and effectively treat hydrophobicity, improving WHC and plant-available water, of the two types (Straight block and Reverse block), the latter is particularly useful for soils with low WHC; 4) Alkyl Polyglucoside Surfactant is derived from a sugar molecule, it has a synergistic relationship with block Co-Polymer Surfactants which results in a more effective wetting treatment than either can offer alone; 5) Modified Methyl Capped Block Co-Polymer has had its –OH terminal groups replaced by hydrophobic CH_3 ends which attach to the hydrophobic compounds in the soil, allowing for a thinner but continuous water presence around the particles; 6) Multibranch Regenerating Wetting Agents are of a higher molecular weight than other surfactants, and can interact with the environment from each of its many branches, as it biodegrades it actually regenerates itself, so conceivably it requires fewer applications (Zontek and Kostka, 2012). However the most effective wetting agents, as of 2010 (Panina, 2010) were also phytotoxic and resulted in short-term grass damage when applied to golfing greens, as outlined in the abstract of Wolfgang *et al.* (2007), non-ionic wetting agents, however, are less likely to be phytotoxic (Urrestarazu *et al.*, 2008)

Fields, Fonteno and Jackson (2014) found that even when wetting agents were added to a sphagnum peatmoss wetted to 25% moisture by weight (at low, medium and high rates) hydrophobicity was only overcome after ten irrigation events. It is not made clear what grade of peat moss was used (light, medium or dark) and the test used to ascertain container capacity was the funnel method, which is perhaps not the most thorough method (the substrate is submerged for 15 minutes, not one or two days). Their results are a little uneven for their other substrates, but wetting agents have been found to be effective when used with rockwool and coir compost (Urrestarazu *et al.*, 2008). However, Cisar *et al.* (2000) investigated the use of four surfactants on golfing greens (although they don't describe the soil, golfing green topsoils are usually mostly sand with some peat) and found that they were all affective to some degree in reducing SWR.

The benefits of wetting agents can last for up to two years and can cost $25 - $50 (approximately £20 - £40) ha^{-1} year^{-1} (Roper *et al.*, 2015)

Hydrogels

Hydrogels are cross-linked polymers capable of absorbing up to 400 times their own volume in water (Sarvaš, Pavlenda and Takáčová, 2007; Chirino, Vilagrosa and Vallejo, 2011). They are polyacrylamide, propenoate-propenamide or (biodegradeable) cellulose-based copolymers (Fonteno and Bilderback, 2011; Demitri *et al.*, 2013). First used in the 1970's in glasshouse production (Orzolek, 1993), they are added to soil or growing media to increase the water holding capacity of the substrate (Chirino, Vilagrosa and Vallejo, 2011), to increase air capacity, increase nutrient holding ability, reduce compaction and reduce the need for irrigation (Orzolek, 1993; Fonteno and Bilderback, 2011). Demitri *et al.* (2013) added cellulose-based hydrogels to Italian red soil for growing tomatoes inside a glasshouse, their results showed it to be effective at prolonging the periods between watering without adverse results (Akhter *et al.*, 2004). They are commonly used when planting in arid or semi-arid areas (Roldán *et al.*, 1996; Akhter *et al.*, 2004; Nazarli *et al.*, 2010). Akhter *et al.* (2004) found that seed germination (of *Triticum aestivum* - Wheat, *Hordeum vulgare* L. - Barley and *Cicer arietinum* L. - Chickpeas) was not improved by the hydrogel but, like most research, found them to be helpful in increasing seedling survival rates away from the nursery, though Sarvaš, Pavlenda and Takáčová (2007) showed that using too much can be detrimental and lead to plant loss. When Chirino, Vilagrosa and Vallejo (2011) compared growing *Quercus suber* (Cork Oak) seedlings in a peat-based potting compost by itself, with hydrogel or with Sepiolite clay they found the plants grown with the hydrogel had the highest survival rate over a period of more than two years, however not all studies have shown positive effects, and many of these studies focused on shrubs and trees (Fonteno and Bilderback, 2011). Hydrogel does not counteract hydrophobicity, it simply improves the substrates ability to hold water, although salts can alter the crystals ability to absorb water (Fonteno and Bilderback, 2011). Demitri *et al.* (2013) suggest acrylate hydrogel crystals can be phytotoxic, but Montesano *et al.* (2015) confirmed that cellulose-based hydrogels were not. No research appears to have been conducted on whether hydrogel slows the emergence of hydrophobic behaviour, nor how easily hydrogel crystals can take up water in a substrate that is in its hydrophobic state – presumably the crystals can only absorb water if it can come into contact with them.

Hydromulching

Hydromulching is a slurry of seeds, fibre and a tackifier, it will sometimes also have a vegetable colourant, nutrients or other soil conditioners (Natural Resources conservation Service/ United States Department of Agriculture, 2012; Prats *et al.*, 2016; Oliver Brown Ltd., 2017). In a three year study of land in north central Portugal that had been subjected to wildfire, hydromulch was found to reduce hydrophobicity at least for the first two years (Prats *et al.*, 2016), curiously they don't discuss these results except for mentioning that microbial activity was increased as a result of the mulch. They point out that sunlight was intercepted by first the mulch and then the vegetation cover, reducing the surface temperature, and that the water retention capacity was maintained at a higher level than would otherwise be expected (Prats. *et al.*, 2016).

Flushing

Flushing with sodium Hydroxide has been shown to remove hydrophobicity after as little as three treatments by Karnok *et al.* (1993), working on golfing greens they saturated the top 50cm of the ground with a solution of 0.1 *M* NaOH then flushed with plain water. The principle was to simply wash away the humic acid with an alkaline. Panina (2010) suggested that this might cause growth problems, and Karnok *et al.* (1993) did note phytotoxicity towards the bentgrass in temperatures ≥35˚C.

Altering Texture

For potting compost, it has been suggested that adding sand, vermiculite or perlite can improve water uptake and reduce hydrophobicity, it seems unlikely that sand would remain useful for long, before being coated with exactly the same compounds that were rendering the rest of the substrate hydrophobic, however no study, to date, appears to have investigated this.

Seaweed

Ozdemir, Dede and Celebi (2015) found that adding seaweed to uncomposted hazelnut residues (which have been found to be even more hydrophobic than peat (Dede *et al.*, 2011)) reduced the hydrophobicity from severe to moderate.

They suggested, reasonably, that this could be due to the seaweed comprising of 50% polysaccharide alginate, which is hydrophilic (Han, Clarke and Pratt, 2014). Since seaweed is considered a good substrate improver in general (Dede *et al.*, 2011; Han, Clarke and Pratt, 2014) it would seem to be worthy of further investigation with more common potting composts.

Bioremediation (Microbial remediation)

Franco, Michelson and Oades (2000) hypothesized that the wax residues left by plant matter could be treated in a similar way to oil spills by using bioremediation. They added slow release fertilisers, designed for cleaning up rude oil spills, to stimulate the microbial population, however while their glasshouse based pot trials were successful (using sand as the substrate), in the field the results were not significant, they suggest that the glasshouse environment was more conducive to microbial life than the South Australian fields they used.

Biochar

Biochar has been found to be effective in reducing or eliminating soil water repellency. Hallin *et al.* (2015) investigated a coarse and a fine biochar added to water repellant soil and found that the fine biochar added at 10% in weight reduced the repellency by 50% and a 25% addition removed it entirely. The coarse biochar had an ameliorant effect, but not to the same degree.

Sepiolite clay

Chirino, Vilagrosa and Vallejo (2011) looked at Sepiolite as an additive to peat-based potting compost to improve the water holding capacity, as a 2:1

structured clay it is expandable and able to absorb a great deal of water (Galan, 1996), however while it was more successful than the control, it was not as able to help the tree seedlings survive as using hydrogel.

Kaolinite

Treatment with kaolinite, or illite clays as a top dressing or ploughed in will reduce water repellency (Ma'shum, Oades and Tate, 1989 – abstract; Lichner *et al.*, 2006; Diamantis *et al.*, 2017) without altering bulk density (Reatto *et al.*, 2009) or Water Holding Capacity (Michel, 2009), or increasing shrinkage (Reatto *et al.*, 2009). Wallis and Horne (1992, cited by Panina, 2010) suggest it could either be added to golfing greens after coring, or before the turf is laid, in the mixing of the substrate (standard greens are 90% sand, and only 1% organic matter (Panina, 2010)). Panina (2010) warns that such treatments should be very accurate, to avoid loss of permeability or problematic compaction. That said, kaolinite has been used in agricultural soils as an ameliorant for at least forty seven years (Cann, 2000), in particular in sandy soils (Diamantis *et al.*, 2017), claying has doubled yields according to Cann (2000). In Australia, the three most western states having collectively the largest area of hydrophobic soils of any country in the world (Blackwell, 2000), 'claying', that is the addition of 1% - 2% (McKissock, Gilkes and Walker, 2002) kaolin-rich clays or soils to fields, is a standard practice where it is cost-effective (Roper *et al.*, 2015, estimate this treatment to cost between \$500 - \$900 – approximately £390 - £700 - ha^{-1} year^{-1}), this has improved cereal yields up to three times the original value (Carter *et al.*, 1998, cited by McKissock, Gilkes and Walker, 2002). Once present, the clay stays in situ, in Australia it has been found that kaolin will remain effective for several years (Ward, 1993, cited by Cann, 2000;

McKissock, Gilkes and Walker, 2002), Roper *et al.*, 2015 state 15+ years, and Cann (2000) cites a personal communication (Obst) where he was told that kaolin spread thirty years before was still an effective ameliorant. Kaolin is considered 'masking', it is thought that because of its structure, which causes it to spread out in water, rather than clump together, it coats hydrophobic particles (Müller and Deurer, 2011; Diamantis *et al.*, 2017), and studies show it to be the ameliorant with the least risk to preferential flow, leaching and pesticide concentration, although it is a slow option when chosen for the purpose of water table contamination (Blackwell, 2000), in fact it has been found that the presence of kaolin will increase the effectiveness of pesticides (Cann, 2000). Diamantis *et al.* (2017) applied kaolinite rich soil both dry and suspended in water to the hydrophobic soil beneath olive trees in Greece, the suspension immediately relieved SWR (74% reduction), the dry application reduced it by only 26% at first, but after three wetting/drying cycles the repellency was reduced to 76% of its original level, once present, the clay stays in situ, and this showed no sign of reducing in effectiveness after six weeks.

In the lab, using sand made hydrophobic with stearic acid, Dlapa *et al.* (2004) investigated kaolinite and Ca-Montmorillonite (a 2:1 clay) for their amelioration abilities. They found that the 2:1 clay made the sand more hydrophobic, but kaolinite decreased hydrophobicity, in one treatment by an order of magnitude, this agrees with the work of other researchers (McKissock, Gilkes and Walker, 2002). They suggested that their results showed it was the mineralogy that was significant, and repeated the belief, expressed by other researchers, that the kaolinite is effective by spreading out in water and coating the individual particles, placing a barrier between the hydrophobic layer and the water; they made another suggestion, however. They pointed out that a substrates response to water is dependent on the Lifshitz-van der Waals forces, and that hydrophobicity reduces as the density of the charges and polar groups reduce, in particular hydroxyl groups. $–OH^-$ groups can be found densely packed on the surfaces of kaolinite, making it hydrophilic in itself (also, Lichner *et al.*, 2006). Lichner *et al.* (2006) also looked at Kaolinite and Ca-Montmorillonite, but also Na-Montmorillonite, they found that Kaolinite and Na-Montmorillonite were both effective at reducing hydrophobicity, they suggest that the differences in inner-particle forces in the two kinds of Montmorillonite explain the different results.

Diamantis *et al.* (2017) applied kaolinite rich soil both dry and suspended in water to the hydrophobic soil beneath olive trees in Greece, the suspension immediately relieved SWR (74% reduction), the dry application reduced it by only 26% at first, but after three wetting/drying cycles the repellency was reduced to 76% of its original level. some researchers have found that a wetting then drying cycle was necessary to trigger the masking effect of kaolin (ref.), however the work of McKissock, Gilkes and Walker (2002) sowed that this was not necessary to obtain amelioration, but that a wetting/drying cycle did improve the effect – they suggested that this was due to the water spreading the kaolinite more evenly through the soil. Kaiser and Zech (2000) found that removing the aluminium and iron from clays that were effective in the sorption of organic matter markedly reduced that effectiveness, unfortunately they do not mention which clays they used, since they were isolated from soils, but do say that 2:1 clays were only a small fraction. Cann (2000) describes a study where the soil was found to increase after application of kaolin, however, this kaolin was from local land, and unlikely to be purified,

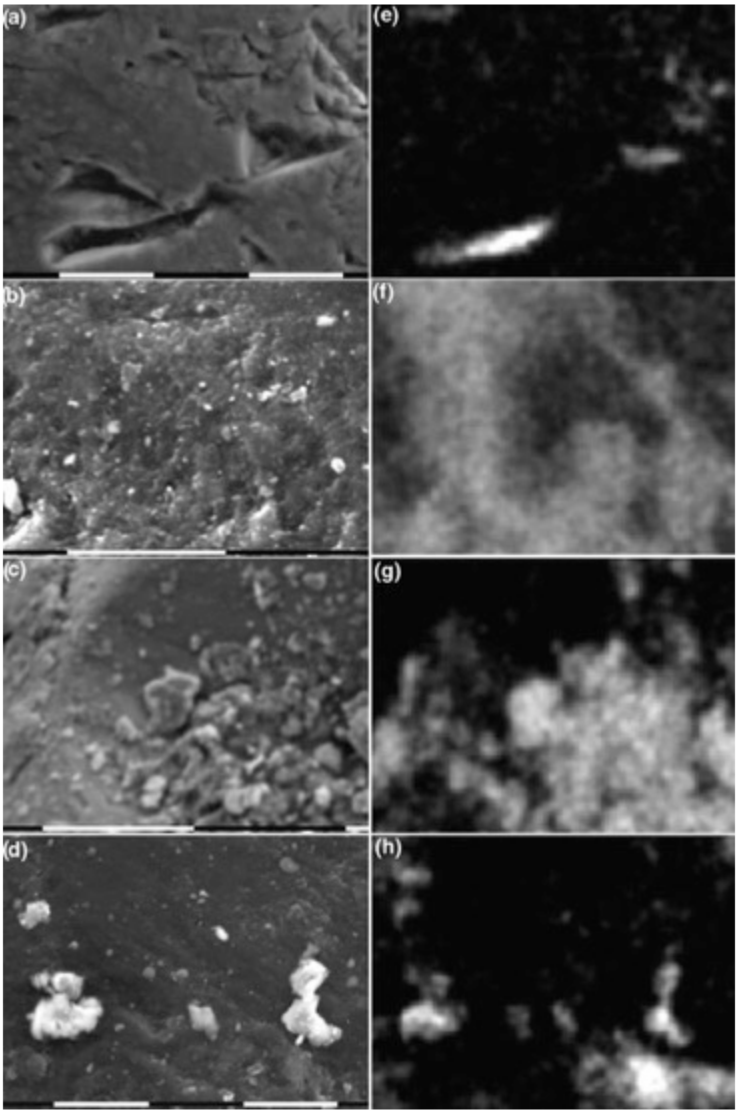


Figure A1 ‘Scanning electron micrographs showing the distribution of clay on the surface of sand grains. The four images on the left are secondary electron images of the surface of sand grains: (a) sand grain after treatment to remove clay and organic matter; (b) surface of untreated sand grain showing a discontinuous coating of clay sized material; (c) sand with Georgia kaolinite added (dry mix); and (d) sand with Wyoming bentonite added (dry mix). The corresponding images on the right (e, f, g, h) are derived from energy dispersive X-ray dot maps showing the distribution of aluminium on the surface of the sand grains. Aluminium is present in clay minerals. The scale bars represent 10 mm in each case.’ (McKissock, Gilkes and Walker, 2002, p.236, copyright granted).

As can be seen from the images above, especially image c, kaolin clings to sand particles even when dry.

The only study found for this review that researched the effect of clay on the hydrophobicity of peat (prepared as a potting compost, rather than a peat soil) is the work of Michel (2009). He used a clay that was 65% smectite, which is a clay that clumps together, 25% illite and 8% kaolinite – the last two being dispersing clays. By mixing this clay on a 9:1 ratio by volume with the peat he found that hydrophobicity was significantly improved without affecting water holding capacity or the water retention curves.

Other Methods

Other methods include zero-tillage (Blackwell, 2000), ploughing (because in some areas zero-tillage has been found to increase hydrophobicity), furrow sowing (Roper *et al.*, 2015), using plants that are adapted to water-scarce, hydrophobic soils, removal of hydrophobic topsoil and ploughing to control water movement (Blackwell, 2000, Roper *et al.*, 2015), however all these methods are for soil, not organic potting substrates.

Methods of Testing

A drop of water can remain as a bead on a surface (static), or spread across, and be absorbed by the surface (dynamic), indicating a lowering of surface tension (Chau *et al.*, 2014).

There are some questions around sampling soil in the field and in the lab, concerns about the effect of sieving on samples do not particularly affect artificial organic substrates since they are already homogenised, but the concern for soil is that hydrophobic coatings can be removed, or surfaces could be roughened, altering surface contact with the water (Badía *et al.*, 2013), but Badía *et al.* (2013) found only weak changes in samples, however Doerr *et al.* (2006) tested their samples of sandstone-based soils both *in situ* and in the lab, air-drying and sieving the samples and found differences, however they chose to analyse their laboratory results because they were more standardised. Sieving did, however, allow Arcenegui *et al*. (2007) to investigate the hydrophobicity of the different particle fractions of their burnt samples, and Mataix-Solera and Doerr (2004) working with both burnt and unburnt sites.

The method of drying might cause alteration, however. It has been suggested that oven-drying can increase hydrophobicity in soils (Ma'shum and Farmer, 1985 and Franco *et al*., 1995, cited by Doerr, 1998), however Wang, Wu and Wu (2000) advise drying below 105˚C for at least 24 hours, then cooling them to room temperature for their proposed methods of Water-entry value. Also the act of moving the samples could modify them (Doerr and Thomas, 2000), Rowell (1994) points out that moist papers (referring to Whatman filter papers) lose moisture at a rate of about $1 \mathrm{mgs}^{-1}$ if waved about, which shows just how easy it is to lose data. Researchers working on potting media also do not need to worry, as soil scientists do, about the depth the soil sample has been taken from, and whether any mixing of layers has occurred (Crockford, 1991, cited by Badía *et al*., 2013; Doerr, 1998). Arcenegui *et al.* (2007) chose to air-dry their samples in the lab before sieving, several researchers perform the same or similar experiments both in the field and air-dried in the lab for comparison (Doerr *et al*., 2009b).

Soil water repellency is often hampered by inconsistencies in sample collection, preparation and measurement (Moody and Schlossberg, 2010), all of which depend heavily on the researcher involved.

Methods of measuring soil water repellency have not yet been standardized (Badía *et al.*, 2013), some of which are not suitable to bulk testing (Doerr, 1998), however there are three methods generally used.

The Water Drop Penetration Time test (WDPT test) measures the persistence/decay of hydrophobicity by measuring the time taken, in seconds, for a drop of deionised water to overcome the surface tension of a porous surface and infiltrate the substrate (Doerr, 1998; Diehl, 2013; Chau *et al.* 2014). The substrate is usually prepared by air-drying, bringing all samples to the same moisture level (usually a defined room humidity) but sometimes by oven-drying (generally a 105˚C for 24 hours) then cooling to room temperature (Wang, Wu and Wu, 2000), sieving to 2mm (to remove the coarsest, non-sand fraction), although Badía *et al.* (2013) showed that the disturbance of soil samples by sieving altered the results, then putting into a petri dish and smoothing the surface by hand (Diehl, 2013). Three drops of distilled/deionized water are then generally placed on the surface using a syringe, or less commonly a dropper (Wang, Wu and Wu, 2000), from a height of on average 5mm above the surface, though some researchers have performed the test from 10mm above (Lichner *et al.*, 2013), to avoid impact disturbance. Diehl (2013) states that different drop sizes are incomparable, but the experience of the current work suggests no noticeable difference between large and small drops for penetration time. The persistence is associated with the energy required to move the surface from a hydrophobic to a hydrophilic state (Chau *et al.*, 2014). The classifications are arbitrary (Diehl, 2013), but since they are generally accepted, work well and allow for comparison with other researchers works.

Table A1 WDPT test classifications (Diehl, 2013)

Classification no.	Seconds for infiltration/$_s$	Description
1	$<5_s$	wettable soil
2	$5_s – 60_s$	slightly water repellent
3	$61_s – 600_s$	strongly water repellent
4	$600_s – 3600_s$	severely water repellent
5	$>3600_s$	extremely water repellent

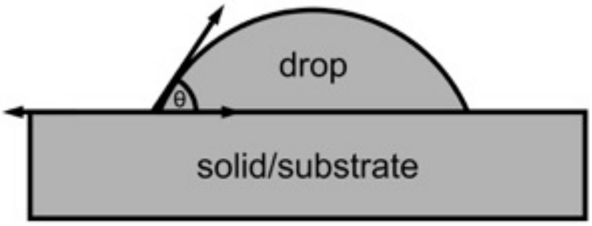
It can be very time consuming (Doerr, 1998), the highest category is >3600 seconds – an hour, due to the large difference in possible results, the results are often converted into a logarithm (Lozano *et al.*, 2013). There is a large degree of human error possible when a method relies on simple counting of seconds, because of these doubts Doerr (1998) ran the test, carefully sieving and preparing the petri dishes, and replicating each drop 15 times. For 96% of his samples there was no range or a range of just one category, so he concluded that this test, if properly run, was a suitable method of discovering hydrophobicity, Doerr *et al.* (2009b) also found very little variation between samples from the same site. Despite concerns, a tally of the papers used in this literature review suggests it is the most popular method for researchers, possibly because it is a very simple and cheap test to perform, one of only a few methods suitable for large sample sizes (Doerr, 1998), Doerr *et al.* (2009b) considers it the most ‘meaningful’ of the possible tests.

The Molarity of Ethanol Droplet method (MED), otherwise called Ethanol Percentage test (EP). It indirectly measures the surface tension/energy of the substrate (Doerr, 1998; Badía *et al.*, 2013; Diehl, 2013) by the concentration of ethanol dissolved in water required for a drop of the solution to infiltrate a substrate within ten seconds (Roy and McGill, 1998) or instantaneously (Diehl, 2013). Soils with an MED index of ≤1 are not significantly water repellent, and those with an index of ≥2.2 are labeled severely water repellent (Roy and McGill, 1998). According to Badía *et al.* (2013) this method is commonly used in the field because of the speed of execution, and often in the lab too, being suitable for large numbers of samples (Doerr, 1998), however a quick tally of 35 papers used in this work, 25 used the WDPT test, eight used the MED test, and three used both. Doerr (1998) found a good correlation (99% of samples agreed) between testing of *in situ* samples, and lab prepared samples (homogenised and sifted). Roy and McGill (1998) consider it a fast and reliable method for oven-dried and air-dried soils, Doerr (1998) agrees with this assessment, but doubts its accuracy with sieved and/or bulked field samples, and cites Crockford *et al.* (1994) for poor reproducibility of results, Badía *et al.* (2013) agrees that sieving alters the results. It is unsuitable for substrates exhibiting low water repellency (Chau *et al.*, 2014), or for substrates with moisture content above air-drying since the water present attracts the water in the droplet through ‘cohesive forces’ (Roy and McGill, 1998). Citing Roy and McGill (2002), Moody and Schlossberg (2010) also make the argument that its statistical strength is limited and Gilboa *et al.* (2006, cited by Moody and Schlossberg, 2010) were unable to accurately predict hydrophobic behaviour using the method.

Doerr (1998) performed the test using increasing ethanol concentrations of 0, 3, 5, 8.5, 13, 24 and 36 per cent by volume, applying the solutions with a medical dropper onto smoothed (by hand after being sieved to <2mm) soil surfaces in petri dishes. The drops were placed onto the soil surface from no higher than 5mm to avoid disturbing the surface with the kinetic force. The results into categories from 1 (very hydrophilic) to 7 (very hydrophobic). He found that there was a 99% comparability between his field and lab samples and little variability between replicates.

Some investigation has gone into the differences between MED and WDPT tests, generally speaking the results are similar, with MED over estimating results with sieved samples, and WDPT tests underestimating the same results (lab samples compared to field samples) (Badía *et al.*, 2013). Doerr (1998) found that there was a close relationship between the WDPT test and the MED when the WDPT was in its highest range (above 60s) but the results were increasingly less comparable at values below that time.

The sessile contact angle/sessile drop method (SDM) of a bead of water on a surface is dependent on the relationship between liquid to vapour, solid to vapour and solid to liquid (Chau *et al.*, 2014) and measures the angle between the horizontal solid layer and the liquid drop:



(Zenfire Design, 2017, copyright granted)

When the contact angle is greater than 90º it is considered hydrophobic (Letey, Carrillo and Pang, 2000; Leelamanie and Karube, 2009). The surface free energy of the substrate particles can be found from the following equation (Good and Girifalco, 1960, cited by Leelamanie and Karube, 2009):

$$\cos\theta = 2\Phi(\Upsilon_s/Y_L)^{1/2} - 1$$

‘Where θ is the contact angle, Φ is the interaction parameter and Y_L is the surface tension of the liquid’ (Leelamanie and Karube, 2009, p. 458).

Considerations also need to be made for the uneven texture of the substrate, and assumptions made about the elliptical shape of the drop (Diehl, 2013).

The drop is examined either using goniometer and a microscope, or more simply by taking a photograph and taking the measurement from that (Diehl, 2013). It is not well suited to an uneven surface so a method was developed by Bachmann *et al*. (2000) using double sides adhesive tape to create a single layer of substrate particles stuck to a microscope slide, however, even this uneven surface will affect the results (Leelamanie and Karube, 2009). This method only measures a moment in time, however, giving no indication of persistence over time, Leelamanie and Karube (2009) tested it against the

Water Drop Penetration Time (WDPT) test (outlined below), to evaluate time dependency on the contact angle, they found that while initial results agreed, as the contact angle decreased over time the correlation was lost, this should have been expected considering that the sessile drop method using a single layer of particles over an impenetrable plastic layer, whereas the WDPT test uses a petri dish of substrate.

Used in tandem, Chau *et al.* (2014) postulate that the contact angle test and the WDPT test can be used to evaluate and predict the severity and persistence of hydrophobicity in soil, their results do suggest this, but with the caveat that each site is different and will need its own evaluation – one could argue that, knowing how many factors are involved in a soil becoming repellent, this result was inevitable. However, when dealing with artificial organic substrate, being far more homogolous, this may be a useful set of results. Leelamanie and Karube (2009) found that there was a direct relationship between persistence and contact angle, however their work was on sand treated with hydrophobic compounds, and this relationship has not always been observed in naturally hydrophobic soils, Zavala *et al.* (2009) working with Mediterranean soils found a correlation but Chau *et al* (2014) working with Canadian soils contaminated with crude oil didn't, nor did Doerr *et al.* (2009b) when looking at soil under temperate conifer forests in the U.S.A.. Wijewardana *et al.* (2016) worked with Japanese forest soils and New Zealand pasture soils and found a 'close agreement' (p. 150) with WDPT test, MED test and SDM tests.

The Capillary Rise Method (CRM). Water moves against gravity in soils and substrates via capillarity due to surface tension (Liu *et al.*, 2014), some researchers use this fact to indirectly measure hydrophobicity. CRM is used by some researchers (e.g. Leelamanie, Karube and Yoshida, 2008), and compares the angle of capillary rise (based on the Washburn equation) through a narrow tube of a substrate of a wetting liquid such as n-hexane or ethanol with that of water (Letey, Carrillo and Pang, 2000; Diehl, 2013).

The simple equation is:

$$h = 2_{\Upsilon 1} \cos \theta / r\, \rho g$$

'where h is the height of the rise, ϒ1 the liquid-air surface tension, θ the liquid-solid contact angle, r the capillary radius, ρ the liquid density, and g the gravitational constant' (Letey, Carrillo and Pang, 2000, pp. 61-62).

Capillary tubes are not true substitutes for substrate pores (Letey, Carrillo and Pang, 2000), of course, and while useful in some circumstances, it is limited in that it does not measure a contact angle greater than 90˚ (Michel, Rivière and Bellon-Fontaine, 2001), it often over estimates (Diehl, 2013) and is time consuming (Moody and Schlossberg, 2010).

Other methods include the 90˚ surface tension test, which is similar to the MED/EP test (Letey, Carrillo and Pang, 2000; Moody and Schlossberg, 2010) which is also only useful for a contact angle of less than 90˚, the Repellency Index measurements, which are 'complex, tedious and costly, yet [dependable]' (Moody and Schlossberg, 2010), the Wihelmy plate method, which fixes samples on a plate the submerges them and measures the advancing and receding contact angles as the samples are removed form the liquid, this method often underestimates (Diehl, 2013) and thermal analysis (Wallis and Horne, 1992, cited by Leelamanie, Karube and Yoshida, 2008). The Equivalent

Cross Section (ECS) measures water repellency by quantifying the level of preferential flow in a cross section of soil to a uniform depth (Beckett, Fourie and Toll, 2016). Wang, Wu and Wu (2000) developed a method of measuring ‘Water-entry Value’, which sees a prepared tube of substrate, and measures the ponding volume of water required to force water to infiltrate the soil – an obvious concern with this method is the way the tube is packed, but it is a relatively simple method, alternatively an open tube can be lowered into water, it is intended to work in tandem with the WDPT test.

Hydrophobicity classification and testing is yet to be standardized, and needs to be, for an example, take two studies discussed in this review - Ferreira *et al.* (2000) classed a soil that took less than a minute for a drop of water to infiltrate it as being hydrophilic, however Robinson (1999) classed the English potato field he was studying as class two hydrophobic – even though the soil also took less than a minute to allow the water drops to infiltrate, Bisdom, Dekker and Schoute (1993) also went with this definition.

Appendix 2 – personal communications (emails)

Email from Prof. Peter Convey on the hydrophobicity of Antarctic soils (19 May 2017, 13:59):

Dear Sarah

your message has been passed to me as an Antarctic terrestrial ecologist, though not a soil scientist.

I've not come across this concept before, but have two thoughts:

- first, for most of Antarctica, soils are extremely poorly developed, and many true soil scientists would say they do not come under the definition of 'soils', with an almost complete lack of development of normal soil horizons. Rather in many if not most areas what we call soils are in reality simply ground up rock, with very very little organic content. Such generally particulate 'soils' are very porous to any water that does fall on them (if you hunt on the web, there is a book from about 2002 by Beyer and Bolter that gives a pretty thorough overview of Antarctic soil environments.

- second, there are some small areas where what we would recognise as a normal 'brown soil' does develop, mostly close to the very limited higher plant occurrences on the Antarctic Peninsula and Scotia Arc islands. I've done quite a lot of work with these plants, and my off the cuff impression is that the soil behaves no differently in relation to water droplets to soils anywhere else. If you move further north to the sub-Antarctic islands, which are chronically cool and wet rather then extremely cold and frozen, these also don't look to me to behave differently to any other soild either.

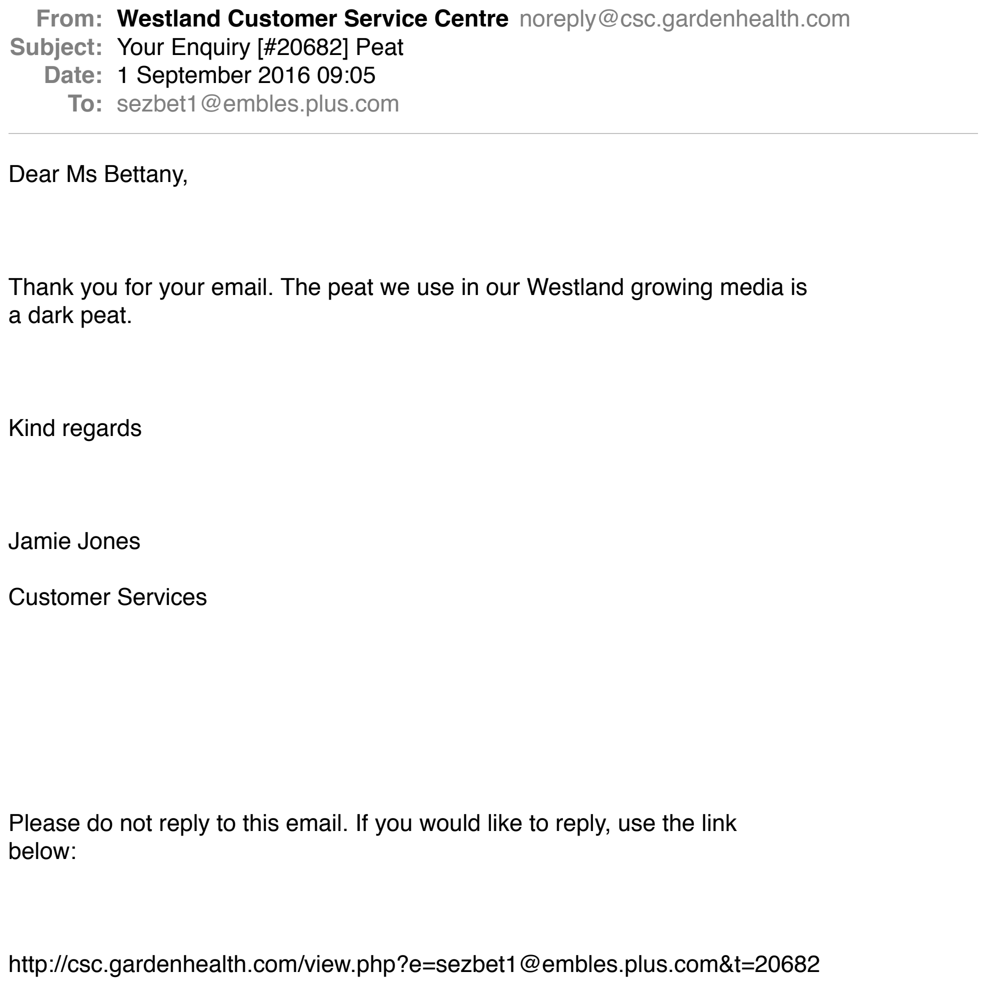
- although we do have soil samples here in Cambridge, plainly they are not in the natural condition (they will either have been stored dried or frozen, and in either case disturbed), so i don't think it would be possible to test this as of now.

Best wishes
pete

Prof Peter Convey

Individual Merit Scientist
British Antarctic Survey
High Cross
Madingley Road
Cambridge CB3 0ET
United Kingdom

Email from Westland Horticulture about peat:



From: **Westland Customer Service Centre** noreply@csc.gardenhealth.com
Subject: Your Enquiry [#20682] Peat
Date: 1 September 2016 09:05
To: sezbet1@embles.plus.com

Dear Ms Bettany,

Thank you for your email. The peat we use in our Westland growing media is a dark peat.

Kind regards

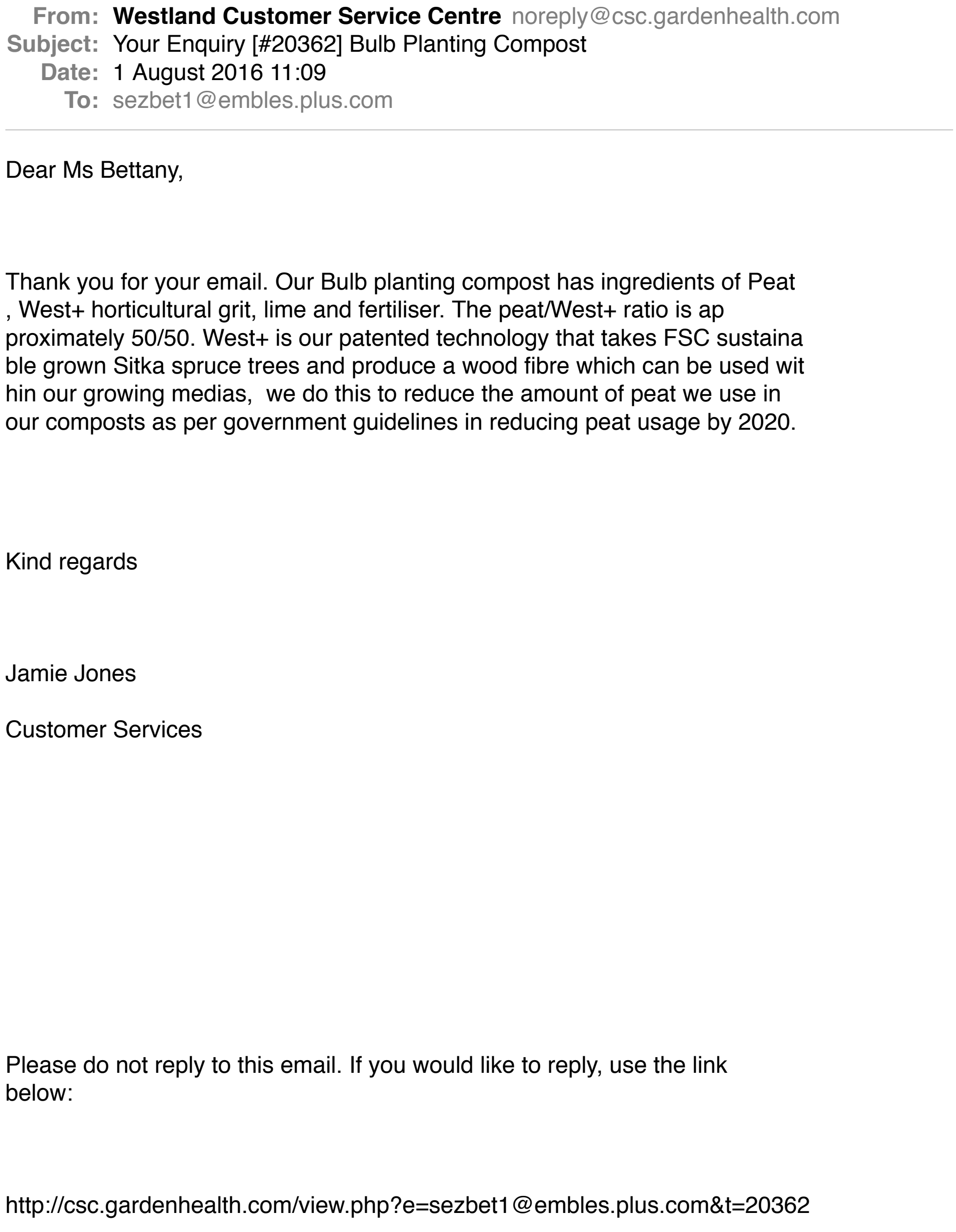
Jamie Jones

Customer Services

Please do not reply to this email. If you would like to reply, use the link below:

http://csc.gardenhealth.com/view.php?e=sezbet1@embles.plus.com&t=20682

Email from Westland Horticulture regarding bulb fibre substrate:



From: **Westland Customer Service Centre** noreply@csc.gardenhealth.com
Subject: Your Enquiry [#20362] Bulb Planting Compost
Date: 1 August 2016 11:09
To: sezbet1@embles.plus.com

Dear Ms Bettany,

Thank you for your email. Our Bulb planting compost has ingredients of Peat , West+ horticultural grit, lime and fertiliser. The peat/West+ ratio is approximately 50/50. West+ is our patented technology that takes FSC sustainable grown Sitka spruce trees and produce a wood fibre which can be used within our growing medias, we do this to reduce the amount of peat we use in our composts as per government guidelines in reducing peat usage by 2020.

Kind regards

Jamie Jones

Customer Services

Please do not reply to this email. If you would like to reply, use the link below:

http://csc.gardenhealth.com/view.php?e=sezbet1@embles.plus.com&t=20362

Email from Melcourt Industries regarding the substrate mix designed for Watering Lane nursery:

From: **Neil Gray** Neil.Gray@melcourt.co.uk
Subject: RE: Watering Lane Nursery
Date: 12 July 2017 15:59
To: sezbet@me.com

Dear Sarah

The formulation for the Eden Mix is as follows:

Melcourt Growbark Pine	40%
Melcourt Sylvafibre	50%
Sterilised Loam	10%
Magnesium Limestone	1kg/m^3
Base fertiliser	1.5kg/m^3
Calcium Ammonium Nitrate	0.4kg/m^3
Wetter	

I have attached the technical data sheets for the Growbark and Sylvafibre for your information.

Please feel free in contacting me if you require additional information on the growing media that has been used in your trials.

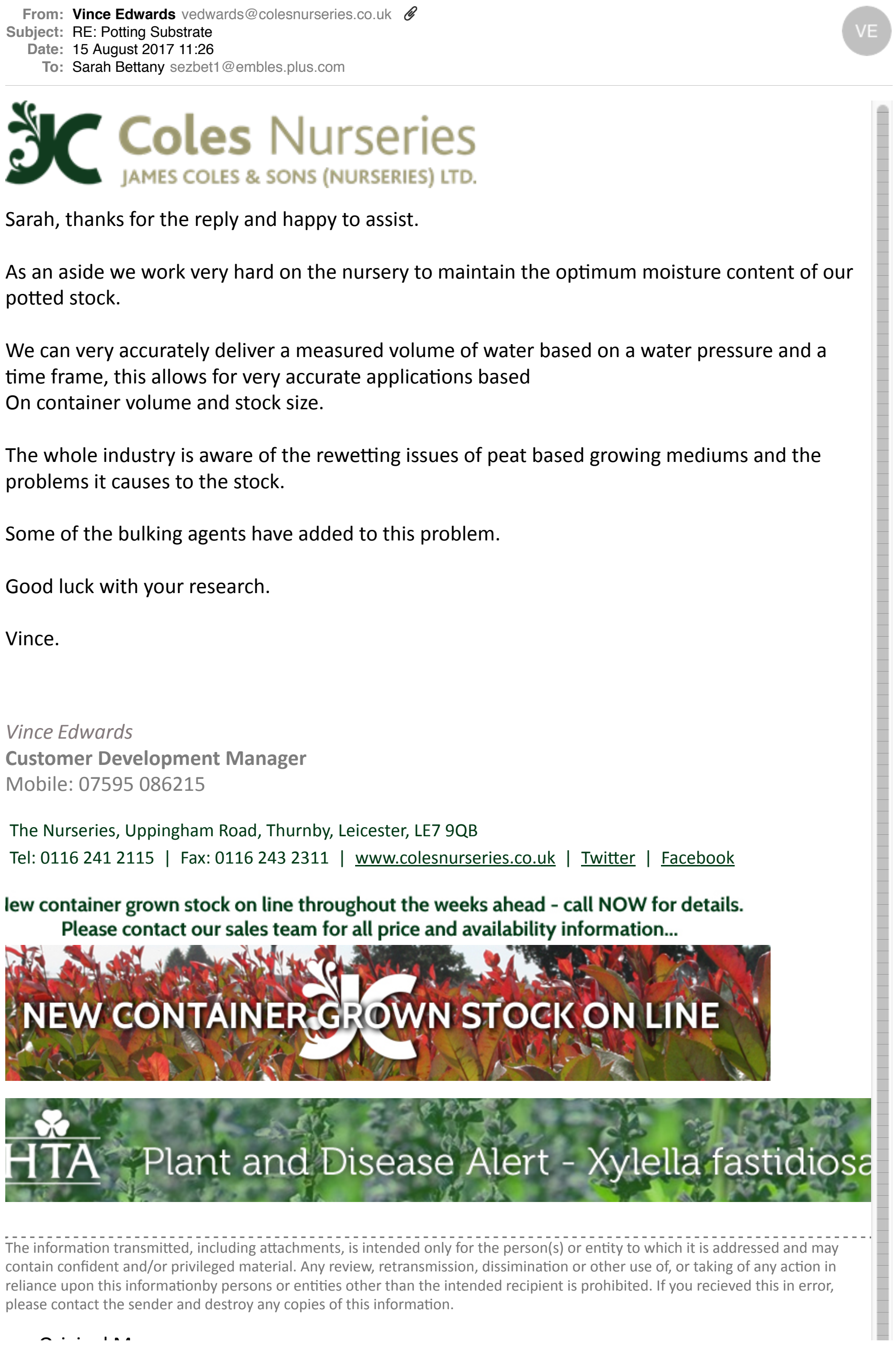
Many thanks and good luck with writing up your Thesis.

Neil Gray
Technical Sales Manager

Melcourt
Industries Limited
Proven • Safe • Sustainable

Melcourt Industries Ltd, Boldridge Brake, Long Newnton, Tetbury, Glos GL8 8RT.
Tel: 01403 731533 Mobile: 07850 670511
Email: neil@melcourt.co.uk Website: www.melcourt.co.uk
Registered in England No 1734220

Email from Vince Edwards regarding hydrophobicity in potting substrates:



From: **Vince Edwards** vedwards@colesnurseries.co.uk
Subject: RE: Potting Substrate
Date: 15 August 2017 11:26
To: Sarah Bettany sezbet1@embles.plus.com

Sarah, thanks for the reply and happy to assist.

As an aside we work very hard on the nursery to maintain the optimum moisture content of our potted stock.

We can very accurately deliver a measured volume of water based on a water pressure and a time frame, this allows for very accurate applications based
On container volume and stock size.

The whole industry is aware of the rewetting issues of peat based growing mediums and the problems it causes to the stock.

Some of the bulking agents have added to this problem.

Good luck with your research.

Vince.

Vince Edwards
Customer Development Manager
Mobile: 07595 086215

The Nurseries, Uppingham Road, Thurnby, Leicester, LE7 9QB
Tel: 0116 241 2115 | Fax: 0116 243 2311 | www.colesnurseries.co.uk | Twitter | Facebook

lew container grown stock on line throughout the weeks ahead - call NOW for details.
Please contact our sales team for all price and availability information...

Message from Timstar regarding the sieves used in this study:

From: **Melanie Webb** [redacted]
Subject: Sieves
Date: 7 August 2016 19:47
To: sezbet@me.com

Reply from supplier regarding soil sieve sizes...

From: Timstar [sales@timstar.co.uk]
Sent: 05 August 2016 15:16
To: Melanie Webb
Subject: Your Question Posted

[Timstar]<http://www.timstar.co.uk/index.php/>
Dear Melanie Webb,

Thankyou for asking Question...

Here is information of your Query/Question.

Question Status : Active.

Asked By : Melanie Webb

Your Email : melanie.webb@duchy.ac.uk

Your Question : Are the 'mesh numbers' from the BS-410 or TYLER system, or do they refer to um? If possible, could you provide the numbers in mm?Many thanks

Answer : The most closely match the US system, but there are some differences. Mesh Aperture 10 2 mm 20 900 microns 30 600 microns 40 400 microns 60 250 microns 80 200 microns 100 140 microns 120 125 microns 250 63 microns

Thank you again, Timstar

Appendix 3 Lab-based experiments raw data

A3.1 Bulb fibre physical data

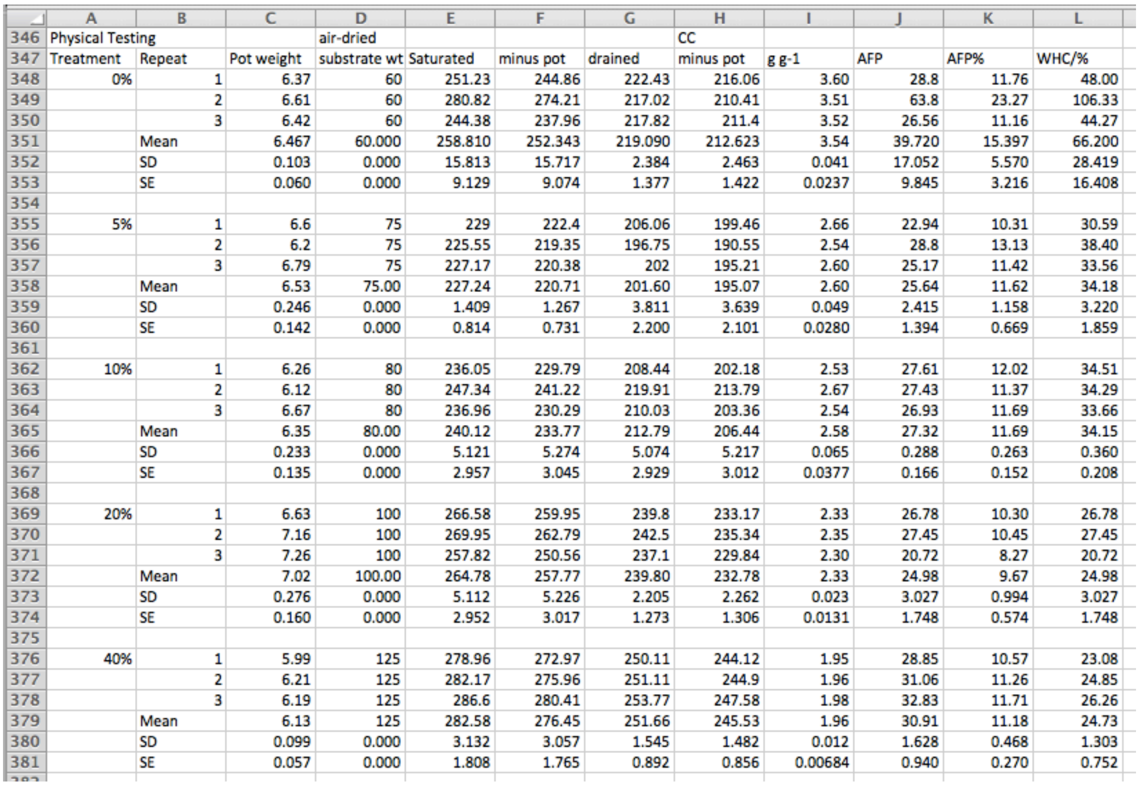
Table A3.1.1 Particle distribution of bulb fibre (50% peat, with composted wood and grit), with different concentrations of kaolinite by % weight, between <2mm and >0.063mm.

Sieve data		Treatment				
Mesh size	mm^{-1}	0%	5%	10%	20%	40%
		Weight of sieved fractions g^{-1}				
>10	2	52.85	46.54	39.83	34.52	20.14
10	0.841	14.93	12.97	13.76	11.98	10.89
20	0.595	8.12	7.6	7.47	7.33	9.02
30	0.420	3.81	4.1	3.93	4.29	5.67
40	0.250	7.52	8.99	8.94	10.75	13.99
60	0.177	4.58	6.43	6.92	9.05	12.34
80	0.149	0.8	1.26	1.54	2.58	4.7
100	0.125	1.8	3.21	3.79	5.52	16.12
120	0.063	4	6.84	10.52	12.69	7.98
250	<0.063	1.81	1.92	1.81	0.89	0.23
	Total	100.22	99.86	99.51	99.6	101.08

Table A3.1.2 comparisons of moisture content and volumes of bulb fibre (50% peat with composted wood and grit) with different concentrations, by % weight, of kaolinite.

Treatment % Kaolinite	Fresh weight g^{-1}	Oven-dried weight g^{-1}	% difference g^{-1}	Fresh volume cm^3	Dried volume cm^3	% difference cm^3
0	100	55.97	44.03	254	115.22	54.63
5	100	57.38	42.62	273	177.8	34.87
10	100	58.7	41.3	265	162.22	38.78
20	100	61.37	38.63	249	146.67	41.1
40	100	71.32	28.68	209	133.33	36.21

A3.1.3 Physical testing results: raw data



	A	B	C	D	E	F	G	H	I	J	K	L
346	Physical Testing			air-dried				CC				
347	Treatment	Repeat	Pot weight	substrate wt	Saturated	minus pot	drained	minus pot	g g-1	AFP	AFP%	WHC/%
348	0%	1	6.37	60	251.23	244.86	222.43	216.06	3.60	28.8	11.76	48.00
349		2	6.61	60	280.82	274.21	217.02	210.41	3.51	63.8	23.27	106.33
350		3	6.42	60	244.38	237.96	217.82	211.4	3.52	26.56	11.16	44.27
351		Mean	6.467	60.000	258.810	252.343	219.090	212.623	3.54	39.720	15.397	66.200
352		SD	0.103	0.000	15.813	15.717	2.384	2.463	0.041	17.052	5.570	28.419
353		SE	0.060	0.000	9.129	9.074	1.377	1.422	0.0237	9.845	3.216	16.408
354												
355	5%	1	6.6	75	229	222.4	206.06	199.46	2.66	22.94	10.31	30.59
356		2	6.2	75	225.55	219.35	196.75	190.55	2.54	28.8	13.13	38.40
357		3	6.79	75	227.17	220.38	202	195.21	2.60	25.17	11.42	33.56
358		Mean	6.53	75.00	227.24	220.71	201.60	195.07	2.60	25.64	11.62	34.18
359		SD	0.246	0.000	1.409	1.267	3.811	3.639	0.049	2.415	1.158	3.220
360		SE	0.142	0.000	0.814	0.731	2.200	2.101	0.0280	1.394	0.669	1.859
361												
362	10%	1	6.26	80	236.05	229.79	208.44	202.18	2.53	27.61	12.02	34.51
363		2	6.12	80	247.34	241.22	219.91	213.79	2.67	27.43	11.37	34.29
364		3	6.67	80	236.96	230.29	210.03	203.36	2.54	26.93	11.69	33.66
365		Mean	6.35	80.00	240.12	233.77	212.79	206.44	2.58	27.32	11.69	34.15
366		SD	0.233	0.000	5.121	5.274	5.074	5.217	0.065	0.288	0.263	0.360
367		SE	0.135	0.000	2.957	3.045	2.929	3.012	0.0377	0.166	0.152	0.208
368												
369	20%	1	6.63	100	266.58	259.95	239.8	233.17	2.33	26.78	10.30	26.78
370		2	7.16	100	269.95	262.79	242.5	235.34	2.35	27.45	10.45	27.45
371		3	7.26	100	257.82	250.56	237.1	229.84	2.30	20.72	8.27	20.72
372		Mean	7.02	100.00	264.78	257.77	239.80	232.78	2.33	24.98	9.67	24.98
373		SD	0.276	0.000	5.112	5.226	2.205	2.262	0.023	3.027	0.994	3.027
374		SE	0.160	0.000	2.952	3.017	1.273	1.306	0.0131	1.748	0.574	1.748
375												
376	40%	1	5.99	125	278.96	272.97	250.11	244.12	1.95	28.85	10.57	23.08
377		2	6.21	125	282.17	275.96	251.11	244.9	1.96	31.06	11.26	24.85
378		3	6.19	125	286.6	280.41	253.77	247.58	1.98	32.83	11.71	26.26
379		Mean	6.13	125	282.58	276.45	251.66	245.53	1.96	30.91	11.18	24.73
380		SD	0.099	0.000	3.132	3.057	1.545	1.482	0.012	1.628	0.468	1.303
381		SE	0.057	0.000	1.808	1.765	0.892	0.856	0.00684	0.940	0.270	0.752

One-Way ANOVA: WHC versus Treatment3

Method

```
Null hypothesis          H0: All means are equal
Alternative hypothesis   H1: At least one mean is different

Equal variances were assumed for the analysis.
```

Factor Information

```
Factor      Levels  Values
Treatment3       5  0%, 10%, 20%, 40%, 5%
```

Analysis of Variance

```
Source      DF   Adj SS   Adj MS  F-Value  P-Value
Treatment3   4  3490.55  872.638     3.51   0.0488
Error       10  2486.62  248.662
Total       14  5977.17
```

Model Summary

```
      S    R-sq  R-sq(adj)  R-sq(pred)
15.7690  58.40%     41.76%       6.40%
```

Means

```
Treatment3  N     Mean   StDev             95% CI
0%          3    66.20   34.80       (45.91, 86.49)
10%         3  34.1533  0.4412  (13.8678, 54.4389)
20%         3   24.983   3.707     (4.698, 45.269)
40%         3  24.7300  1.5934   (4.4445, 45.0155)
5%          3   34.183   3.942    (13.898, 54.469)

Pooled StDev = 15.7690
```

Kruskal-Wallis: CC gg versus Treatment3

Descriptive Statistics

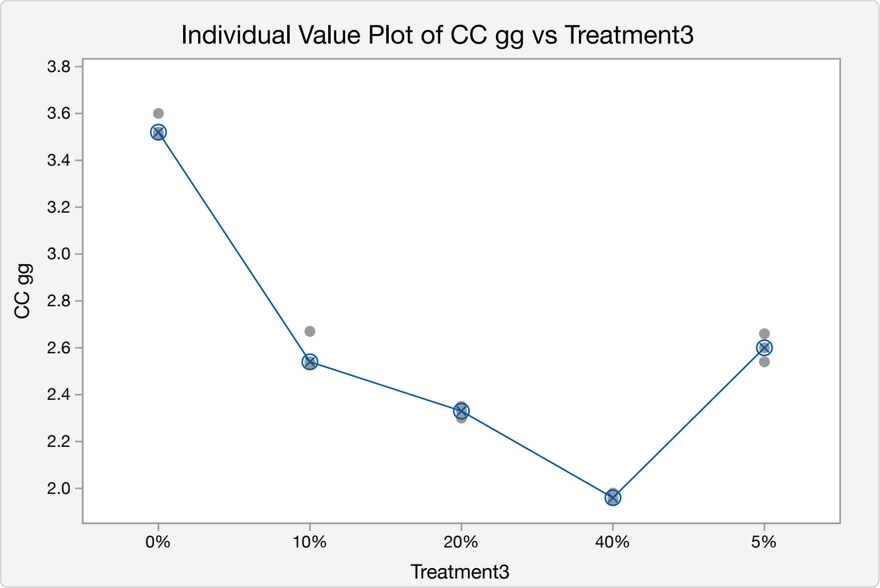
Treatment3	N	Median	Mean Rank	Z-Value
0%	3	3.52	14.0	2.60
10%	3	2.54	9.2	0.51
20%	3	2.33	5.0	-1.30
40%	3	1.96	2.0	-2.60
5%	3	2.60	9.8	0.79
Overall	15		8.0	

The chi-square approximation may not be accurate when some sample sizes are less than 5.

Test

Null hypothesis	H_0: All medians are equal
Alternative hypothesis	H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	4	12.86	0.0120
Adjusted for ties	4	12.88	0.0119



One-Way ANOVA: CC gg versus Treatment3

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment3	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment3	4	4.11089	1.02772	395.28	<0.0001
Error	10	0.02600	0.00260		
Total	14	4.13689			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0509902	99.37%	99.12%	98.59%

Means

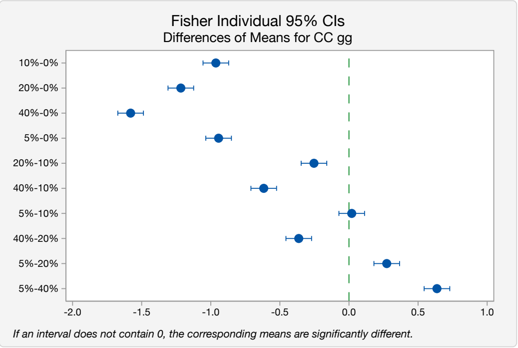
Treatment3	N	Mean	StDev	95% CI
0%	3	3.54333	0.04933	(3.47774, 3.60893)
10%	3	2.58000	0.07810	(2.51441, 2.64559)
20%	3	2.32667	0.02517	(2.26107, 2.39226)
40%	3	1.96333	0.015275	(1.89774, 2.02893)
5%	3	2.60000	0.06000	(2.53441, 2.66559)

Pooled StDev = 0.0509902

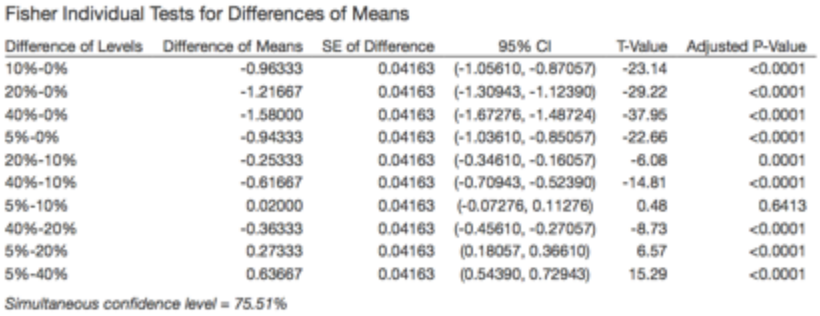
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment3	N	Mean	Grouping			
0%	3	3.54333	A			
5%	3	2.60000		B		
10%	3	2.58000		B		
20%	3	2.32667			C	
40%	3	1.96333				D

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-0.96333	0.04163	(-1.05610, -0.87057)	-23.14	<0.0001
20%-0%	-1.21667	0.04163	(-1.30943, -1.12390)	-29.22	<0.0001
40%-0%	-1.58000	0.04163	(-1.67276, -1.48724)	-37.95	<0.0001
5%-0%	-0.94333	0.04163	(-1.03610, -0.85057)	-22.66	<0.0001
20%-10%	-0.25333	0.04163	(-0.34610, -0.16057)	-6.08	0.0001
40%-10%	-0.61667	0.04163	(-0.70943, -0.52390)	-14.81	<0.0001
5%-10%	0.02000	0.04163	(-0.07276, 0.11276)	0.48	0.6413
40%-20%	-0.36333	0.04163	(-0.45610, -0.27057)	-8.73	<0.0001
5%-20%	0.27333	0.04163	(0.18057, 0.36610)	6.57	<0.0001
5%-40%	0.63667	0.04163	(0.54390, 0.72943)	15.29	<0.0001

Simultaneous confidence level = 75.51%

One-Way ANOVA: AFP versus Treatment3

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment3	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment3	4	53.470	13.3676	1.32	0.3265
Error	10	101.036	10.1036		
Total	14	154.506			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.17862	34.61%	8.45%	0.00%

Means

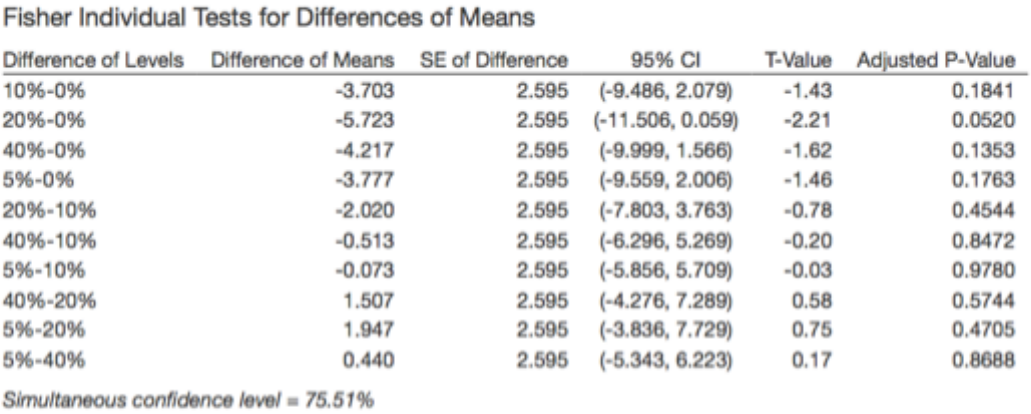
Treatment3	N	Mean	StDev	95% CI
0%	3	15.397	6.825	(11.308, 19.486)
10%	3	11.6933	0.3250	(7.6043, 15.7824)
20%	3	9.6733	1.2176	(5.5843, 13.7624)
40%	3	11.1800	0.5742	(7.0910, 15.2690)
5%	3	11.6200	1.4206	(7.5310, 15.7090)

Pooled StDev = 3.17862

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment3	N	Mean	Grouping
0%	3	15.397	A
10%	3	11.6933	A
5%	3	11.6200	A
40%	3	11.1800	A
20%	3	9.6733	A

Means that do not share a letter are significantly different.

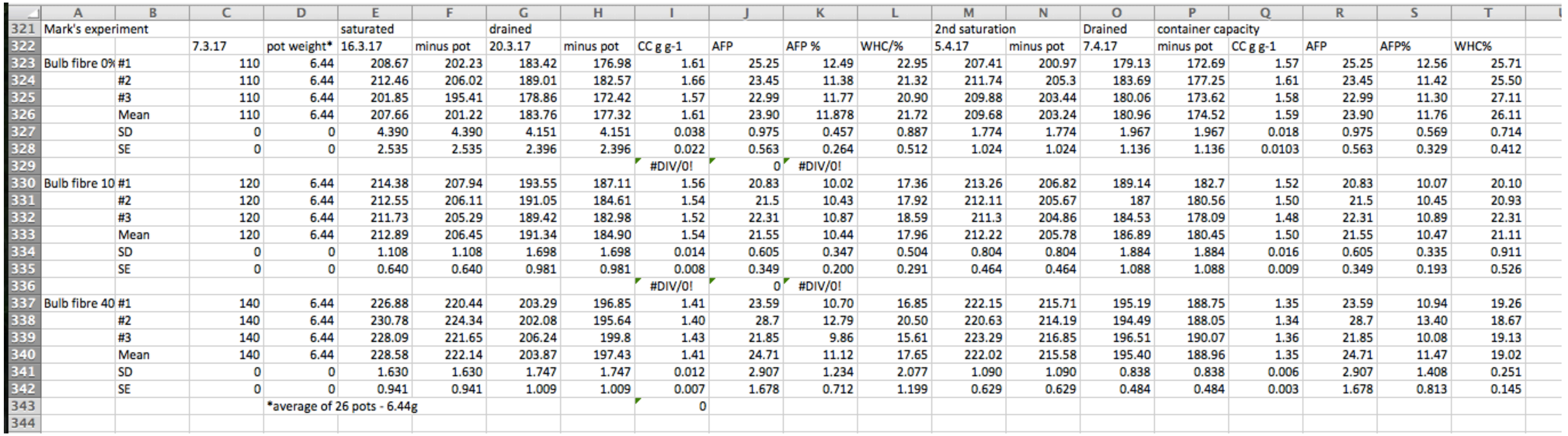


Fisher Individual Tests for Differences of Means

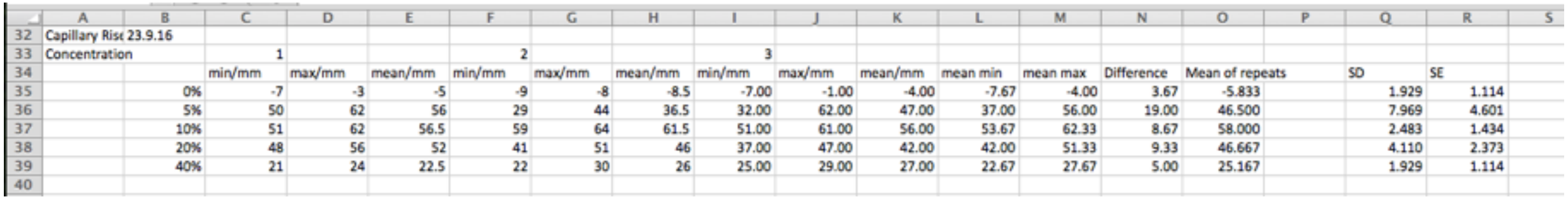
Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-3.703	2.595	(-9.486, 2.079)	-1.43	0.1841
20%-0%	-5.723	2.595	(-11.506, 0.059)	-2.21	0.0520
40%-0%	-4.217	2.595	(-9.999, 1.566)	-1.62	0.1353
5%-0%	-3.777	2.595	(-9.559, 2.006)	-1.46	0.1763
20%-10%	-2.020	2.595	(-7.803, 3.763)	-0.78	0.4544
40%-10%	-0.513	2.595	(-6.296, 5.269)	-0.20	0.8472
5%-10%	-0.073	2.595	(-5.856, 5.709)	-0.03	0.9780
40%-20%	1.507	2.595	(-4.276, 7.289)	0.58	0.5744
5%-20%	1.947	2.595	(-3.836, 7.729)	0.75	0.4705
5%-40%	0.440	2.595	(-5.343, 6.223)	0.17	0.8688

Simultaneous confidence level = 75.51%

A3.1.4 Test of repeated wetting/drying and capillary rise test: raw data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
321	Mark's experiment				saturated		drained						2nd saturation		Drained	container capacity				
322			7.3.17	pot weight*	16.3.17	minus pot	20.3.17	minus pot	CC g g-1	AFP	AFP %	WHC/%	5.4.17	minus pot	7.4.17	minus pot	CC g g-1	AFP	AFP%	WHC%
323	Bulb fibre 0%	#1	110	6.44	208.67	202.23	183.42	176.98	1.61	25.25	12.49	22.95	207.41	200.97	179.13	172.69	1.57	25.25	12.56	25.71
324		#2	110	6.44	212.46	206.02	189.01	182.57	1.66	23.45	11.38	21.32	211.74	205.3	183.69	177.25	1.61	23.45	11.42	25.50
325		#3	110	6.44	201.85	195.41	178.86	172.42	1.57	22.99	11.77	20.90	209.88	203.44	180.06	173.62	1.58	22.99	11.30	27.11
326		Mean	110	6.44	207.66	201.22	183.76	177.32	1.61	23.90	11.878	21.72	209.68	203.24	180.96	174.52	1.59	23.90	11.76	26.11
327		SD	0	0	4.390	4.390	4.151	4.151	0.038	0.975	0.457	0.887	1.774	1.774	1.967	1.967	0.018	0.975	0.569	0.714
328		SE	0	0	2.535	2.535	2.396	2.396	0.022	0.563	0.264	0.512	1.024	1.024	1.136	1.136	0.0103	0.563	0.329	0.412
329									#DIV/0!	0	#DIV/0!									
330	Bulb fibre 10	#1	120	6.44	214.38	207.94	193.55	187.11	1.56	20.83	10.02	17.36	213.26	206.82	189.14	182.7	1.52	20.83	10.07	20.10
331		#2	120	6.44	212.55	206.11	191.05	184.61	1.54	21.5	10.43	17.92	212.11	205.67	187	180.56	1.50	21.5	10.45	20.93
332		#3	120	6.44	211.73	205.29	189.42	182.98	1.52	22.31	10.87	18.59	211.3	204.86	184.53	178.09	1.48	22.31	10.89	22.31
333		Mean	120	6.44	212.89	206.45	191.34	184.90	1.54	21.55	10.44	17.96	212.22	205.78	186.89	180.45	1.50	21.55	10.47	21.11
334		SD	0	0	1.108	1.108	1.698	1.698	0.014	0.605	0.347	0.504	0.804	0.804	1.884	1.884	0.016	0.605	0.335	0.911
335		SE	0	0	0.640	0.640	0.981	0.981	0.008	0.349	0.200	0.291	0.464	0.464	1.088	1.088	0.009	0.349	0.193	0.526
336									#DIV/0!	0	#DIV/0!									
337	Bulb fibre 40	#1	140	6.44	226.88	220.44	203.29	196.85	1.41	23.59	10.70	16.85	222.15	215.71	195.19	188.75	1.35	23.59	10.94	19.26
338		#2	140	6.44	230.78	224.34	202.08	195.64	1.40	28.7	12.79	20.50	220.63	214.19	194.49	188.05	1.34	28.7	13.40	18.67
339		#3	140	6.44	228.09	221.65	206.24	199.8	1.43	21.85	9.86	15.61	223.29	216.85	196.51	190.07	1.36	21.85	10.08	19.13
340		Mean	140	6.44	228.58	222.14	203.87	197.43	1.41	24.71	11.12	17.65	222.02	215.58	195.40	188.96	1.35	24.71	11.47	19.02
341		SD	0	0	1.630	1.630	1.747	1.747	0.012	2.907	1.234	2.077	1.090	1.090	0.838	0.838	0.006	2.907	1.408	0.251
342		SE	0	0	0.941	0.941	1.009	1.009	0.007	1.678	0.712	1.199	0.629	0.629	0.484	0.484	0.003	1.678	0.813	0.145
343				*average of 26 pots - 6.44g					0											
344																				



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
32	Capillary Rise	23.9.16																	
33	Concentration		1			2			3										
34			min/mm	max/mm	mean/mm	min/mm	max/mm	mean/mm	min/mm	max/mm	mean/mm	mean min	mean max	Difference	Mean of repeats		SD	SE	
35		0%	-7	-3	-5	-9	-8	-8.5	-7.00	-1.00	-4.00	-7.67	-4.00	3.67	-5.833		1.929	1.114	
36		5%	50	62	56	29	44	36.5	32.00	62.00	47.00	37.00	56.00	19.00	46.500		7.969	4.601	
37		10%	51	62	56.5	59	64	61.5	51.00	61.00	56.00	53.67	62.33	8.67	58.000		2.483	1.434	
38		20%	48	56	52	41	51	46	37.00	47.00	42.00	42.00	51.33	9.33	46.667		4.110	2.373	
39		40%	21	24	22.5	22	30	26	25.00	29.00	27.00	22.67	27.67	5.00	25.167		1.929	1.114	
40																			

One-Way ANOVA: Capillary Rise versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	7672.1	1918.03	68.02	<0.0001
Error	10	282.0	28.20		
Total	14	7954.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.31037	96.45%	95.04%	92.02%

Means

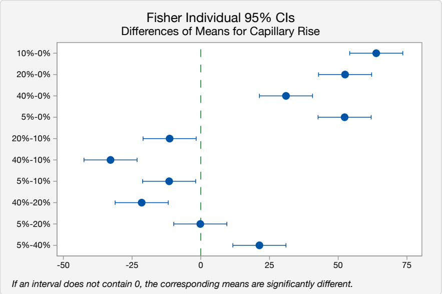
Treatment1	N	Mean	StDev	95% CI
0%	3	-5.833	2.363	(-12.665, 0.998)
10%	3	58.000	3.041	(51.169, 64.831)
20%	3	46.667	5.033	(39.835, 53.498)
40%	3	25.167	2.363	(18.335, 31.998)
5%	3	46.500	9.760	(39.669, 53.331)

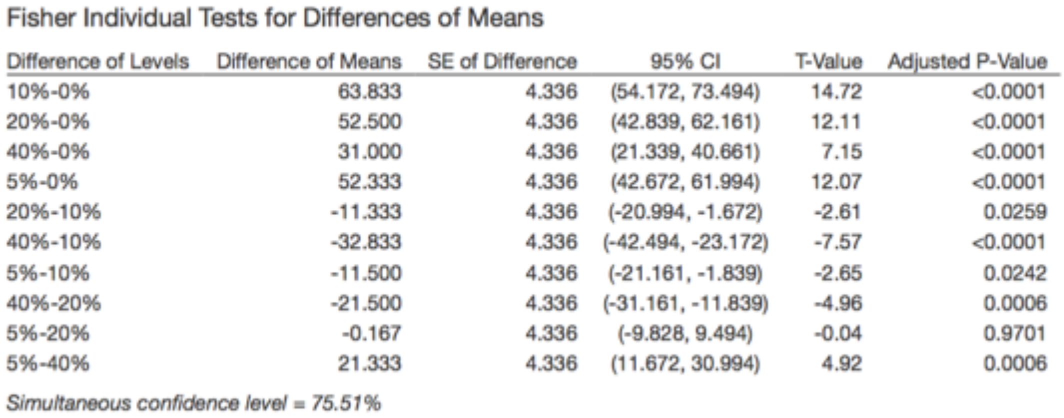
Pooled StDev = 5.31037

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping			
10%	3	58.000	A			
20%	3	46.667		B		
5%	3	46.500		B		
40%	3	25.167			C	
0%	3	-5.833				D

Means that do not share a letter are significantly different.



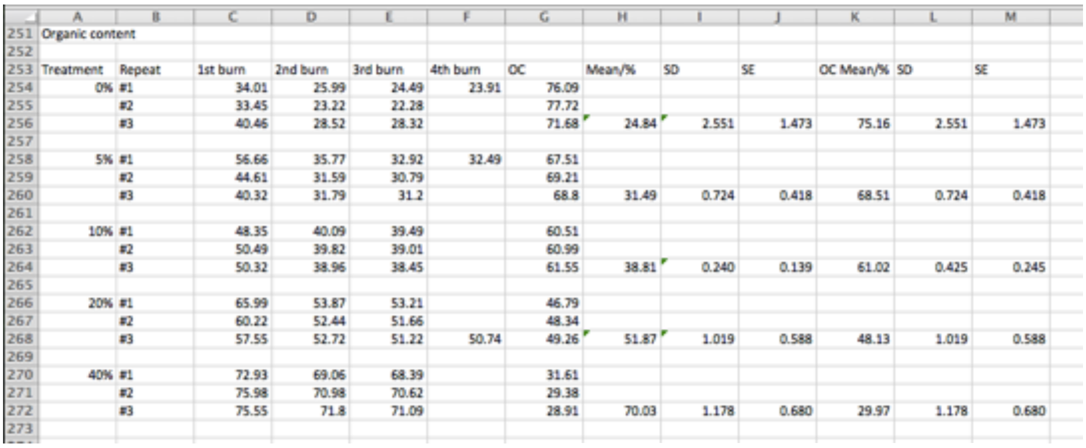


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	63.833	4.336	(54.172, 73.494)	14.72	<0.0001
20%-0%	52.500	4.336	(42.839, 62.161)	12.11	<0.0001
40%-0%	31.000	4.336	(21.339, 40.661)	7.15	<0.0001
5%-0%	52.333	4.336	(42.672, 61.994)	12.07	<0.0001
20%-10%	-11.333	4.336	(-20.994, -1.672)	-2.61	0.0259
40%-10%	-32.833	4.336	(-42.494, -23.172)	-7.57	<0.0001
5%-10%	-11.500	4.336	(-21.161, -1.839)	-2.65	0.0242
40%-20%	-21.500	4.336	(-31.161, -11.839)	-4.96	0.0006
5%-20%	-0.167	4.336	(-9.828, 9.494)	-0.04	0.9701
5%-40%	21.333	4.336	(11.672, 30.994)	4.92	0.0006

Simultaneous confidence level = 75.51%

A3.1.5 Organic content: raw data



	A	B	C	D	E	F	G	H	I	J	K	L	M
251	Organic content												
252													
253	Treatment	Repeat	1st burn	2nd burn	3rd burn	4th burn	OC	Mean/%	SD	SE	OC Mean/%	SD	SE
254	0%	#1	34.01	25.99	24.49	23.91	76.09						
255		#2	33.45	23.22	22.28		77.72						
256		#3	40.46	28.52	28.32		71.68	24.84	2.551	1.473	75.16	2.551	1.473
257													
258	5%	#1	56.66	35.77	32.92	32.49	67.51						
259		#2	44.61	31.59	30.79		69.21						
260		#3	40.32	31.79	31.2		68.8	31.49	0.724	0.418	68.51	0.724	0.418
261													
262	10%	#1	48.35	40.09	39.49		60.51						
263		#2	50.49	39.82	39.01		60.99						
264		#3	50.32	38.96	38.45		61.55	38.81	0.240	0.139	61.02	0.425	0.245
265													
266	20%	#1	65.99	53.87	53.21		46.79						
267		#2	60.22	52.44	51.66		48.34						
268		#3	57.55	52.72	51.22	50.74	49.26	51.87	1.019	0.588	48.13	1.019	0.588
269													
270	40%	#1	72.93	69.06	68.39		31.61						
271		#2	75.98	70.98	70.62		29.38						
272		#3	75.55	71.8	71.09		28.91	70.03	1.178	0.680	29.97	1.178	0.680
273													

One-Way ANOVA: Organic content versus Treatment3

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment3	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment3	4	3860.82	965.204	333.72	<0.0001
Error	10	28.92	2.892		
Total	14	3889.74			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.70067	99.26%	98.96%	98.33%

Means

Treatment3	N	Mean	StDev	95% CI
0%	3	75.163	3.125	(72.976, 77.351)
10%	3	61.0167	0.5205	(58.8289, 63.2044)
20%	3	48.1300	1.2483	(45.9422, 50.3178)
40%	3	29.9667	1.4424	(27.7789, 32.1544)
5%	3	68.5067	0.8871	(66.3189, 70.6944)

Pooled StDev = 1.70067

Grouping Information Using the Fisher LSD Method and 95% Confidence

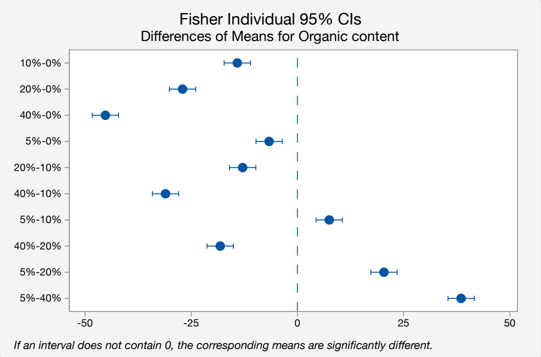
Treatment3	N	Mean	Grouping
0%	3	75.163	A
5%	3	68.5067	B
10%	3	61.0167	C
20%	3	48.1300	D
40%	3	29.9667	E

Means that do not share a letter are significantly different.

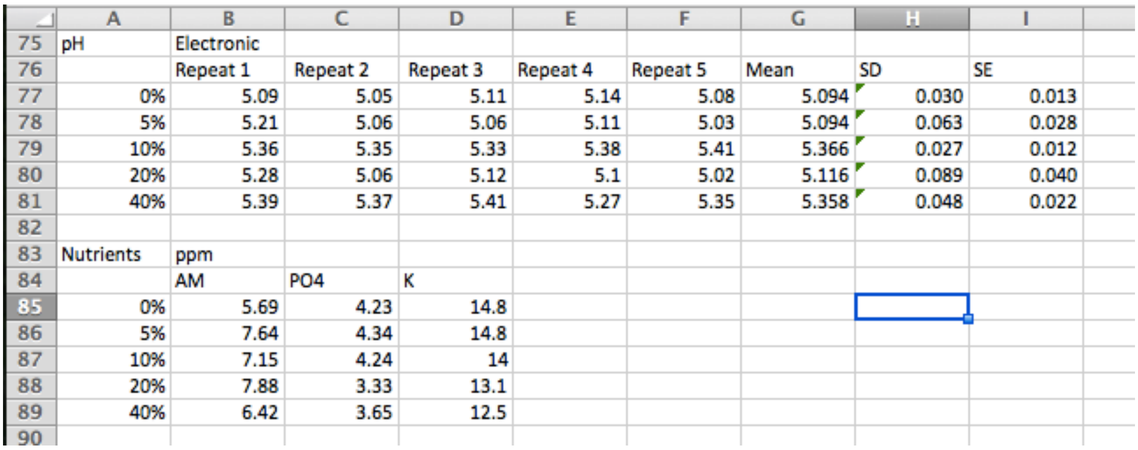
Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-14.147	1.389	(-17.241, -11.053)	-10.19	<0.0001
20%-0%	-27.033	1.389	(-30.127, -23.939)	-19.47	<0.0001
40%-0%	-45.197	1.389	(-48.291, -42.103)	-32.55	<0.0001
5%-0%	-6.657	1.389	(-9.751, -3.563)	-4.79	0.0007
20%-10%	-12.887	1.389	(-15.981, -9.793)	-9.28	<0.0001
40%-10%	-31.050	1.389	(-34.144, -27.956)	-22.36	<0.0001
5%-10%	7.490	1.389	(4.396, 10.584)	5.39	0.0003
40%-20%	-18.163	1.389	(-21.257, -15.069)	-13.08	<0.0001
5%-20%	20.377	1.389	(17.283, 23.471)	14.67	<0.0001
5%-40%	38.540	1.389	(35.446, 41.634)	27.75	<0.0001

Simultaneous confidence level = 75.51%



A3.1.6 pH and nutrients



	A	B	C	D	E	F	G	H	I
75	pH	Electronic							
76		Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5	Mean	SD	SE
77	0%	5.09	5.05	5.11	5.14	5.08	5.094	0.030	0.013
78	5%	5.21	5.06	5.06	5.11	5.03	5.094	0.063	0.028
79	10%	5.36	5.35	5.33	5.38	5.41	5.366	0.027	0.012
80	20%	5.28	5.06	5.12	5.1	5.02	5.116	0.089	0.040
81	40%	5.39	5.37	5.41	5.27	5.35	5.358	0.048	0.022
82									
83	Nutrients	ppm							
84		AM	PO4	K					
85	0%	5.69	4.23	14.8					
86	5%	7.64	4.34	14.8					
87	10%	7.15	4.24	14					
88	20%	7.88	3.33	13.1					
89	40%	6.42	3.65	12.5					
90									

One-Way ANOVA: pH versus Treatment

Method

```
Null hypothesis         H₀: All means are equal
Alternative hypothesis  H₁: At least one mean is different
Equal variances were assumed for the analysis.
```

Factor Information

```
Factor     Levels  Values
Treatment       5  0%, 10%, 20%, 40%, 5%
```

Analysis of Variance

```
Source     DF    Adj SS    Adj MS  F-Value  P-Value
Treatment   4  0.409456  0.102364    25.73  <0.0001
Error      20  0.079560  0.003978
Total      24  0.489016
```

Model Summary

```
        S    R-sq  R-sq(adj)  R-sq(pred)
0.0630714  83.73%     80.48%      74.58%
```

Means

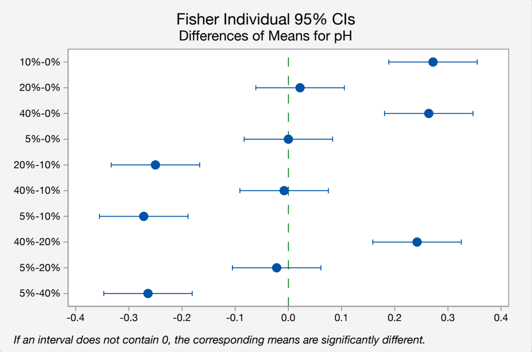
```
Treatment  N     Mean    StDev            95% CI
0%         5  5.09400  0.03362  (5.03516, 5.15284)
10%        5  5.36600  0.03050  (5.30716, 5.42484)
20%        5  5.11600  0.09940  (5.05716, 5.17484)
40%        5  5.35800  0.05404  (5.29916, 5.41684)
5%         5  5.09400  0.07092  (5.03516, 5.15284)
Pooled StDev = 0.0630714
```

Grouping Information Using the Fisher LSD Method and 95% Confidence

```
Treatment  N     Mean  Grouping
10%        5  5.36600  A
40%        5  5.35800  A
20%        5  5.11600     B
5%         5  5.09400     B
0%         5  5.09400     B
Means that do not share a letter are significantly different.
```

Fisher Individual Tests for Differences of Means

```
Difference  Difference  SE of                               Adjusted
of Levels   of Means    Difference       95% CI             T-Value  P-Value
10%-0%       0.27200    0.03989   (0.18879, 0.35521)          6.82   <0.0001
20%-0%       0.02200    0.03989   (-0.06121, 0.10521)         0.55    0.5874
40%-0%       0.26400    0.03989   (0.18079, 0.34721)          6.62   <0.0001
5%-0%        0.00000    0.03989   (-0.08321, 0.08321)         0.00    1.0000
20%-10%     -0.25000    0.03989   (-0.33321, -0.16679)       -6.27   <0.0001
40%-10%     -0.00800    0.03989   (-0.09121, 0.07521)        -0.20    0.8431
5%-10%      -0.27200    0.03989   (-0.35521, -0.18879)       -6.82   <0.0001
40%-20%      0.24200    0.03989   (0.15879, 0.32521)          6.07   <0.0001
5%-20%      -0.02200    0.03989   (-0.10521, 0.06121)        -0.55    0.5874
5%-40%      -0.26400    0.03989   (-0.34721, -0.18079)       -6.62   <0.0001
Simultaneous confidence level = 73.57%
```



A3.1.7 Water drop penetration time test results for bulb fibre

One-Way ANOVA: Time/s versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	92336468	23084117	730249.11	<0.0001
Error	40	1264	32		
Total	44	92337732			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.62239	100.00%	100.00%	100.00%

Means

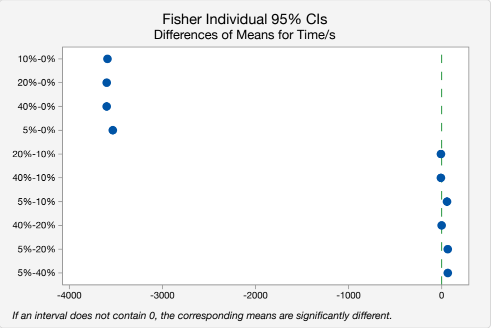
Treatment	N	Mean	StDev	95% CI
0%	9	3600	0	(3596.21, 3603.79)
10%	9	9.1622	1.3081	(5.3745, 12.9500)
20%	9	1.1489	0.3145	(-2.6389, 4.9366)
40%	9	0.78778	0.13065	(-2.99998, 4.57554)
5%	9	66.466	12.499	(62.678, 70.253)

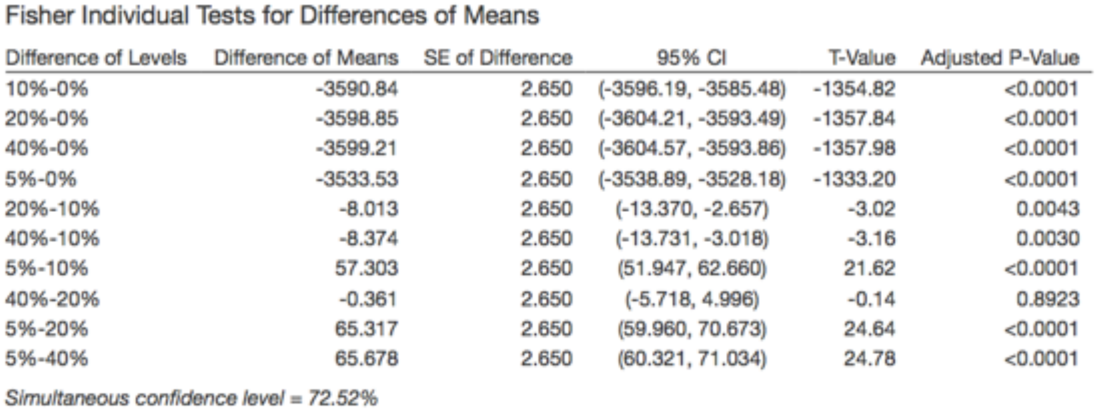
Pooled StDev = 5.62239

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping			
0%	9	3600	A			
5%	9	66.466		B		
10%	9	9.1622			C	
20%	9	1.1489				D
40%	9	0.78778				D

Means that do not share a letter are significantly different.





Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-3590.84	2.650	(-3596.19, -3585.48)	-1354.82	<0.0001
20%-0%	-3598.85	2.650	(-3604.21, -3593.49)	-1357.84	<0.0001
40%-0%	-3599.21	2.650	(-3604.57, -3593.86)	-1357.98	<0.0001
5%-0%	-3533.53	2.650	(-3538.89, -3528.18)	-1333.20	<0.0001
20%-10%	-8.013	2.650	(-13.370, -2.657)	-3.02	0.0043
40%-10%	-8.374	2.650	(-13.731, -3.018)	-3.16	0.0030
5%-10%	57.303	2.650	(51.947, 62.660)	21.62	<0.0001
40%-20%	-0.361	2.650	(-5.718, 4.996)	-0.14	0.8923
5%-20%	65.317	2.650	(59.960, 70.673)	24.64	<0.0001
5%-40%	65.678	2.650	(60.321, 71.034)	24.78	<0.0001

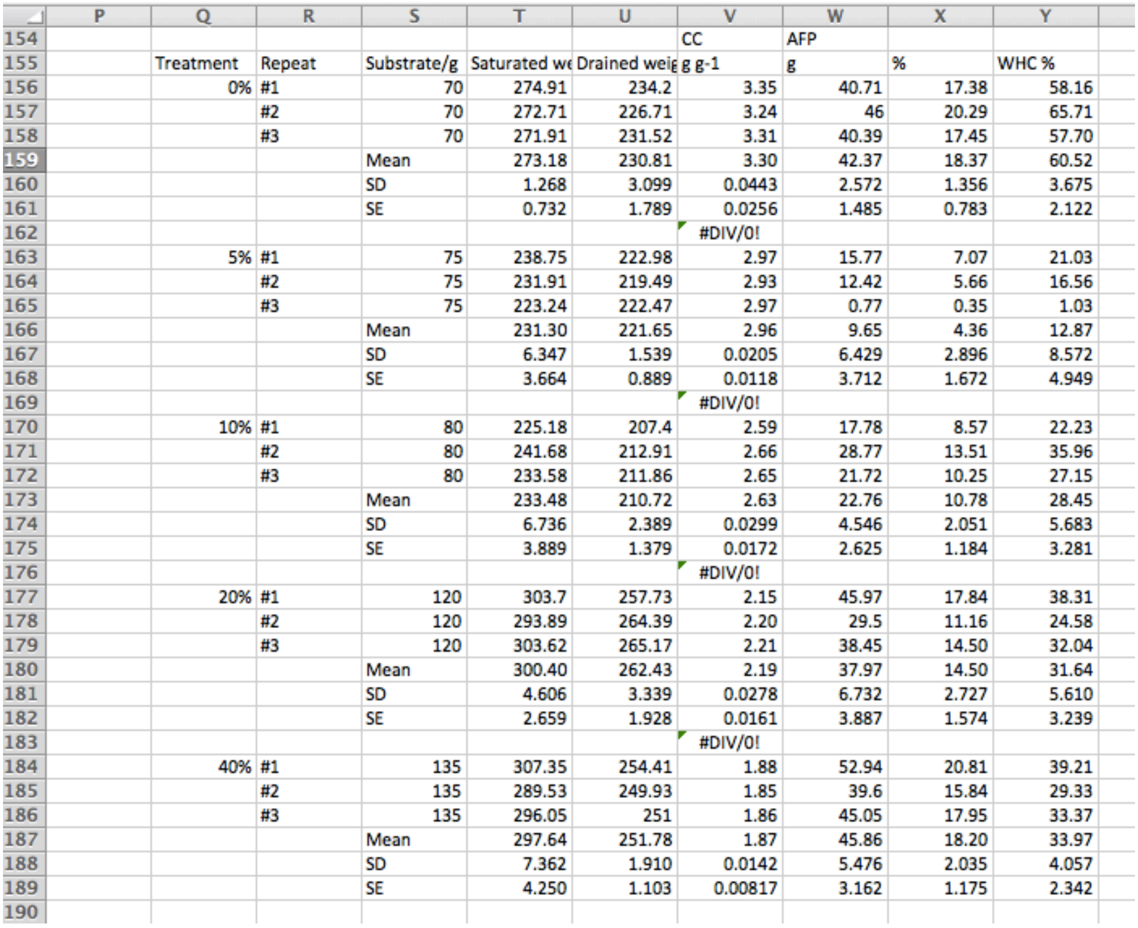
Simultaneous confidence level = 72.52%

3.2 Peat

Table 3.2.1 particle distribution of dark peat, with different concentrations of kaolinite by % weight, between <2mm and >0.063mm.

Sieve data		Treatment				
Mesh size	mm	0%	5%	10%	20%	40%
		Weight of sieved fractions g				
10	>2	21.77	20.74	17.34	14.91	8.53
20	2	18.59	15.59	13.92	11.69	14.91
30	0.9	12.42	11.9	11.99	12.22	13.91
40	0.6	8.38	7.14	8.28	8.39	8.25
60	0.4	14.9	16.89	18.89	19.47	20
80	0.25	9.83	9.83	10.06	12.45	12.64
100	0.2	1.65	3.46	2.49	3.2	3.44
120	0.14	3.75	7.12	5.39	6.91	2.93
250	0.125	7.18	6.66	10.82	10.13	14.77
<250	0.063	0.88	0.33	0.49	0.2	0.35
	Total	99.35	99.66	99.67	99.57	99.73

3.2.2 Physical tests: raw data



	P	Q	R	S	T	U	V	W	X	Y
154							CC	AFP		
155		Treatment	Repeat	Substrate/g	Saturated we	Drained weig	g g-1	g	%	WHC %
156		0%	#1	70	274.91	234.2	3.35	40.71	17.38	58.16
157			#2	70	272.71	226.71	3.24	46	20.29	65.71
158			#3	70	271.91	231.52	3.31	40.39	17.45	57.70
159				Mean	273.18	230.81	3.30	42.37	18.37	60.52
160				SD	1.268	3.099	0.0443	2.572	1.356	3.675
161				SE	0.732	1.789	0.0256	1.485	0.783	2.122
162							#DIV/0!			
163		5%	#1	75	238.75	222.98	2.97	15.77	7.07	21.03
164			#2	75	231.91	219.49	2.93	12.42	5.66	16.56
165			#3	75	223.24	222.47	2.97	0.77	0.35	1.03
166				Mean	231.30	221.65	2.96	9.65	4.36	12.87
167				SD	6.347	1.539	0.0205	6.429	2.896	8.572
168				SE	3.664	0.889	0.0118	3.712	1.672	4.949
169							#DIV/0!			
170		10%	#1	80	225.18	207.4	2.59	17.78	8.57	22.23
171			#2	80	241.68	212.91	2.66	28.77	13.51	35.96
172			#3	80	233.58	211.86	2.65	21.72	10.25	27.15
173				Mean	233.48	210.72	2.63	22.76	10.78	28.45
174				SD	6.736	2.389	0.0299	4.546	2.051	5.683
175				SE	3.889	1.379	0.0172	2.625	1.184	3.281
176							#DIV/0!			
177		20%	#1	120	303.7	257.73	2.15	45.97	17.84	38.31
178			#2	120	293.89	264.39	2.20	29.5	11.16	24.58
179			#3	120	303.62	265.17	2.21	38.45	14.50	32.04
180				Mean	300.40	262.43	2.19	37.97	14.50	31.64
181				SD	4.606	3.339	0.0278	6.732	2.727	5.610
182				SE	2.659	1.928	0.0161	3.887	1.574	3.239
183							#DIV/0!			
184		40%	#1	135	307.35	254.41	1.88	52.94	20.81	39.21
185			#2	135	289.53	249.93	1.85	39.6	15.84	29.33
186			#3	135	296.05	251	1.86	45.05	17.95	33.37
187				Mean	297.64	251.78	1.87	45.86	18.20	33.97
188				SD	7.362	1.910	0.0142	5.476	2.035	4.057
189				SE	4.250	1.103	0.00817	3.162	1.175	2.342
190										

One-Way ANOVA: WHC versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	3554.77	888.693	17.72	0.0002
Error	10	501.46	50.146		
Total	14	4056.23			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.08141	87.64%	82.69%	72.18%

Means

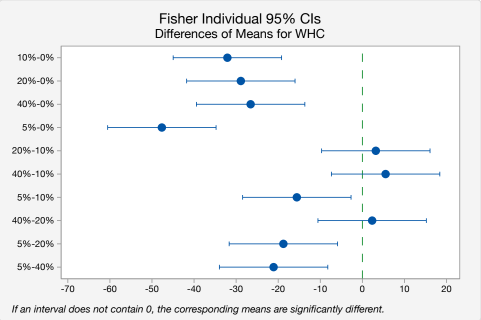
Treatment1	N	Mean	StDev	95% CI
0%	3	60.523	4.498	(51.414, 69.633)
10%	3	28.447	6.956	(19.337, 37.556)
20%	3	31.643	6.874	(22.534, 40.753)
40%	3	33.970	4.967	(24.860, 43.080)
5%	3	12.873	10.497	(3.764, 21.983)

Pooled StDev = 7.08141

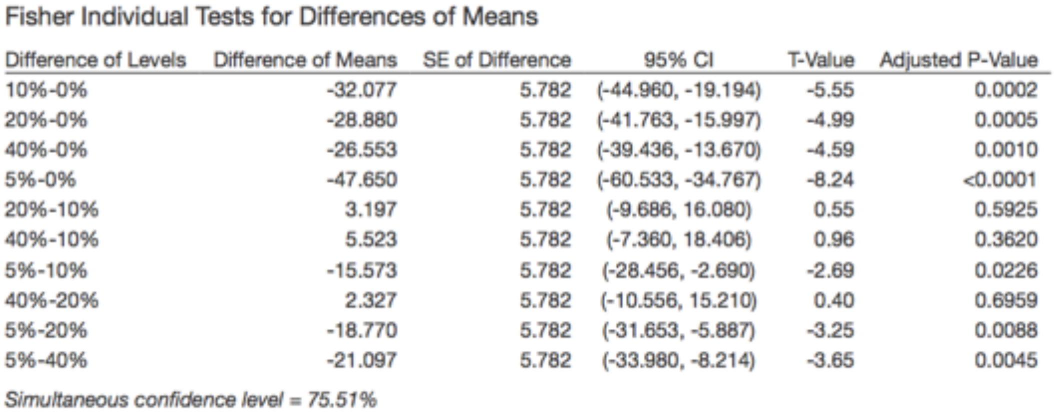
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping		
0%	3	60.523	A		
40%	3	33.970		B	
20%	3	31.643		B	
10%	3	28.447		B	
5%	3	12.873			C

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-32.077	5.782	(-44.960, -19.194)	-5.55	0.0002
20%-0%	-28.880	5.782	(-41.763, -15.997)	-4.99	0.0005
40%-0%	-26.553	5.782	(-39.436, -13.670)	-4.59	0.0010
5%-0%	-47.650	5.782	(-60.533, -34.767)	-8.24	<0.0001
20%-10%	3.197	5.782	(-9.686, 16.080)	0.55	0.5925
40%-10%	5.523	5.782	(-7.360, 18.406)	0.96	0.3620
5%-10%	-15.573	5.782	(-28.456, -2.690)	-2.69	0.0226
40%-20%	2.327	5.782	(-10.556, 15.210)	0.40	0.6959
5%-20%	-18.770	5.782	(-31.653, -5.887)	-3.25	0.0088
5%-40%	-21.097	5.782	(-33.980, -8.214)	-3.65	0.0045

Simultaneous confidence level = 75.51%

One-Way ANOVA: CC versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	3.99337	0.998343	788.17	<0.0001
Error	10	0.01267	0.001267		
Total	14	4.00604			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0355903	99.68%	99.56%	99.29%

Means

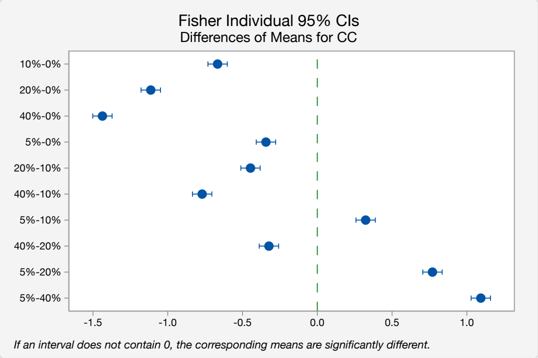
Treatment1	N	Mean	StDev	95% CI
0%	3	3.30000	0.05568	(3.25422, 3.34578)
10%	3	2.63333	0.03786	(2.58755, 2.67912)
20%	3	2.18667	0.03215	(2.14088, 2.23245)
40%	3	1.86333	0.015275	(1.81755, 1.90912)
5%	3	2.95667	0.02309	(2.91088, 3.00245)

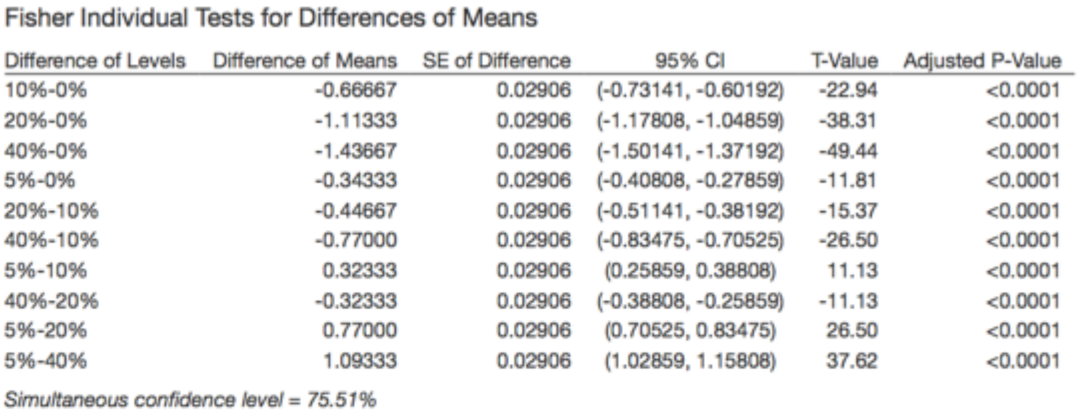
Pooled StDev = 0.0355903

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping				
0%	3	3.30000	A				
5%	3	2.95667		B			
10%	3	2.63333			C		
20%	3	2.18667				D	
40%	3	1.86333					E

Means that do not share a letter are significantly different.





Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-0.66667	0.02906	(-0.73141, -0.60192)	-22.94	<0.0001
20%-0%	-1.11333	0.02906	(-1.17808, -1.04859)	-38.31	<0.0001
40%-0%	-1.43667	0.02906	(-1.50141, -1.37192)	-49.44	<0.0001
5%-0%	-0.34333	0.02906	(-0.40808, -0.27859)	-11.81	<0.0001
20%-10%	-0.44667	0.02906	(-0.51141, -0.38192)	-15.37	<0.0001
40%-10%	-0.77000	0.02906	(-0.83475, -0.70525)	-26.50	<0.0001
5%-10%	0.32333	0.02906	(0.25859, 0.38808)	11.13	<0.0001
40%-20%	-0.32333	0.02906	(-0.38808, -0.25859)	-11.13	<0.0001
5%-20%	0.77000	0.02906	(0.70525, 0.83475)	26.50	<0.0001
5%-40%	1.09333	0.02906	(1.02859, 1.15808)	37.62	<0.0001

Simultaneous confidence level = 75.51%

One-Way ANOVA: AFP% versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	412.388	103.097	13.22	0.0005
Error	10	78.000	7.800		
Total	14	490.388			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.79285	84.09%	77.73%	64.21%

Means

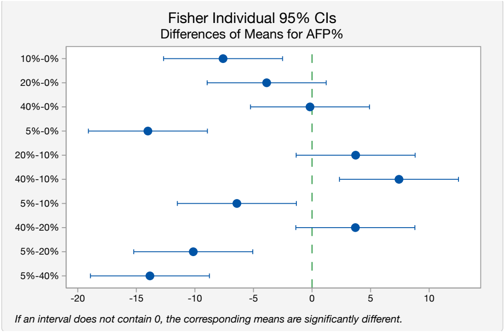
Treatment1	N	Mean	StDev	95% CI
0%	3	18.3733	1.6603	(14.7806, 21.9661)
10%	3	10.777	2.512	(7.184, 14.369)
20%	3	14.500	3.340	(10.907, 18.093)
40%	3	18.200	2.494	(14.607, 21.793)
5%	3	4.360	3.544	(0.767, 7.953)

Pooled StDev = 2.79285

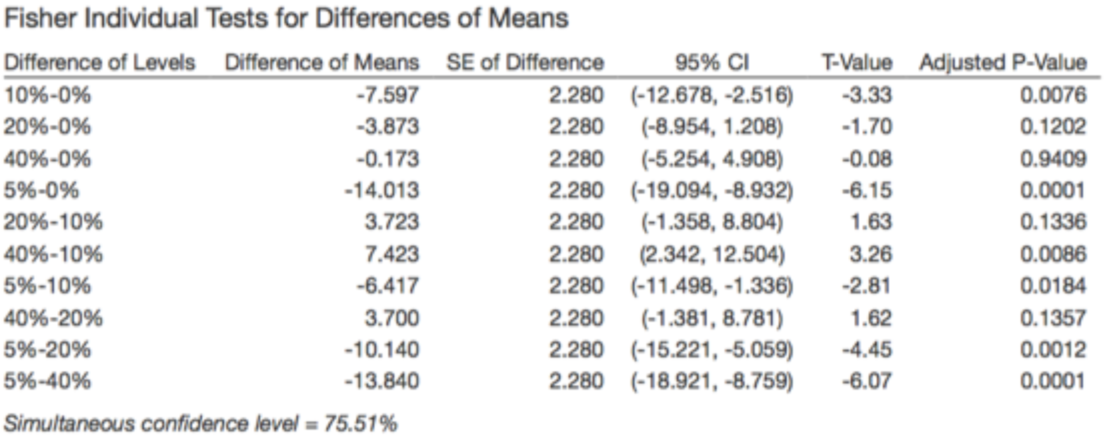
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping		
0%	3	18.3733	A		
40%	3	18.200	A		
20%	3	14.500	A	B	
10%	3	10.777		B	
5%	3	4.360			C

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.

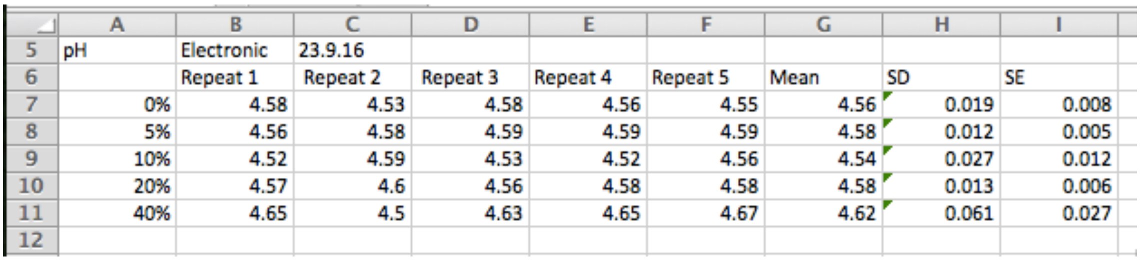


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-7.597	2.280	(-12.678, -2.516)	-3.33	0.0076
20%-0%	-3.873	2.280	(-8.954, 1.208)	-1.70	0.1202
40%-0%	-0.173	2.280	(-5.254, 4.908)	-0.08	0.9409
5%-0%	-14.013	2.280	(-19.094, -8.932)	-6.15	0.0001
20%-10%	3.723	2.280	(-1.358, 8.804)	1.63	0.1336
40%-10%	7.423	2.280	(2.342, 12.504)	3.26	0.0086
5%-10%	-6.417	2.280	(-11.498, -1.336)	-2.81	0.0184
40%-20%	3.700	2.280	(-1.381, 8.781)	1.62	0.1357
5%-20%	-10.140	2.280	(-15.221, -5.059)	-4.45	0.0012
5%-40%	-13.840	2.280	(-18.921, -8.759)	-6.07	0.0001

Simultaneous confidence level = 75.51%

3.2.3 pH raw data



	A	B	C	D	E	F	G	H	I
5	pH	Electronic	23.9.16						
6		Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5	Mean	SD	SE
7	0%	4.58	4.53	4.58	4.56	4.55	4.56	0.019	0.008
8	5%	4.56	4.58	4.59	4.59	4.59	4.58	0.012	0.005
9	10%	4.52	4.59	4.53	4.52	4.56	4.54	0.027	0.012
10	20%	4.57	4.6	4.56	4.58	4.58	4.58	0.013	0.006
11	40%	4.65	4.5	4.63	4.65	4.67	4.62	0.061	0.027
12									

One-Way ANOVA: pH versus Treatment

Method

Null hypothesis H_0: All means are equal
Alternative hypothesis H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	0.0082	0.00205	1.47	0.2472
Error	20	0.0278	0.00139		
Total	24	0.0360			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0372827	22.78%	7.33%	0.00%

Means

Treatment	N	Mean	StDev	95% CI
0%	5	4.80600	0.02881	(4.77122, 4.84078)
10%	5	4.80000	0.02550	(4.76522, 4.83478)
20%	5	4.84200	0.05541	(4.80722, 4.87678)
40%	5	4.83800	0.03962	(4.80322, 4.87278)
5%	5	4.80400	0.02881	(4.76922, 4.83878)

Pooled StDev = 0.0372827

Grouping Information Using the Fisher LSD Method and 95% Confidence

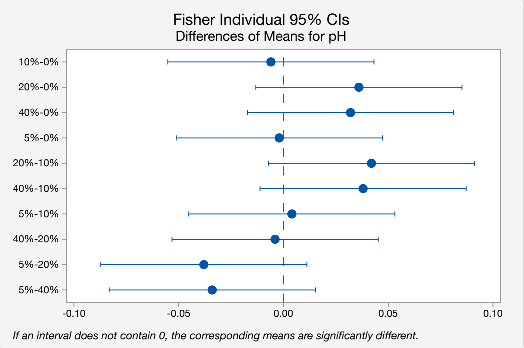
Treatment	N	Mean	Grouping
20%	5	4.84200	A
40%	5	4.83800	A
0%	5	4.80600	A
5%	5	4.80400	A
10%	5	4.80000	A

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

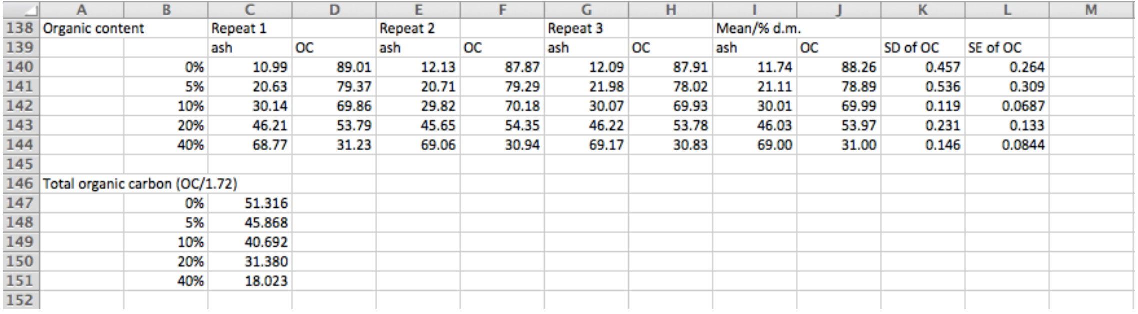
Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-0.00600	0.02358	(-0.05519, 0.04319)	-0.25	0.8017
20%-0%	0.03600	0.02358	(-0.01319, 0.08519)	1.53	0.1425
40%-0%	0.03200	0.02358	(-0.01719, 0.08119)	1.36	0.1899
5%-0%	-0.00200	0.02358	(-0.05119, 0.04719)	-0.08	0.9332
20%-10%	0.04200	0.02358	(-0.00719, 0.09119)	1.78	0.0901
40%-10%	0.03800	0.02358	(-0.01119, 0.08719)	1.61	0.1227
5%-10%	0.00400	0.02358	(-0.04519, 0.05319)	0.17	0.8670
40%-20%	-0.00400	0.02358	(-0.05319, 0.04519)	-0.17	0.8670
5%-20%	-0.03800	0.02358	(-0.08719, 0.01119)	-1.61	0.1227
5%-40%	-0.03400	0.02358	(-0.08319, 0.01519)	-1.44	0.1648

Simultaneous confidence level = 73.57%



If an interval does not contain 0, the corresponding means are significantly different.

3.2.4 Organic content



	A	B	C	D	E	F	G	H	I	J	K	L	M
138	Organic content		Repeat 1		Repeat 2		Repeat 3		Mean/% d.m.				
139			ash	OC	ash	OC	ash	OC	ash	OC	SD of OC	SE of OC	
140		0%	10.99	89.01	12.13	87.87	12.09	87.91	11.74	88.26	0.457	0.264	
141		5%	20.63	79.37	20.71	79.29	21.98	78.02	21.11	78.89	0.536	0.309	
142		10%	30.14	69.86	29.82	70.18	30.07	69.93	30.01	69.99	0.119	0.0687	
143		20%	46.21	53.79	45.65	54.35	46.22	53.78	46.03	53.97	0.231	0.133	
144		40%	68.77	31.23	69.06	30.94	69.17	30.83	69.00	31.00	0.146	0.0844	
145													
146	Total organic carbon (OC/1.72)												
147		0%	51.316										
148		5%	45.868										
149		10%	40.692										
150		20%	31.380										
151		40%	18.023										
152													

One-Way ANOVA: Organic content versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	6105.11	1526.28	6524.78	<0.0001
Error	10	2.34	0.23		
Total	14	6107.45			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.483653	99.96%	99.95%	99.91%

Means

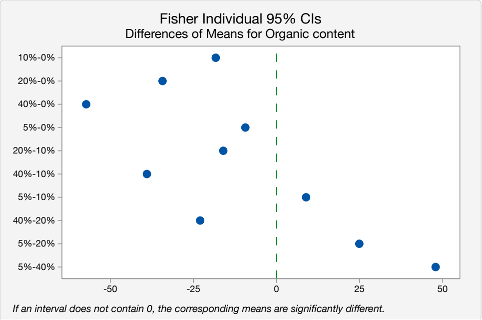
Treatment1	N	Mean	StDev	95% CI
0%	3	88.2633	0.6469	(87.6412, 88.8855)
10%	3	69.9900	0.16823	(69.3678, 70.6122)
20%	3	53.9733	0.3262	(53.3512, 54.5955)
40%	3	31.0000	0.2066	(30.3778, 31.6222)
5%	3	78.8933	0.7574	(78.2712, 79.5155)

Pooled StDev = 0.483653

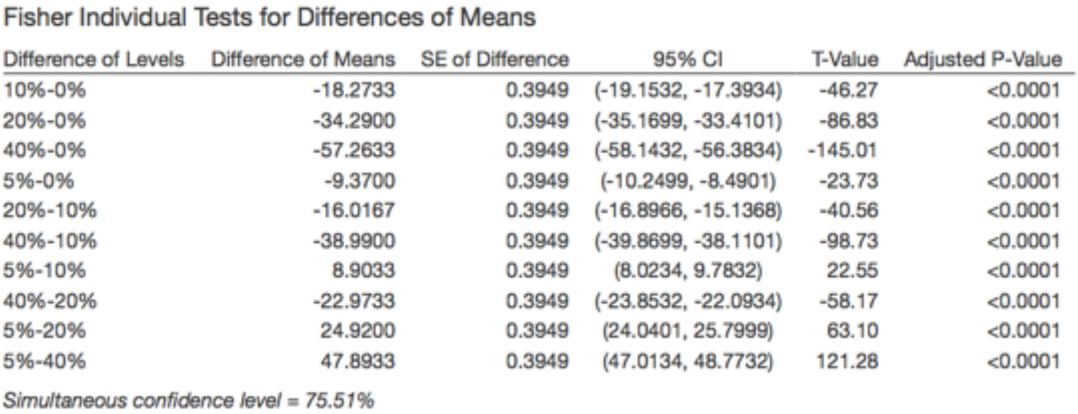
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping				
0%	3	88.2633	A				
5%	3	78.8933		B			
10%	3	69.9900			C		
20%	3	53.9733				D	
40%	3	31.0000					E

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.

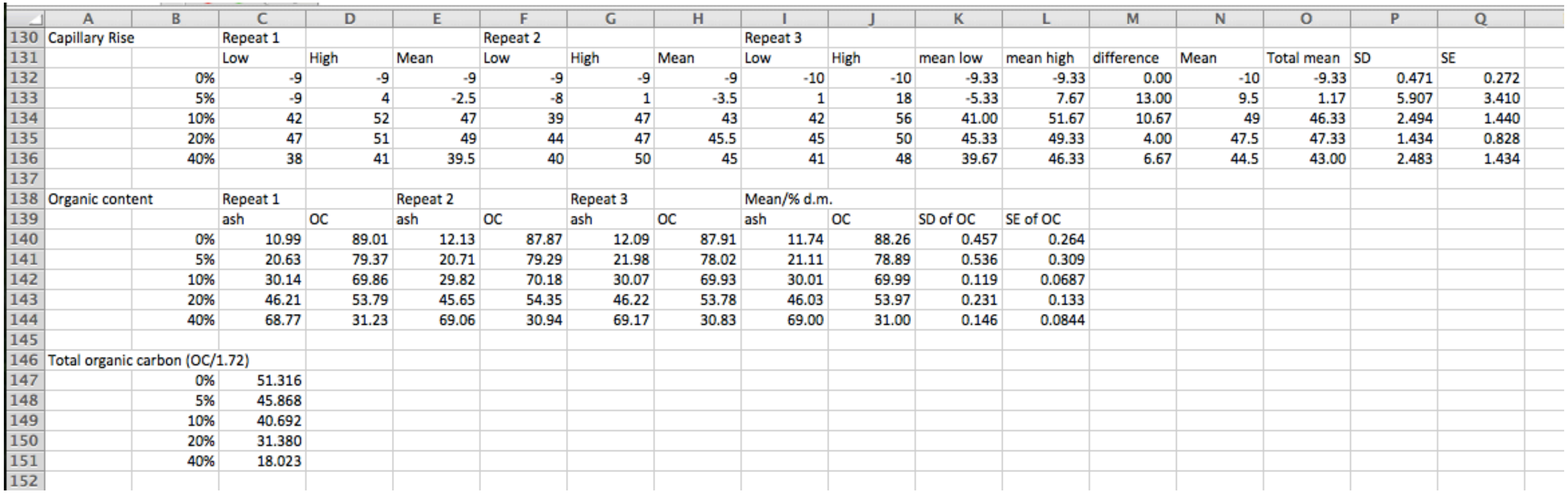


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-18.2733	0.3949	(-19.1532, -17.3934)	-46.27	<0.0001
20%-0%	-34.2900	0.3949	(-35.1699, -33.4101)	-86.83	<0.0001
40%-0%	-57.2633	0.3949	(-58.1432, -56.3834)	-145.01	<0.0001
5%-0%	-9.3700	0.3949	(-10.2499, -8.4901)	-23.73	<0.0001
20%-10%	-16.0167	0.3949	(-16.8966, -15.1368)	-40.56	<0.0001
40%-10%	-38.9900	0.3949	(-39.8699, -38.1101)	-98.73	<0.0001
5%-10%	8.9033	0.3949	(8.0234, 9.7832)	22.55	<0.0001
40%-20%	-22.9733	0.3949	(-23.8532, -22.0934)	-58.17	<0.0001
5%-20%	24.9200	0.3949	(24.0401, 25.7999)	63.10	<0.0001
5%-40%	47.8933	0.3949	(47.0134, 48.7732)	121.28	<0.0001

Simultaneous confidence level = 75.51%

3.2.5 Capillary rise raw data:



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
130	Capillary Rise		Repeat 1			Repeat 2			Repeat 3								
131			Low	High	Mean	Low	High	Mean	Low	High	mean low	mean high	difference	Mean	Total mean	SD	SE
132		0%	-9	-9	-9	-9	-9	-9	-10	-10	-9.33	-9.33	0.00	-10	-9.33	0.471	0.272
133		5%	-9	4	-2.5	-8	1	-3.5	1	18	-5.33	7.67	13.00	9.5	1.17	5.907	3.410
134		10%	42	52	47	39	47	43	42	56	41.00	51.67	10.67	49	46.33	2.494	1.440
135		20%	47	51	49	44	47	45.5	45	50	45.33	49.33	4.00	47.5	47.33	1.434	0.828
136		40%	38	41	39.5	40	50	45	41	48	39.67	46.33	6.67	44.5	43.00	2.483	1.434
137																	
138	Organic content		Repeat 1		Repeat 2		Repeat 3		Mean/% d.m.								
139			ash	OC	ash	OC	ash	OC	ash	OC	SD of OC	SE of OC					
140		0%	10.99	89.01	12.13	87.87	12.09	87.91	11.74	88.26	0.457	0.264					
141		5%	20.63	79.37	20.71	79.29	21.98	78.02	21.11	78.89	0.536	0.309					
142		10%	30.14	69.86	29.82	70.18	30.07	69.93	30.01	69.99	0.119	0.0687					
143		20%	46.21	53.79	45.65	54.35	46.22	53.78	46.03	53.97	0.231	0.133					
144		40%	68.77	31.23	69.06	30.94	69.17	30.83	69.00	31.00	0.146	0.0844					
145																	
146	Total organic carbon (OC/1.72)																
147		0%	51.316														
148		5%	45.868														
149		10%	40.692														
150		20%	31.380														
151		40%	18.023														
152																	

Kruskal-Wallis: Capillary Rise versus Treatment1

Descriptive Statistics

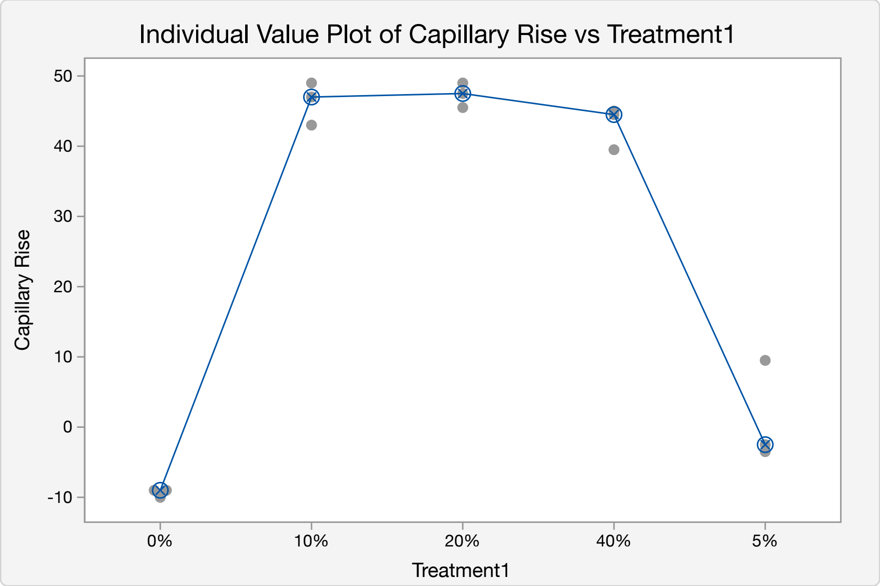
Treatment1	N	Median	Mean Rank	Z-Value
0%	3	-9.0	2.0	-2.60
10%	3	47.0	11.5	1.52
20%	3	47.5	12.8	2.09
40%	3	44.5	8.7	0.29
5%	3	-2.5	5.0	-1.30
Overall	15		8.0	

The chi-square approximation may not be accurate when some sample sizes are less than 5.

Test

Null hypothesis	H_0: All medians are equal
Alternative hypothesis	H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	4	12.16	0.0162
Adjusted for ties	4	12.20	0.0159



One-Way ANOVA: Capillary Rise versus Treatment1

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment1	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment1	4	9066.73	2266.68	152.47	<0.0001
Error	10	148.67	14.87		
Total	14	9215.40			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.85573	98.39%	97.74%	96.37%

Means

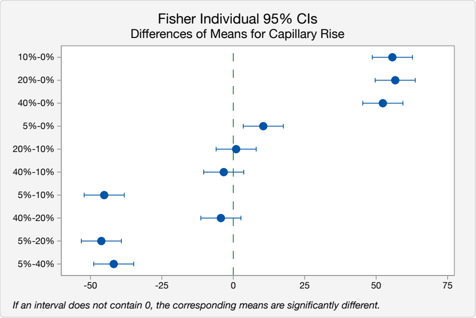
Treatment1	N	Mean	StDev	95% CI
0%	3	-9.3333	0.5774	(-14.2934, -4.3733)
10%	3	46.333	3.055	(41.373, 51.293)
20%	3	47.333	1.756	(42.373, 52.293)
40%	3	43.000	3.041	(38.040, 47.960)
5%	3	1.167	7.234	(-3.793, 6.127)

Pooled StDev = 3.85573

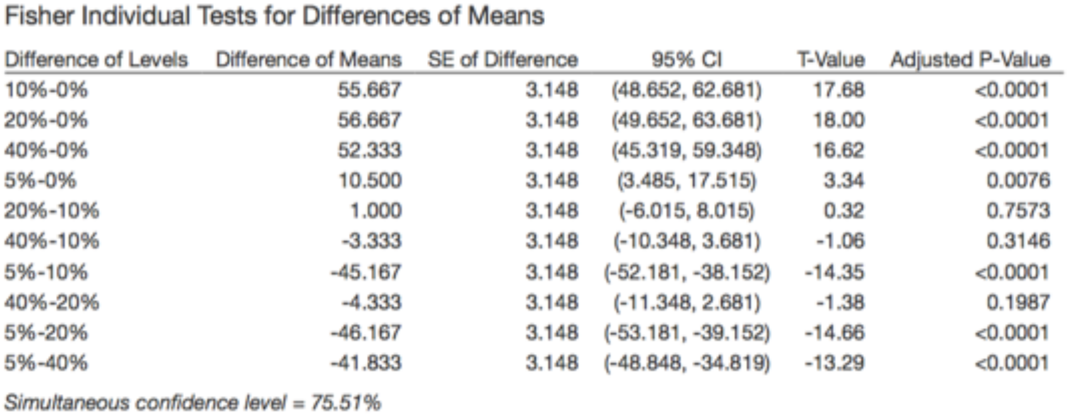
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment1	N	Mean	Grouping		
20%	3	47.333	A		
10%	3	46.333	A		
40%	3	43.000	A		
5%	3	1.167		B	
0%	3	-9.3333			C

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	55.667	3.148	(48.652, 62.681)	17.68	<0.0001
20%-0%	56.667	3.148	(49.652, 63.681)	18.00	<0.0001
40%-0%	52.333	3.148	(45.319, 59.348)	16.62	<0.0001
5%-0%	10.500	3.148	(3.485, 17.515)	3.34	0.0076
20%-10%	1.000	3.148	(-6.015, 8.015)	0.32	0.7573
40%-10%	-3.333	3.148	(-10.348, 3.681)	-1.06	0.3146
5%-10%	-45.167	3.148	(-52.181, -38.152)	-14.35	<0.0001
40%-20%	-4.333	3.148	(-11.348, 2.681)	-1.38	0.1987
5%-20%	-46.167	3.148	(-53.181, -39.152)	-14.66	<0.0001
5%-40%	-41.833	3.148	(-48.848, -34.819)	-13.29	<0.0001

Simultaneous confidence level = 75.51%

A3.2.6 WDPT tests

One-Way ANOVA: Time/s2 versus Peat

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Peat	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Peat	4	93037407	23259352	20729623.59	<0.0001
Error	40	45	1		
Total	44	93037452			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.05926	100.00%	100.00%	100.00%

Means

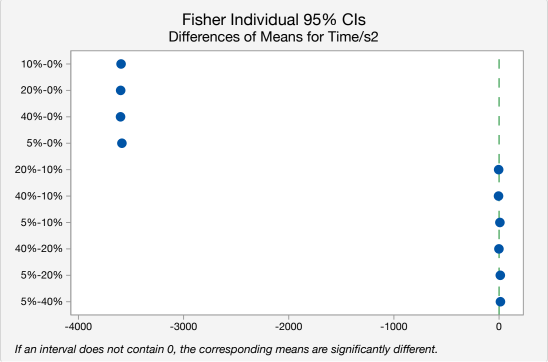
Peat	N	Mean	StDev	95% CI
0%	9	3600	0	(3599.29, 3600.71)
10%	9	5.5300	0.3800	(4.8164, 6.2436)
20%	9	1.7344	0.5152	(1.0208, 2.4481)
40%	9	0.47778	0.11606	(-0.23584, 1.19139)
5%	9	13.5333	2.2775	(12.8197, 14.2469)

Pooled StDev = 1.05926

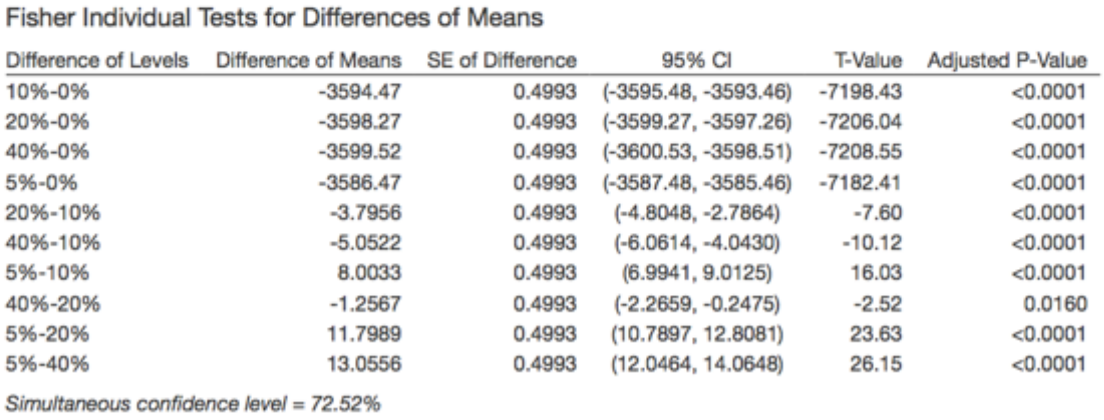
Grouping Information Using the Fisher LSD Method and 95% Confidence

Peat	N	Mean	Grouping				
0%	9	3600	A				
5%	9	13.5333		B			
10%	9	5.5300			C		
20%	9	1.7344				D	
40%	9	0.47778					E

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-3594.47	0.4993	(-3595.48, -3593.46)	-7198.43	<0.0001
20%-0%	-3598.27	0.4993	(-3599.27, -3597.26)	-7206.04	<0.0001
40%-0%	-3599.52	0.4993	(-3600.53, -3598.51)	-7208.55	<0.0001
5%-0%	-3586.47	0.4993	(-3587.48, -3585.46)	-7182.41	<0.0001
20%-10%	-3.7956	0.4993	(-4.8048, -2.7864)	-7.60	<0.0001
40%-10%	-5.0522	0.4993	(-6.0614, -4.0430)	-10.12	<0.0001
5%-10%	8.0033	0.4993	(6.9941, 9.0125)	16.03	<0.0001
40%-20%	-1.2567	0.4993	(-2.2659, -0.2475)	-2.52	0.0160
5%-20%	11.7989	0.4993	(10.7897, 12.8081)	23.63	<0.0001
5%-40%	13.0556	0.4993	(12.0464, 14.0648)	26.15	<0.0001

Simultaneous confidence level = 72.52%

Appendix 3.3 Substrates used in Experiment 1: bulb fibre (37:4), John Innes no.2 (20:1) and Watering Lane mix (10:1)

A3.3.1 Particle sizes of bulb fibre, John Innes no.2 and the Watering Lane mix with and without kaolinite added by weight ratio.

Sieve data			Treatment					
Mesh size	mm^{-1}		Bulb Fibre	Bulb Fibre + kaolinite (37:4)	John Innes no.2	John Innes no.2 + kaolinite (1:20)	WL	WL + kaolinite (1:10)
>10	>2	Particle distribution g^{-1}	52.85	26.25	6.41	7.2	20.98	14.42
10	2		14.93	8.2	11.22	8.28	23.99	34.55
20	0.9		8.12	6.48	8.02	6.71	15.55	21.02
30	0.6		3.81	4.03	6.7	6.32	7.71	7.51
40	0.4		7.52	11.59	28.62	28.93	14.95	11.51
60	0.25		4.58	12.68	17.3	18.33	7.09	4.72
80	0.2		0.8	3.72	2.29	1.9	2.06	1.53
100	0.14		1.8	18.5	8.1	7.77	3.67	2.93
120	0.125		4	7.69	10.6	13.31	3.32	1.36
250	0.063		1.81	0.1	0.75	1.04	0.26	0
		Total	100.22	99.24	100.01	99.79	99.58	99.55

A3.3.2 pH

One-Way ANOVA: pH versus Substrate

Method

Null hypothesis H$_0$: All means are equal
Alternative hypothesis H$_1$: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Substrate	3	BF, JI, WL

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Substrate	2	6.19398	3.09699	51.86	<0.0001
Error	27	1.61230	0.05971		
Total	29	7.80628			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.244366	79.35%	77.82%	74.50%

Means

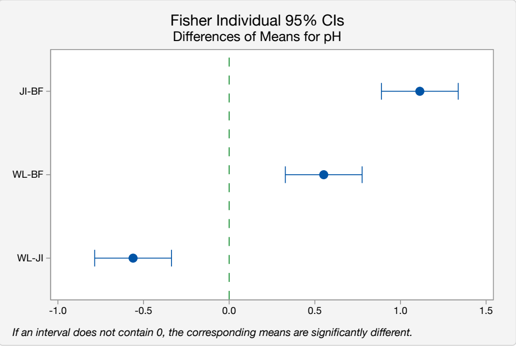
Substrate	N	Mean	StDev	95% CI
BF	10	5.95700	0.20828	(5.79844, 6.11556)
JI	10	7.07000	0.04570	(6.91144, 7.22856)
WL	10	6.5090	0.3656	(6.3504, 6.6676)

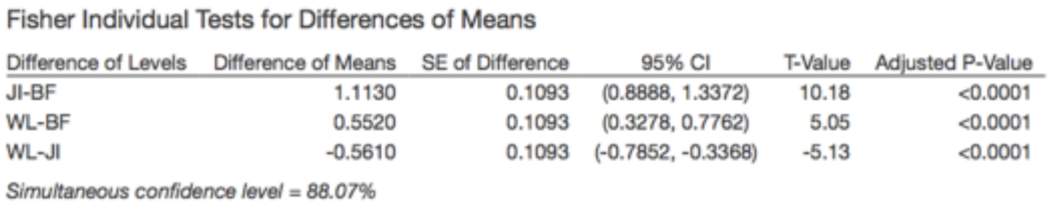
Pooled StDev = 0.244366

Grouping Information Using the Fisher LSD Method and 95% Confidence

Substrate	N	Mean	Grouping		
JI	10	7.07000	A		
WL	10	6.5090		B	
BF	10	5.95700			C

Means that do not share a letter are significantly different.





Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
JI-BF	1.1130	0.1093	(0.8888, 1.3372)	10.18	<0.0001
WL-BF	0.5520	0.1093	(0.3278, 0.7762)	5.05	<0.0001
WL-JI	-0.5610	0.1093	(-0.7852, -0.3368)	-5.13	<0.0001

Simultaneous confidence level = 88.07%

A3.3.3 Capillary rise

One-Way ANOVA: Capillary Rise versus

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment2	6	BF, BF+K, JI, JI+K, WL, WL+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment2	5	19117.6	3823.51	37.85	<0.0001
Error	12	1212.2	101.01		
Total	17	20329.7			

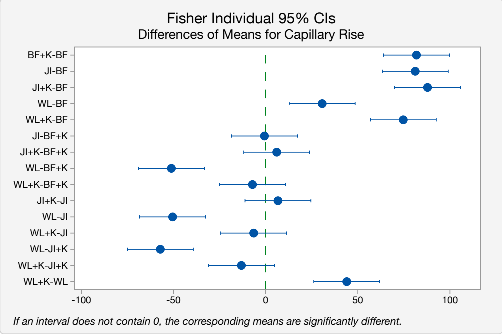
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
10.0506	94.04%	91.55%	86.58%

Means

Treatment2	N	Mean	StDev	95% CI
BF	3	-5.833	2.363	(-18.476, 6.810)
BF+K	3	76.000	16.039	(63.357, 88.643)
JI	3	75.333	5.965	(62.690, 87.976)
JI+K	3	82.000	5.766	(69.357, 94.643)
WL	3	24.833	13.605	(12.190, 37.476)
WL+K	3	68.833	9.452	(56.190, 81.476)

Pooled StDev = 10.0506



If an interval does not contain 0, the corresponding means are significantly different.

Treatment2	N	Mean	Grouping		
JI+K	3	82.000	A		
BF+K	3	76.000	A		
JI	3	75.333	A		
WL+K	3	68.833	A		
WL	3	24.833		B	
BF	3	-5.833			C

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF+K-BF	81.833	8.206	(63.953, 99.713)	9.97	<0.0001
JI-BF	81.167	8.206	(63.287, 99.047)	9.89	<0.0001
JI+K-BF	87.833	8.206	(69.953, 105.713)	10.70	<0.0001
WL-BF	30.667	8.206	(12.787, 48.547)	3.74	0.0028
WL+K-BF	74.667	8.206	(56.787, 92.547)	9.10	<0.0001
JI-BF+K	-0.667	8.206	(-18.547, 17.213)	-0.08	0.9366
JI+K-BF+K	6.000	8.206	(-11.880, 23.880)	0.73	0.4787
WL-BF+K	-51.167	8.206	(-69.047, -33.287)	-6.24	<0.0001
WL+K-BF+K	-7.167	8.206	(-25.047, 10.713)	-0.87	0.3996
JI+K-JI	6.667	8.206	(-11.213, 24.547)	0.81	0.4324
WL-JI	-50.500	8.206	(-68.380, -32.620)	-6.15	<0.0001
WL+K-JI	-6.500	8.206	(-24.380, 11.380)	-0.79	0.4437
WL-JI+K	-57.167	8.206	(-75.047, -39.287)	-6.97	<0.0001
WL+K-JI+K	-13.167	8.206	(-31.047, 4.713)	-1.60	0.1346
WL+K-WL	44.000	8.206	(26.120, 61.880)	5.36	0.0002

Simultaneous confidence level = 68.63%

A3.3.4 John Innes no.2 Water drop penetration time test at 5% moisture

One-Way ANOVA: Time/s3 versus JI treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
JI treatment	2	JI, JI+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
JI treatment	1	636.888	636.888	170.72	<0.0001
Error	16	59.690	3.731		
Total	17	696.578			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.93148	91.43%	90.90%	89.15%

Means

JI treatment	N	Mean	StDev	95% CI
JI	9	13.1678	2.7235	(11.8029, 14.5326)
JI+K	9	1.27111	0.20955	(-0.09374, 2.63597)

Pooled StDev = 1.93148

Grouping Information Using the Fisher LSD Method and 95% Confidence

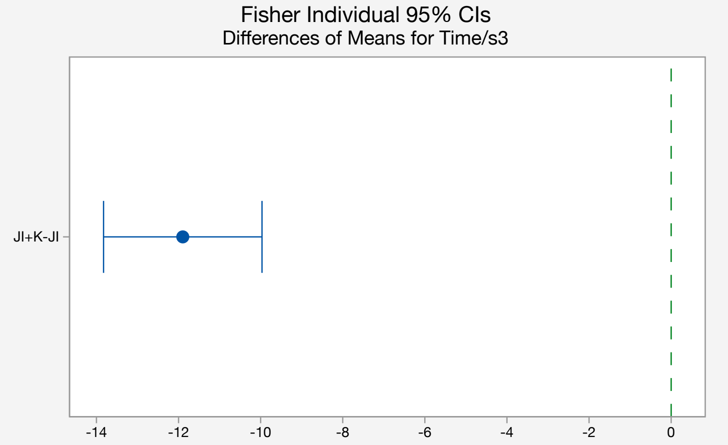
JI treatment	N	Mean	Grouping	
JI	9	13.1678	A	
JI+K	9	1.27111		B

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Val
JI+K-JI	-11.8967	0.9105	(-13.8269, -9.9665)	-13.

Simultaneous confidence level = 95.00%



If an interval does not contain 0, the corresponding means are significantly different.

A3.3.5 John Innes no.2 Water drop penetration time test at 10% moisture

One-Way ANOVA: Time/s4 versus JI treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
JI treatment	2	JI, JI+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
JI treatment	1	0.093889	0.0938889	10.99	0.0044
Error	16	0.136711	0.0085444		
Total	17	0.230600			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0924362	40.72%	37.01%	24.97%

Means

JI treatment	N	Mean	StDev	95% CI
JI	9	0.35111	0.05487	(0.28579, 0.41643)
JI+K	9	0.49556	0.11865	(0.43024, 0.56087)

Pooled StDev = 0.0924362

Grouping Information Using the Fisher LSD Method and 95% Confidence

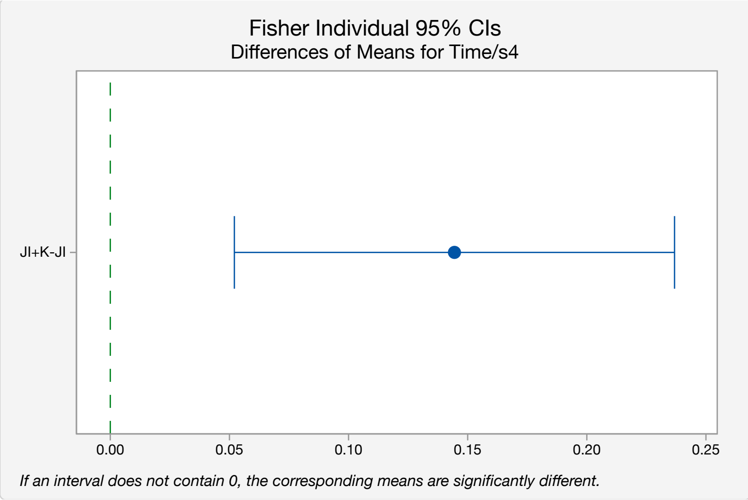
JI treatment	N	Mean	Grouping	
JI+K	9	0.49556	A	
JI	9	0.35111		B

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
JI+K-JI	0.14444	0.04357	(0.05207, 0.23682)	3.31	0.0044

Simultaneous confidence level = 95.00%



A3.3.6 Watering Lane mix Water drop penetration time test at 10% moisture

One-Way ANOVA: Time/s5 versus WL Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
WL Treatment	2	WL, WL+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
WL Treatment	1	50362.9	50362.9	804.81	<0.0001
Error	16	1001.2	62.6		
Total	17	51364.2			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.91058	98.05%	97.93%	97.53%

Means

WL Treatment	N	Mean	StDev	95% CI
WL	9	106.644	11.186	(101.055, 112.234)
WL+K	9	0.85333	0.14714	(-4.73656, 6.44322)

Pooled StDev = 7.91058

Grouping Information Using the Fisher LSD Method and 95% Confidence

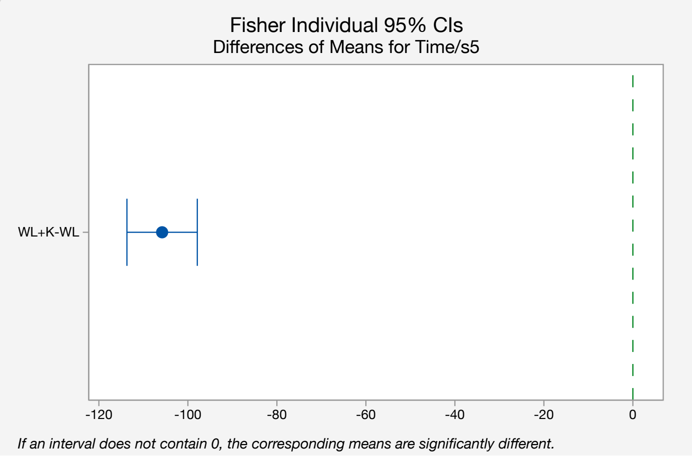
WL Treatment	N	Mean	Grouping	
WL	9	106.644	A	
WL+K	9	0.85333		B

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
WL+K-WL	-105.791	3.729	(-113.696, -97.886)	-28.37	<0.0001

Simultaneous confidence level = 95.00%



A3.3.7 Bulb fibre Water drop penetration time test at 40% moisture

One-Way ANOVA: Time/s6 versus BF Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
BF Treatment	2	BF, BF+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
BF Treatment	1	58307581	58307581	1.53441E+10	<0.0001
Error	16	0	0		
Total	17	58307581			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0616441	100.00%	100.00%	100.00%

Means

BF Treatment	N	Mean	StDev	95% CI
BF	9	3600	0	(3599.96, 3600.04)
BF+K	9	0.38333	0.08718	(0.33977, 0.42689)

Pooled StDev = 0.0616441

Grouping Information Using the Fisher LSD Method and 95% Confidence

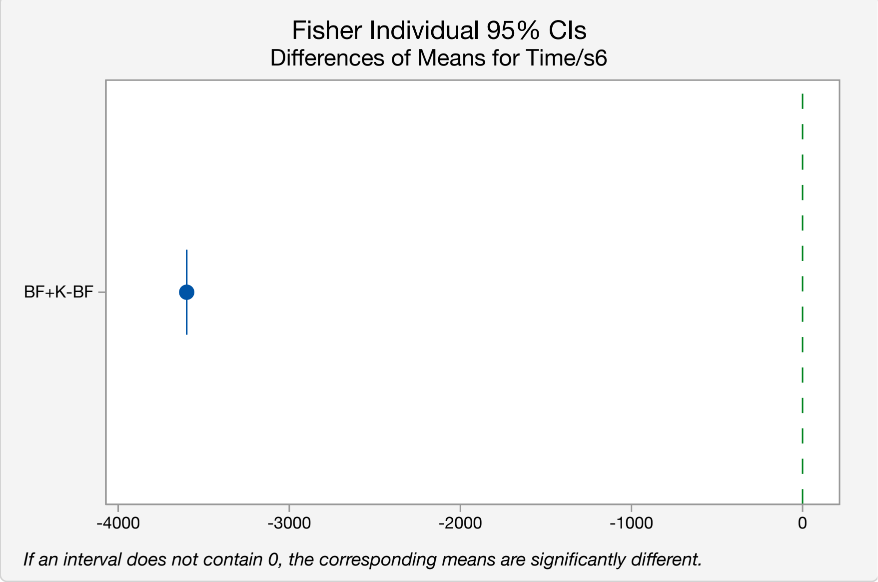
BF Treatment	N	Mean	Grouping	
BF	9	3600	A	
BF+K	9	0.38333		B

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF+K-BF	-3599.62	0.02906	(-3599.68, -3599.56)	-123871.30	<0.0001

Simultaneous confidence level = 95.00%



A3.3.8 Physical tests

One-Way ANOVA: WHC versus Treatment *

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment *	6	BF, BF+K, JI, JI+K, WL, WL+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment *	5	8915.4	1783.08	7.81	0.0018
Error	12	2738.2	228.18		
Total	17	11653.6			

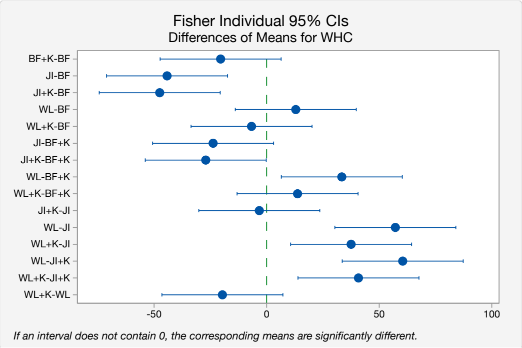
Model Summary

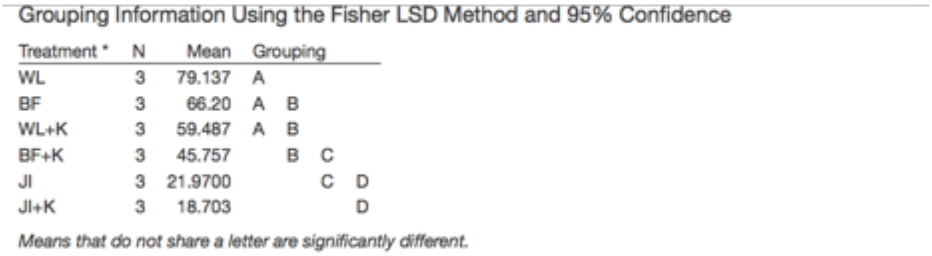
S	R-sq	R-sq(adj)	R-sq(pred)
15.1057	76.50%	66.71%	47.13%

Means

Treatment *	N	Mean	StDev	95% CI
BF	3	66.20	34.80	(47.20, 85.20)
BF+K	3	45.757	3.361	(26.755, 64.759)
JI	3	21.9700	1.3852	(2.9680, 40.9720)
JI+K	3	18.703	2.569	(-0.299, 37.705)
WL	3	79.137	6.269	(60.135, 98.139)
WL+K	3	59.487	9.934	(40.485, 78.489)

Pooled StDev = 15.1057

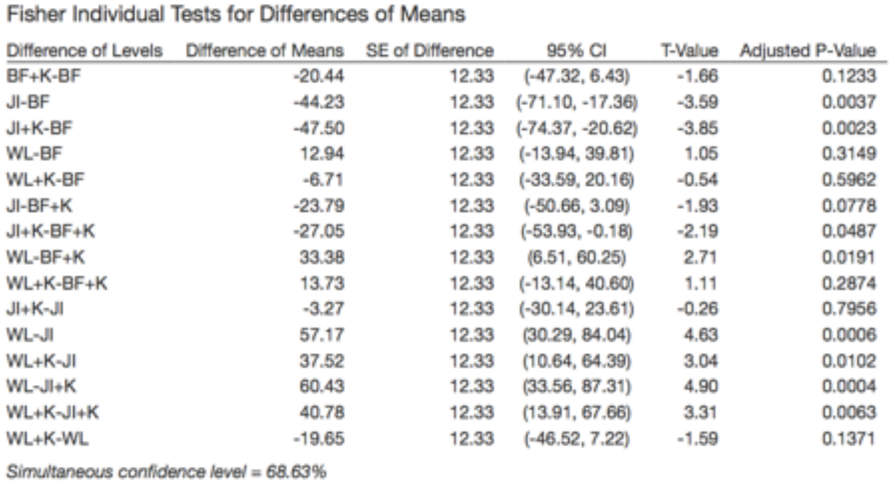




Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment *	N	Mean	Grouping
WL	3	79.137	A
BF	3	66.20	A B
WL+K	3	59.487	A B
BF+K	3	45.757	B C
JI	3	21.9700	C D
JI+K	3	18.703	D

Means that do not share a letter are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF+K-BF	-20.44	12.33	(-47.32, 6.43)	-1.66	0.1233
JI-BF	-44.23	12.33	(-71.10, -17.36)	-3.59	0.0037
JI+K-BF	-47.50	12.33	(-74.37, -20.62)	-3.85	0.0023
WL-BF	12.94	12.33	(-13.94, 39.81)	1.05	0.3149
WL+K-BF	-6.71	12.33	(-33.59, 20.16)	-0.54	0.5962
JI-BF+K	-23.79	12.33	(-50.66, 3.09)	-1.93	0.0778
JI+K-BF+K	-27.05	12.33	(-53.93, -0.18)	-2.19	0.0487
WL-BF+K	33.38	12.33	(6.51, 60.25)	2.71	0.0191
WL+K-BF+K	13.73	12.33	(-13.14, 40.60)	1.11	0.2874
JI+K-JI	-3.27	12.33	(-30.14, 23.61)	-0.26	0.7956
WL-JI	57.17	12.33	(30.29, 84.04)	4.63	0.0006
WL+K-JI	37.52	12.33	(10.64, 64.39)	3.04	0.0102
WL-JI+K	60.43	12.33	(33.56, 87.31)	4.90	0.0004
WL+K-JI+K	40.78	12.33	(13.91, 67.66)	3.31	0.0063
WL+K-WL	-19.65	12.33	(-46.52, 7.22)	-1.59	0.1371

Simultaneous confidence level = 68.63%

One-Way ANOVA: CC versus Treatment *

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment *	6	BF, BF+K, JI, JI+K, WL, WL+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment *	5	9.34703	1.86941	607.39	<0.0001
Error	12	0.03693	0.00308		
Total	17	9.38396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0554777	99.61%	99.44%	99.11%

Means

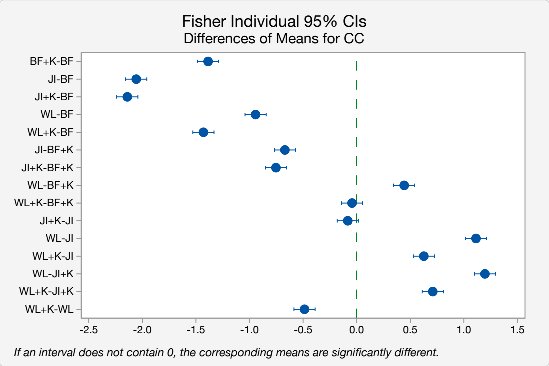
Treatment *	N	Mean	StDev	95% CI
BF	3	3.54333	0.04933	(3.47355, 3.61312)
BF+K	3	2.15667	0.06429	(2.08688, 2.22645)
JI	3	1.48667	0.05774	(1.41688, 1.55645)
JI+K	3	1.40333	0.005774	(1.33355, 1.47312)
WL	3	2.60000	0.05292	(2.53021, 2.66979)
WL+K	3	2.11333	0.07572	(2.04355, 2.18312)

Pooled StDev = 0.0554777

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment *	N	Mean	Grouping			
BF	3	3.54333	A			
WL	3	2.60000		B		
BF+K	3	2.15667			C	
WL+K	3	2.11333			C	
JI	3	1.48667				D
JI+K	3	1.40333				D

Means that do not share a letter are significantly different.


Fisher Individual 95% CIs
Differences of Means for CC

If an interval does not contain 0, the corresponding means are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF+K-BF	-1.38667	0.04530	(-1.48536, -1.28797)	-30.61	<0.0001
JI-BF	-2.05667	0.04530	(-2.15536, -1.95797)	-45.40	<0.0001
JI+K-BF	-2.14000	0.04530	(-2.23869, -2.04131)	-47.24	<0.0001
WL-BF	-0.94333	0.04530	(-1.04203, -0.84464)	-20.83	<0.0001
WL+K-BF	-1.43000	0.04530	(-1.52869, -1.33131)	-31.57	<0.0001
JI-BF+K	-0.67000	0.04530	(-0.76869, -0.57131)	-14.79	<0.0001
JI+K-BF+K	-0.75333	0.04530	(-0.85203, -0.65464)	-16.63	<0.0001
WL-BF+K	0.44333	0.04530	(0.34464, 0.54203)	9.79	<0.0001
WL+K-BF+K	-0.04333	0.04530	(-0.14203, 0.05536)	-0.96	0.3576
JI+K-JI	-0.08333	0.04530	(-0.18203, 0.01536)	-1.84	0.0907
WL-JI	1.11333	0.04530	(1.01464, 1.21203)	24.58	<0.0001
WL+K-JI	0.62667	0.04530	(0.52797, 0.72536)	13.83	<0.0001
WL-JI+K	1.19667	0.04530	(1.09797, 1.29536)	26.42	<0.0001
WL+K-JI+K	0.71000	0.04530	(0.61131, 0.80869)	15.67	<0.0001
WL+K-WL	-0.48667	0.04530	(-0.58536, -0.38797)	-10.74	<0.0001

Simultaneous confidence level = 68.63%

One-Way ANOVA: AFP versus Treatmen

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment *	6	BF, BF+K, JI, JI+K, WL, WL+K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment *	5	804.709	160.942	11.10	0.0004
Error	12	174.055	14.505		
Total	17	978.764			

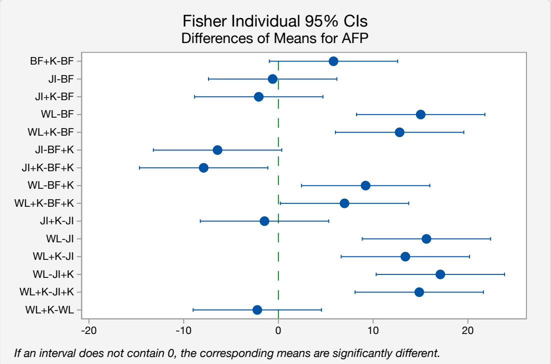
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.80849	82.22%	74.81%	59.99%

Means

Treatment *	N	Mean	StDev	95% CI
BF	3	15.397	6.825	(10.606, 20.188)
BF+K	3	21.213	1.887	(16.422, 26.004)
JI	3	14.7900	0.7076	(9.9992, 19.5808)
JI+K	3	13.323	1.837	(8.532, 18.114)
WL	3	30.420	2.689	(25.629, 35.211)
WL+K	3	28.193	5.077	(23.402, 32.984)

Pooled StDev = 3.80849



If an interval does not contain 0, the corresponding means are significantly different.

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment *	N	Mean	Grouping
WL	3	30.420	A
WL+K	3	28.193	A
BF+K	3	21.213	B
BF	3	15.397	B C
JI	3	14.7900	B C
JI+K	3	13.323	C

Means that do not share a letter are significantly different.

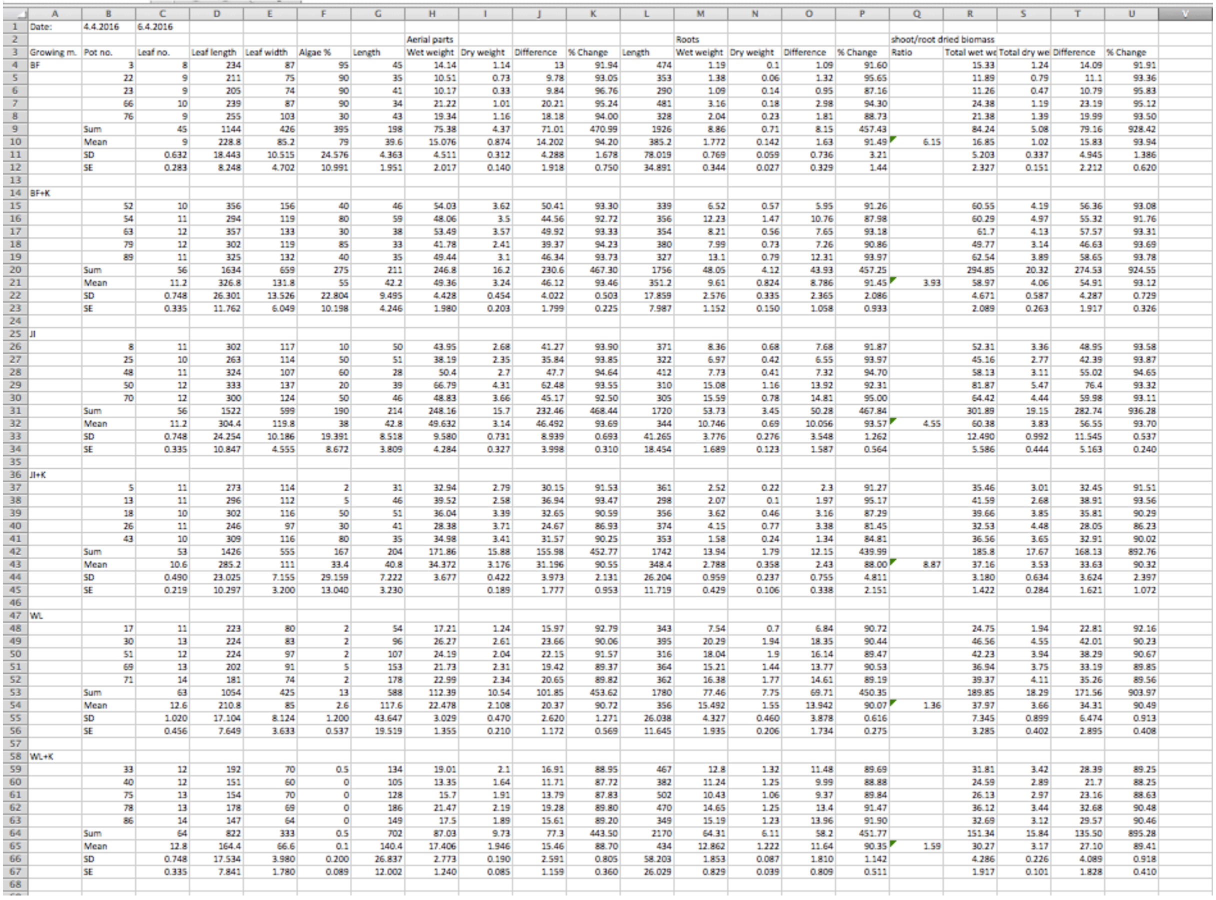
Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF+K-BF	5.817	3.110	(-0.959, 12.592)	1.87	0.0860
JI-BF	-0.607	3.110	(-7.382, 6.169)	-0.20	0.8486
JI+K-BF	-2.073	3.110	(-8.849, 4.702)	-0.67	0.5175
WL-BF	15.023	3.110	(8.248, 21.799)	4.83	0.0004
WL+K-BF	12.797	3.110	(6.021, 19.572)	4.12	0.0014
JI-BF+K	-6.423	3.110	(-13.199, 0.352)	-2.07	0.0612
JI+K-BF+K	-7.890	3.110	(-14.665, -1.115)	-2.54	0.0261
WL-BF+K	9.207	3.110	(2.431, 15.982)	2.96	0.0119
WL+K-BF+K	6.980	3.110	(0.205, 13.755)	2.24	0.0444
JI+K-JI	-1.467	3.110	(-8.242, 5.309)	-0.47	0.6456
WL-JI	15.630	3.110	(8.855, 22.405)	5.03	0.0003
WL+K-JI	13.403	3.110	(6.628, 20.179)	4.31	0.0010
WL-JI+K	17.097	3.110	(10.321, 23.872)	5.50	0.0001
WL+K-JI+K	14.870	3.110	(8.095, 21.645)	4.78	0.0004
WL+K-WL	-2.227	3.110	(-9.002, 4.549)	-0.72	0.4877

Simultaneous confidence level = 68.63%

Appendix 4.1 Experiment 1 raw data

A4.1.1 Mid-way Destructive harvest



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Date:	4.4.2016	6.4.2016																			
2								Aerial parts					Roots				shoot/root dried biomass					
3	Growing m.	Pot no.	Leaf no.	Leaf length	Leaf width	Algae %	Length	Wet weight	Dry weight	Difference	% Change	Length	Wet weight	Dry weight	Difference	% Change	Ratio	Total wet we	Total dry we	Difference	% Change	
4	BF	3	8	234	87	95	45	14.14	1.14	13	91.94	474	1.19	0.1	1.09	91.60		15.33	1.24	14.09	91.91	
5		22	9	211	75	90	35	10.51	0.73	9.78	93.05	353	1.38	0.06	1.32	95.65		11.89	0.79	11.1	93.36	
6		23	9	205	74	90	41	10.17	0.33	9.84	96.76	290	1.09	0.14	0.95	87.16		11.26	0.47	10.79	95.83	
7		66	10	239	87	90	34	21.22	1.01	20.21	95.24	481	3.16	0.18	2.98	94.30		24.38	1.19	23.19	95.12	
8		76	9	255	103	30	43	19.34	1.16	18.18	94.00	328	2.04	0.23	1.81	88.73		21.38	1.39	19.99	93.50	
9		Sum	45	1144	426	395	198	75.38	4.37	71.01	470.99	1926	8.86	0.71	8.15	457.43		84.24	5.08	79.16	928.42	
10		Mean	9	228.8	85.2	79	39.6	15.076	0.874	14.202	94.20	385.2	1.772	0.142	1.63	91.49	6.15	16.85	1.02	15.83	93.94	
11		SD	0.632	18.443	10.515	24.576	4.363	4.511	0.312	4.288	1.678	78.019	0.769	0.059	0.736	3.21		5.203	0.337	4.945	1.386	
12		SE	0.283	8.248	4.702	10.991	1.951	2.017	0.140	1.918	0.750	34.891	0.344	0.027	0.329	1.44		2.327	0.151	2.212	0.620	
13																						
14	BF+K																					
15		52	10	356	156	40	46	54.03	3.62	50.41	93.30	339	6.52	0.57	5.95	91.26		60.55	4.19	56.36	93.08	
16		54	11	294	119	80	59	48.06	3.5	44.56	92.72	356	12.23	1.47	10.76	87.98		60.29	4.97	55.32	91.76	
17		63	12	357	133	30	38	53.49	3.57	49.92	93.33	354	8.21	0.56	7.65	93.18		61.7	4.13	57.57	93.31	
18		79	12	302	119	85	33	41.78	2.41	39.37	94.23	380	7.99	0.73	7.26	90.86		49.77	3.14	46.63	93.69	
19		89	11	325	132	40	35	49.44	3.1	46.34	93.73	327	13.1	0.79	12.31	93.97		62.54	3.89	58.65	93.78	
20		Sum	56	1634	659	275	211	246.8	16.2	230.6	467.30	1756	48.05	4.12	43.93	457.25		294.85	20.32	274.53	924.55	
21		Mean	11.2	326.8	131.8	55	42.2	49.36	3.24	46.12	93.46	351.2	9.61	0.824	8.786	91.45	3.93	58.97	4.06	54.91	93.12	
22		SD	0.748	26.301	13.526	22.804	9.495	4.428	0.454	4.022	0.503	17.859	2.576	0.335	2.365	2.086		4.671	0.587	4.287	0.729	
23		SE	0.335	11.762	6.049	10.198	4.246	1.980	0.203	1.799	0.225	7.987	1.152	0.150	1.058	0.933		2.089	0.263	1.917	0.326	
24																						
25	JI																					
26		8	11	302	117	10	50	43.95	2.68	41.27	93.90	371	8.36	0.68	7.68	91.87		52.31	3.36	48.95	93.58	
27		25	10	263	114	50	51	38.19	2.35	35.84	93.85	322	6.97	0.42	6.55	93.97		45.16	2.77	42.39	93.87	
28		48	11	324	107	60	28	50.4	2.7	47.7	94.64	412	7.73	0.41	7.32	94.70		58.13	3.11	55.02	94.65	
29		50	12	333	137	20	39	66.79	4.31	62.48	93.55	310	15.08	1.16	13.92	92.31		81.87	5.47	76.4	93.32	
30		70	12	300	124	50	46	48.83	3.66	45.17	92.50	305	15.59	0.78	14.81	95.00		64.42	4.44	59.98	93.11	
31		Sum	56	1522	599	190	214	248.16	15.7	232.46	468.44	1720	53.73	3.45	50.28	467.84		301.89	19.15	282.74	936.28	
32		Mean	11.2	304.4	119.8	38	42.8	49.632	3.14	46.492	93.69	344	10.746	0.69	10.056	93.57	4.55	60.38	3.83	56.55	93.70	
33		SD	0.748	24.254	10.186	19.391	8.518	9.580	0.731	8.939	0.693	41.265	3.776	0.276	3.548	1.262		12.490	0.992	11.545	0.537	
34		SE	0.335	10.847	4.555	8.672	3.809	4.284	0.327	3.998	0.310	18.454	1.689	0.123	1.587	0.564		5.586	0.444	5.163	0.240	
35																						
36	JI+K																					
37		5	11	273	114	2	31	32.94	2.79	30.15	91.53	361	2.52	0.22	2.3	91.27		35.46	3.01	32.45	91.51	
38		13	11	296	112	5	46	39.52	2.58	36.94	93.47	298	2.07	0.1	1.97	95.17		41.59	2.68	38.91	93.56	
39		18	10	302	116	50	51	36.04	3.39	32.65	90.59	356	3.62	0.46	3.16	87.29		39.66	3.85	35.81	90.29	
40		26	11	246	97	30	41	28.38	3.71	24.67	86.93	374	4.15	0.77	3.38	81.45		32.53	4.48	28.05	86.23	
41		43	10	309	116	80	35	34.98	3.41	31.57	90.25	353	1.58	0.24	1.34	84.81		36.56	3.65	32.91	90.02	
42		Sum	53	1426	555	167	204	171.86	15.88	155.98	452.77	1742	13.94	1.79	12.15	439.99		185.8	17.67	168.13	892.76	
43		Mean	10.6	285.2	111	33.4	40.8	34.372	3.176	31.196	90.55	348.4	2.788	0.358	2.43	88.00	8.87	37.16	3.53	33.63	90.32	
44		SD	0.490	23.025	7.155	29.159	7.222	3.677	0.422	3.973	2.131	26.204	0.959	0.237	0.755	4.811		3.180	0.634	3.624	2.397	
45		SE	0.219	10.297	3.200	13.040	3.230		0.189	1.777	0.953	11.719	0.429	0.106	0.338	2.151		1.422	0.284	1.621	1.072	
46																						
47	WL																					
48		17	11	223	80	2	54	17.21	1.24	15.97	92.79	343	7.54	0.7	6.84	90.72		24.75	1.94	22.81	92.16	
49		30	13	224	83	2	96	26.27	2.61	23.66	90.06	395	20.29	1.94	18.35	90.44		46.56	4.55	42.01	90.23	
50		51	12	224	97	2	107	24.19	2.04	22.15	91.57	316	18.04	1.9	16.14	89.47		42.23	3.94	38.29	90.67	
51		69	13	202	91	5	153	21.73	2.31	19.42	89.37	364	15.21	1.44	13.77	90.53		36.94	3.75	33.19	89.85	
52		71	14	181	74	2	178	22.99	2.34	20.65	89.82	362	16.38	1.77	14.61	89.19		39.37	4.11	35.26	89.56	
53		Sum	63	1054	425	13	588	112.39	10.54	101.85	453.62	1780	77.46	7.75	69.71	450.35		189.85	18.29	171.56	903.97	
54		Mean	12.6	210.8	85	2.6	117.6	22.478	2.108	20.37	90.72	356	15.492	1.55	13.942	90.07	1.36	37.97	3.66	34.31	90.49	
55		SD	1.020	17.104	8.124	1.200	43.647	3.029	0.470	2.620	1.271	26.038	4.327	0.460	3.878	0.616		7.345	0.899	6.474	0.913	
56		SE	0.456	7.649	3.633	0.537	19.519	1.355	0.210	1.172	0.569	11.645	1.935	0.206	1.734	0.275		3.285	0.402	2.895	0.408	
57																						
58	WL+K																					
59		33	12	192	70	0.5	134	19.01	2.1	16.91	88.95	467	12.8	1.32	11.48	89.69		31.81	3.42	28.39	89.25	
60		40	12	151	60	0	105	13.35	1.64	11.71	87.72	382	11.24	1.25	9.99	88.88		24.59	2.89	21.7	88.25	
61		75	13	154	70	0	128	15.7	1.91	13.79	87.83	502	10.43	1.06	9.37	89.84		26.13	2.97	23.16	88.63	
62		78	13	178	69	0	186	21.47	2.19	19.28	89.80	470	14.65	1.25	13.4	91.47		36.12	3.44	32.68	90.48	
63		86	14	147	64	0	149	17.5	1.89	15.61	89.20	349	15.19	1.23	13.96	91.90		32.69	3.12	29.57	90.46	
64		Sum	64	822	333	0.5	702	87.03	9.73	77.3	443.50	2170	64.31	6.11	58.2	451.77		151.34	15.84	135.50	895.28	
65		Mean	12.8	164.4	66.6	0.1	140.4	17.406	1.946	15.46	88.70	434	12.862	1.222	11.64	90.35	1.59	30.27	3.17	27.10	89.41	
66		SD	0.748	17.534	3.980	0.200	26.837	2.773	0.190	2.591	0.805	58.203	1.853	0.087	1.810	1.142		4.286	0.226	4.089	0.918	
67		SE	0.335	7.841	1.780	0.089	12.002	1.240	0.085	1.159	0.360	26.029	0.829	0.039	0.809	0.511		1.917	0.101	1.828	0.410	
68																						

A4.1.2Mid term statistics

One-Way ANOVA: Leaf no. versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	48.5667	9.71333	13.88	<0.0001
Error	24	16.8000	0.70000		
Total	29	65.3667			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.836660	74.30%	68.94%	59.84%

Means

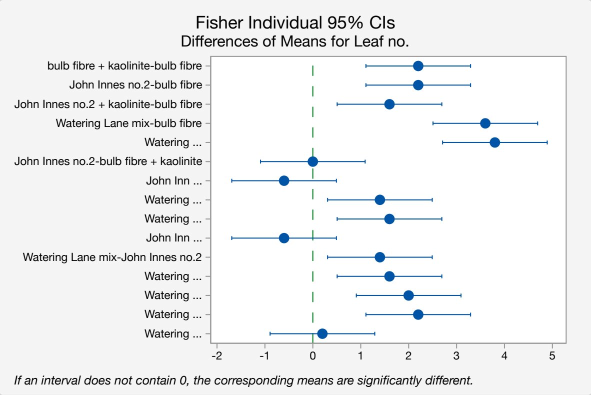
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	9.0000	0.7071	(8.2278, 9.7722)
bulb fibre + kaolinite	5	11.2000	0.8367	(10.4278, 11.9722)
John Innes no.2	5	11.2000	0.8367	(10.4278, 11.9722)
John Innes no.2 + kaolinite	5	10.6000	0.5477	(9.8278, 11.3722)
Watering Lane mix	5	12.6000	1.1402	(11.8278, 13.3722)
Watering Lane mix + kaolinite	5	12.8000	0.8367	(12.0278, 13.5722)

Pooled StDev = 0.836660

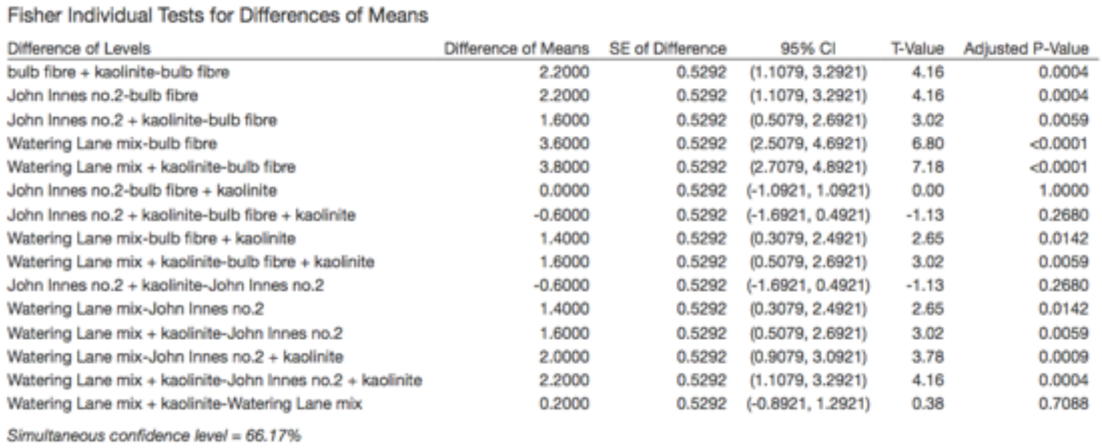
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping		
Watering Lane mix + kaolinite	5	12.8000	A		
Watering Lane mix	5	12.6000	A		
John Innes no.2	5	11.2000		B	
bulb fibre + kaolinite	5	11.2000		B	
John Innes no.2 + kaolinite	5	10.6000		B	
bulb fibre	5	9.0000			C

Means that do not share a letter are significantly different.


Fisher Individual 95% CIs
Differences of Means for Leaf no.

If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	2.2000	0.5292	(1.1079, 3.2921)	4.16	0.0004
John Innes no.2-bulb fibre	2.2000	0.5292	(1.1079, 3.2921)	4.16	0.0004
John Innes no.2 + kaolinite-bulb fibre	1.6000	0.5292	(0.5079, 2.6921)	3.02	0.0059
Watering Lane mix-bulb fibre	3.6000	0.5292	(2.5079, 4.6921)	6.80	<0.0001
Watering Lane mix + kaolinite-bulb fibre	3.8000	0.5292	(2.7079, 4.8921)	7.18	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.0000	0.5292	(-1.0921, 1.0921)	0.00	1.0000
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.6000	0.5292	(-1.6921, 0.4921)	-1.13	0.2680
Watering Lane mix-bulb fibre + kaolinite	1.4000	0.5292	(0.3079, 2.4921)	2.65	0.0142
Watering Lane mix + kaolinite-bulb fibre + kaolinite	1.6000	0.5292	(0.5079, 2.6921)	3.02	0.0059
John Innes no.2 + kaolinite-John Innes no.2	-0.6000	0.5292	(-1.6921, 0.4921)	-1.13	0.2680
Watering Lane mix-John Innes no.2	1.4000	0.5292	(0.3079, 2.4921)	2.65	0.0142
Watering Lane mix + kaolinite-John Innes no.2	1.6000	0.5292	(0.5079, 2.6921)	3.02	0.0059
Watering Lane mix-John Innes no.2 + kaolinite	2.0000	0.5292	(0.9079, 3.0921)	3.78	0.0009
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	2.2000	0.5292	(1.1079, 3.2921)	4.16	0.0004
Watering Lane mix + kaolinite-Watering Lane mix	0.2000	0.5292	(-0.8921, 1.2921)	0.38	0.7088

Simultaneous confidence level = 66.17%

One-Way ANOVA: Height/mm versus Treatment

Method

Null hypothesis H_0: All means are equal
Alternative hypothesis H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	52547.4	10509.5	17.64	<0.0001
Error	24	14296.0	595.7		
Total	29	66843.4			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
24.4063	78.61%	74.16%	66.58%

Means

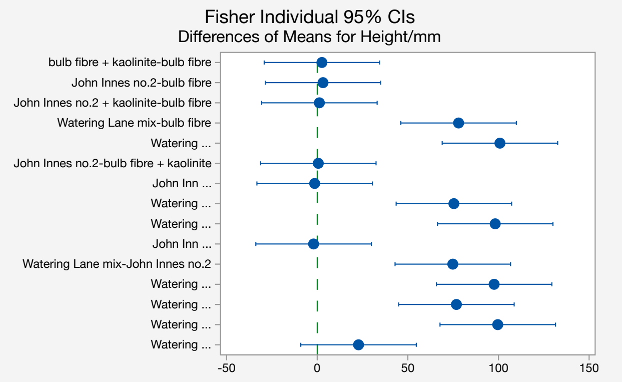
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	39.600	4.879	(17.073, 62.127)
bulb fibre + kaolinite	5	42.200	10.616	(19.673, 64.727)
John Innes no.2	5	42.800	9.524	(20.273, 65.327)
John Innes no.2 + kaolinite	5	40.800	8.075	(18.273, 63.327)
Watering Lane mix	5	117.60	48.80	(95.07, 140.13)
Watering Lane mix + kaolinite	5	140.40	30.00	(117.87, 162.93)

Pooled StDev = 24.4063

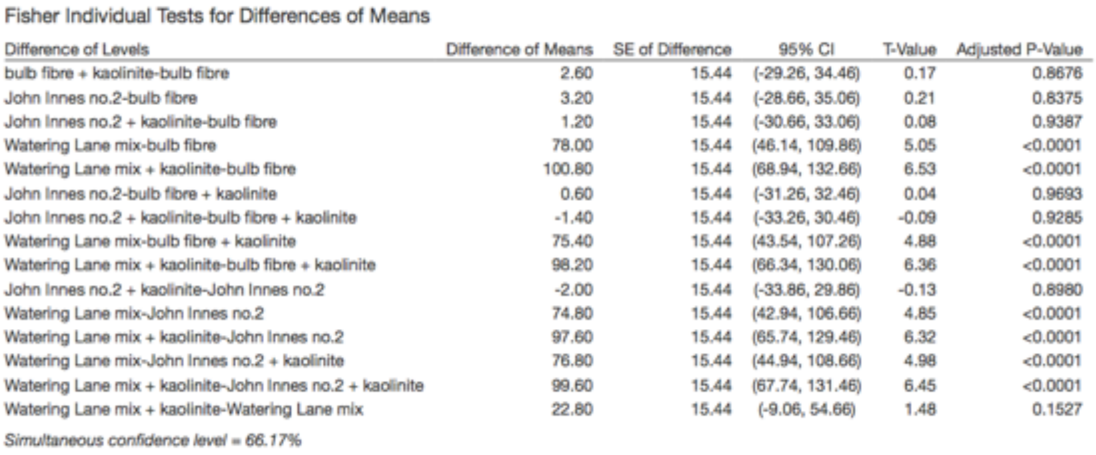
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
Watering Lane mix + kaolinite	5	140.40	A	
Watering Lane mix	5	117.60	A	
John Innes no.2	5	42.800		B
bulb fibre + kaolinite	5	42.200		B
John Innes no.2 + kaolinite	5	40.800		B
bulb fibre	5	39.600		B

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	2.60	15.44	(-29.26, 34.46)	0.17	0.8676
John Innes no.2-bulb fibre	3.20	15.44	(-28.66, 35.06)	0.21	0.8375
John Innes no.2 + kaolinite-bulb fibre	1.20	15.44	(-30.66, 33.06)	0.08	0.9387
Watering Lane mix-bulb fibre	78.00	15.44	(46.14, 109.86)	5.05	<0.0001
Watering Lane mix + kaolinite-bulb fibre	100.80	15.44	(68.94, 132.66)	6.53	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.60	15.44	(-31.26, 32.46)	0.04	0.9693
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-1.40	15.44	(-33.26, 30.46)	-0.09	0.9285
Watering Lane mix-bulb fibre + kaolinite	75.40	15.44	(43.54, 107.26)	4.88	<0.0001
Watering Lane mix + kaolinite-bulb fibre + kaolinite	98.20	15.44	(66.34, 130.06)	6.36	<0.0001
John Innes no.2 + kaolinite-John Innes no.2	-2.00	15.44	(-33.86, 29.86)	-0.13	0.8980
Watering Lane mix-John Innes no.2	74.80	15.44	(42.94, 106.66)	4.85	<0.0001
Watering Lane mix + kaolinite-John Innes no.2	97.60	15.44	(65.74, 129.46)	6.32	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	76.80	15.44	(44.94, 108.66)	4.98	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	99.60	15.44	(67.74, 131.46)	6.45	<0.0001
Watering Lane mix + kaolinite-Watering Lane mix	22.80	15.44	(-9.06, 54.66)	1.48	0.1527

Simultaneous confidence level = 66.17%

One-Way ANOVA: Leaf length/mm versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	352075	70414.9	140.21	<0.0001
Error	24	12053	502.2		
Total	29	364127			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
22.4098	96.69%	96.00%	94.83%

Means

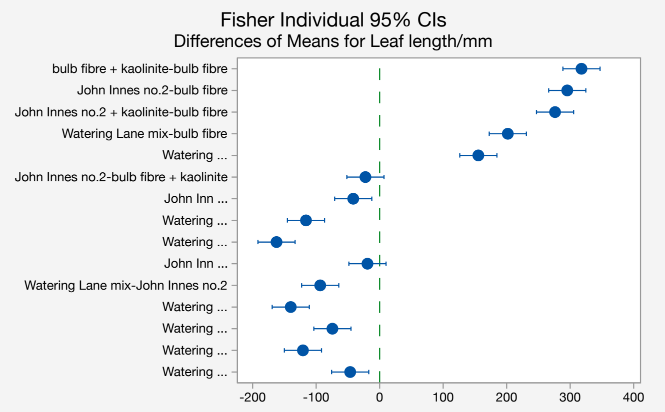
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	9.0000	0.7071	(-11.6843, 29.6843)
bulb fibre + kaolinite	5	326.80	29.41	(306.12, 347.48)
John Innes no.2	5	304.40	27.12	(283.72, 325.08)
John Innes no.2 + kaolinite	5	285.20	25.74	(264.52, 305.88)
Watering Lane mix	5	210.800	19.123	(190.116, 231.484)
Watering Lane mix + kaolinite	5	164.400	19.604	(143.716, 185.084)

Pooled StDev = 22.4098

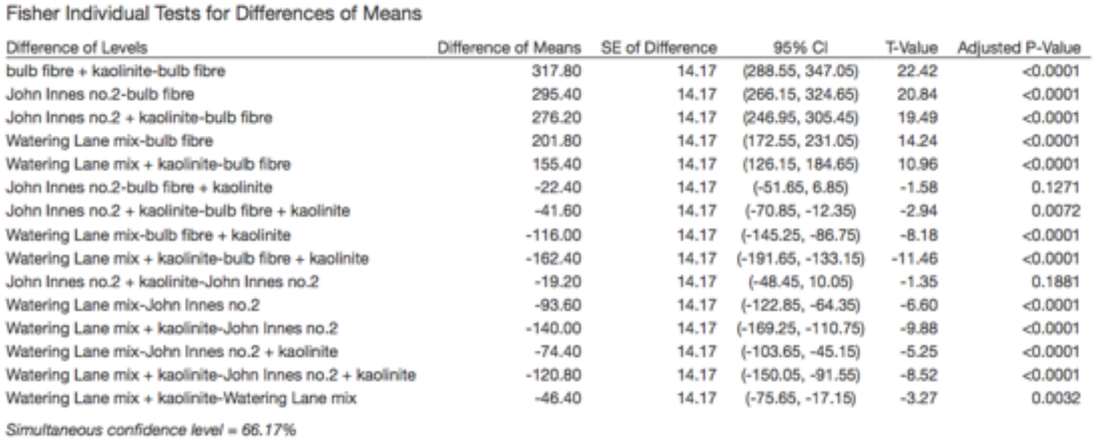
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping
bulb fibre + kaolinite	5	326.80	A
John Innes no.2	5	304.40	A B
John Innes no.2 + kaolinite	5	285.20	B
Watering Lane mix	5	210.800	C
Watering Lane mix + kaolinite	5	164.400	D
bulb fibre	5	9.0000	E

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	317.80	14.17	(288.55, 347.05)	22.42	<0.0001
John Innes no.2-bulb fibre	295.40	14.17	(266.15, 324.65)	20.84	<0.0001
John Innes no.2 + kaolinite-bulb fibre	276.20	14.17	(246.95, 305.45)	19.49	<0.0001
Watering Lane mix-bulb fibre	201.80	14.17	(172.55, 231.05)	14.24	<0.0001
Watering Lane mix + kaolinite-bulb fibre	155.40	14.17	(126.15, 184.65)	10.96	<0.0001
John Innes no.2-bulb fibre + kaolinite	-22.40	14.17	(-51.65, 6.85)	-1.58	0.1271
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-41.60	14.17	(-70.85, -12.35)	-2.94	0.0072
Watering Lane mix-bulb fibre + kaolinite	-116.00	14.17	(-145.25, -86.75)	-8.18	<0.0001
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-162.40	14.17	(-191.65, -133.15)	-11.46	<0.0001
John Innes no.2 + kaolinite-John Innes no.2	-19.20	14.17	(-48.45, 10.05)	-1.35	0.1881
Watering Lane mix-John Innes no.2	-93.60	14.17	(-122.85, -64.35)	-6.60	<0.0001
Watering Lane mix + kaolinite-John Innes no.2	-140.00	14.17	(-169.25, -110.75)	-9.88	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	-74.40	14.17	(-103.65, -45.15)	-5.25	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-120.80	14.17	(-150.05, -91.55)	-8.52	<0.0001
Watering Lane mix + kaolinite-Watering Lane mix	-46.40	14.17	(-75.65, -17.15)	-3.27	0.0032

Simultaneous confidence level = 66.17%

One-Way ANOVA: Leaf width/mm versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	50814.0	10162.8	116.10	<0.0001
Error	24	2100.8	87.5		
Total	29	52914.8			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
9.35593	96.03%	95.20%	93.80%

Means

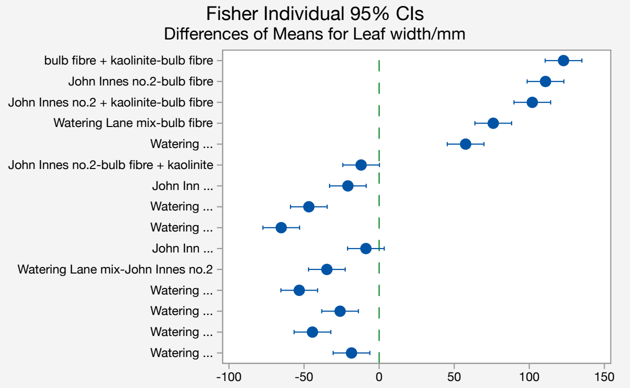
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	9.0000	0.7071	(0.3644, 17.6356)
bulb fibre + kaolinite	5	131.800	15.123	(123.164, 140.436)
John Innes no.2	5	119.800	11.389	(111.164, 128.436)
John Innes no.2 + kaolinite	5	111.000	8.000	(102.364, 119.636)
Watering Lane mix	5	85.000	9.083	(76.364, 93.636)
Watering Lane mix + kaolinite	5	66.600	4.450	(57.964, 75.236)

Pooled StDev = 9.35593

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping				
bulb fibre + kaolinite	5	131.800	A				
John Innes no.2	5	119.800	A	B			
John Innes no.2 + kaolinite	5	111.000		B			
Watering Lane mix	5	85.000			C		
Watering Lane mix + kaolinite	5	66.600				D	
bulb fibre	5	9.0000					E

Means that do not share a letter are significantly different.


Fisher Individual 95% CIs
Differences of Means for Leaf width/mm

If an interval does not contain 0, the corresponding means are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	122.800	5.917	(110.587, 135.013)	20.75	<0.0001
John Innes no.2-bulb fibre	110.800	5.917	(98.587, 123.013)	18.73	<0.0001
John Innes no.2 + kaolinite-bulb fibre	102.000	5.917	(89.787, 114.213)	17.24	<0.0001
Watering Lane mix-bulb fibre	76.000	5.917	(63.787, 88.213)	12.84	<0.0001
Watering Lane mix + kaolinite-bulb fibre	57.600	5.917	(45.387, 69.813)	9.73	<0.0001
John Innes no.2-bulb fibre + kaolinite	-12.000	5.917	(-24.213, 0.213)	-2.03	0.0538
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-20.800	5.917	(-33.013, -8.587)	-3.52	0.0018
Watering Lane mix-bulb fibre + kaolinite	-46.800	5.917	(-59.013, -34.587)	-7.91	<0.0001
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-65.200	5.917	(-77.413, -52.987)	-11.02	<0.0001
John Innes no.2 + kaolinite-John Innes no.2	-8.800	5.917	(-21.013, 3.413)	-1.49	0.1500
Watering Lane mix-John Innes no.2	-34.800	5.917	(-47.013, -22.587)	-5.88	<0.0001
Watering Lane mix + kaolinite-John Innes no.2	-53.200	5.917	(-65.413, -40.987)	-8.99	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	-26.000	5.917	(-38.213, -13.787)	-4.39	0.0002
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-44.400	5.917	(-56.613, -32.187)	-7.50	<0.0001
Watering Lane mix + kaolinite-Watering Lane mix	-18.400	5.917	(-30.613, -6.187)	-3.11	0.0048

Simultaneous confidence level = 66.17%

One-Way ANOVA: Shoots dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	22.3713	4.47426	16.88	<0.0001
Error	24	6.3616	0.26507		
Total	29	28.7329			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.514848	77.86%	73.25%	65.41%

Means

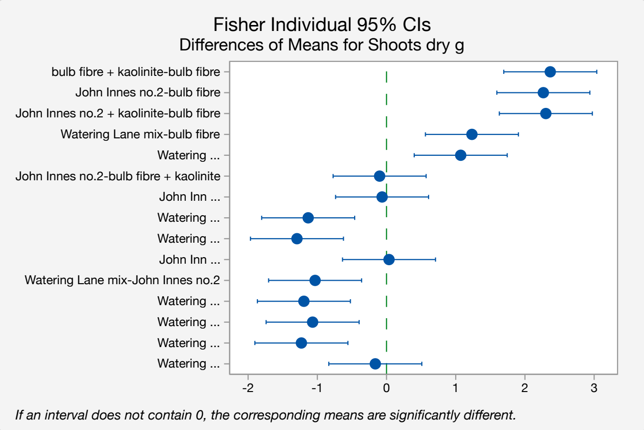
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	0.8740	0.3492	(0.3988, 1.3492)
bulb fibre + kaolinite	5	3.2400	0.5073	(2.7648, 3.7152)
John Innes no.2	5	3.1400	0.8168	(2.6648, 3.6152)
John Innes no.2 + kaolinite	5	3.1760	0.4717	(2.7008, 3.6512)
Watering Lane mix	5	2.1080	0.5255	(1.6328, 2.5832)
Watering Lane mix + kaolinite	5	1.94600	0.21291	(1.47079, 2.42121)

Pooled StDev = 0.514848

Grouping Information Using the Fisher LSD Method and 95% Confidence

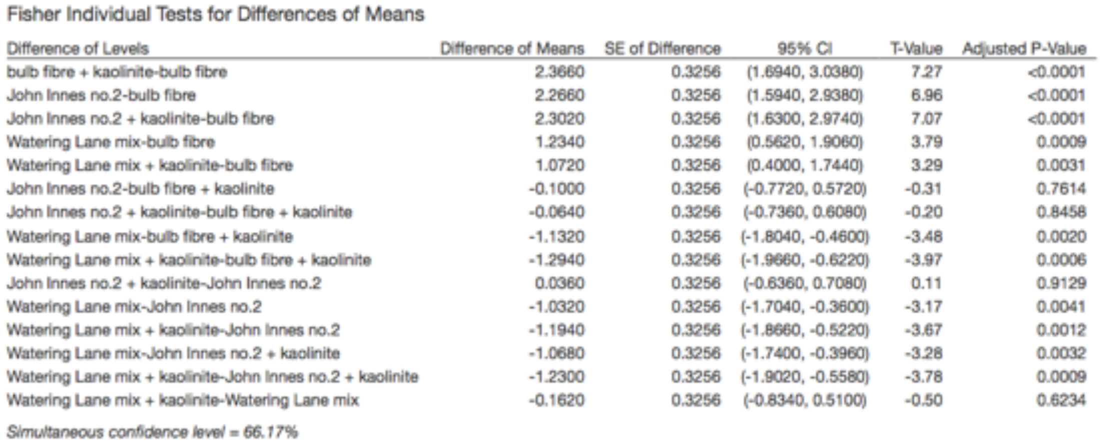
Treatment	N	Mean	Grouping		
bulb fibre + kaolinite	5	3.2400	A		
John Innes no.2 + kaolinite	5	3.1760	A		
John Innes no.2	5	3.1400	A		
Watering Lane mix	5	2.1080		B	
Watering Lane mix + kaolinite	5	1.94600		B	
bulb fibre	5	0.8740			C

Means that do not share a letter are significantly different.



Fisher Individual 95% CIs
Differences of Means for Shoots dry g

If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	2.3660	0.3256	(1.6940, 3.0380)	7.27	<0.0001
John Innes no.2-bulb fibre	2.2660	0.3256	(1.5940, 2.9380)	6.96	<0.0001
John Innes no.2 + kaolinite-bulb fibre	2.3020	0.3256	(1.6300, 2.9740)	7.07	<0.0001
Watering Lane mix-bulb fibre	1.2340	0.3256	(0.5620, 1.9060)	3.79	0.0009
Watering Lane mix + kaolinite-bulb fibre	1.0720	0.3256	(0.4000, 1.7440)	3.29	0.0031
John Innes no.2-bulb fibre + kaolinite	-0.1000	0.3256	(-0.7720, 0.5720)	-0.31	0.7614
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.0640	0.3256	(-0.7360, 0.6080)	-0.20	0.8458
Watering Lane mix-bulb fibre + kaolinite	-1.1320	0.3256	(-1.8040, -0.4600)	-3.48	0.0020
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-1.2940	0.3256	(-1.9660, -0.6220)	-3.97	0.0006
John Innes no.2 + kaolinite-John Innes no.2	0.0360	0.3256	(-0.6360, 0.7080)	0.11	0.9129
Watering Lane mix-John Innes no.2	-1.0320	0.3256	(-1.7040, -0.3600)	-3.17	0.0041
Watering Lane mix + kaolinite-John Innes no.2	-1.1940	0.3256	(-1.8660, -0.5220)	-3.67	0.0012
Watering Lane mix-John Innes no.2 + kaolinite	-1.0680	0.3256	(-1.7400, -0.3960)	-3.28	0.0032
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-1.2300	0.3256	(-1.9020, -0.5580)	-3.78	0.0009
Watering Lane mix + kaolinite-Watering Lane mix	-0.1620	0.3256	(-0.8340, 0.5100)	-0.50	0.6234

Simultaneous confidence level = 66.17%

One-Way ANOVA: Shoots % moisture versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	121.780	24.3560	11.29	<0.0001
Error	24	51.767	2.1570		
Total	29	173.547			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.46866	70.17%	63.96%	53.39%

Means

Treatment	N	Mean	StDev	95% CI
bulb fibre	5	94.1980	1.8778	(92.8424, 95.5536)
bulb fibre + kaolinite	5	93.4620	0.5603	(92.1064, 94.8176)
John Innes no.2	5	93.6880	0.7759	(92.3324, 95.0436)
John Innes no.2 + kaolinite	5	90.554	2.381	(89.198, 91.910)
Watering Lane mix	5	90.7220	1.4209	(89.3664, 92.0776)
Watering Lane mix + kaolinite	5	88.7000	0.9000	(87.3444, 90.0556)

Pooled StDev = 1.46866

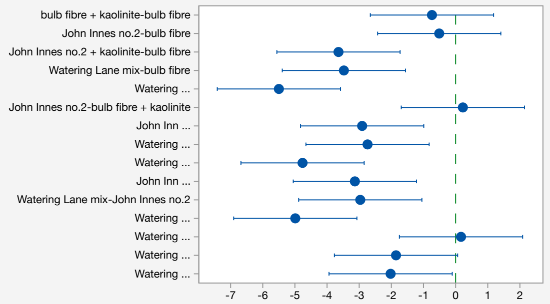
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping		
bulb fibre	5	94.1980	A		
John Innes no.2	5	93.6880	A		
bulb fibre + kaolinite	5	93.4620	A		
Watering Lane mix	5	90.7220		B	
John Innes no.2 + kaolinite	5	90.554		B	C
Watering Lane mix + kaolinite	5	88.7000			C

Means that do not share a letter are significantly different.

Fisher Individual 95% CIs

Differences of Means for Shoots % moisture



If an interval does not contain 0, the corresponding means are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-0.7360	0.9289	(-2.6531, 1.1811)	-0.79	0.4359
John Innes no.2-bulb fibre	-0.5100	0.9289	(-2.4271, 1.4071)	-0.55	0.5880
John Innes no.2 + kaolinite-bulb fibre	-3.6440	0.9289	(-5.5611, -1.7269)	-3.92	0.0006
Watering Lane mix-bulb fibre	-3.4760	0.9289	(-5.3931, -1.5589)	-3.74	0.0010
Watering Lane mix + kaolinite-bulb fibre	-5.4980	0.9289	(-7.4151, -3.5809)	-5.92	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.2260	0.9289	(-1.6911, 2.1431)	0.24	0.8098
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-2.9080	0.9289	(-4.8251, -0.9909)	-3.13	0.0045
Watering Lane mix-bulb fibre + kaolinite	-2.7400	0.9289	(-4.6571, -0.8229)	-2.95	0.0070
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-4.7620	0.9289	(-6.6791, -2.8449)	-5.13	<0.0001
John Innes no.2 + kaolinite-John Innes no.2	-3.1340	0.9289	(-5.0511, -1.2169)	-3.37	0.0025
Watering Lane mix-John Innes no.2	-2.9660	0.9289	(-4.8831, -1.0489)	-3.19	0.0039
Watering Lane mix + kaolinite-John Innes no.2	-4.9880	0.9289	(-6.9051, -3.0709)	-5.37	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	0.1680	0.9289	(-1.7491, 2.0851)	0.18	0.8580
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-1.8540	0.9289	(-3.7711, 0.0631)	-2.00	0.0574
Watering Lane mix + kaolinite-Watering Lane mix	-2.0220	0.9289	(-3.9391, -0.1049)	-2.18	0.0396

Simultaneous confidence level = 66.17%

One-Way ANOVA: roots dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	6.90778	1.38156	14.20	<0.0001
Error	24	2.33436	0.09727		
Total	29	9.24214			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.311873	74.74%	69.48%	60.53%

Means

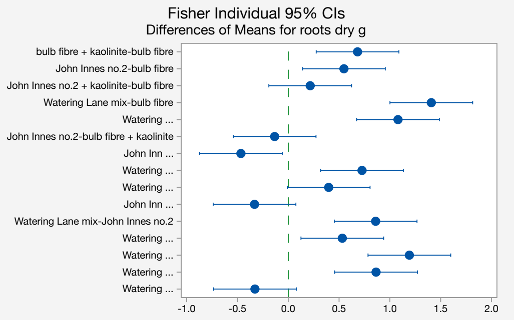
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	0.14200	0.06648	(-0.14586, 0.42986)
bulb fibre + kaolinite	5	0.8240	0.3747	(0.5361, 1.1119)
John Innes no.2	5	0.6900	0.3084	(0.4021, 0.9779)
John Innes no.2 + kaolinite	5	0.3580	0.2644	(0.0701, 0.6459)
Watering Lane mix	5	1.5500	0.5142	(1.2621, 1.8379)
Watering Lane mix + kaolinite	5	1.22200	0.09680	(0.93414, 1.50986)

Pooled StDev = 0.311873

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping				
Watering Lane mix	5	1.5500	A				
Watering Lane mix + kaolinite	5	1.22200	A	B			
bulb fibre + kaolinite	5	0.8240		B	C		
John Innes no.2	5	0.6900			C	D	
John Innes no.2 + kaolinite	5	0.3580				D	E
bulb fibre	5	0.14200					E

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	0.6820	0.1972	(0.2749, 1.0891)	3.46	0.0020
John Innes no.2-bulb fibre	0.5480	0.1972	(0.1409, 0.9551)	2.78	0.0104
John Innes no.2 + kaolinite-bulb fibre	0.2160	0.1972	(-0.1911, 0.6231)	1.10	0.2844
Watering Lane mix-bulb fibre	1.4080	0.1972	(1.0009, 1.8151)	7.14	<0.0001
Watering Lane mix + kaolinite-bulb fibre	1.0800	0.1972	(0.6729, 1.4871)	5.48	<0.0001
John Innes no.2-bulb fibre + kaolinite	-0.1340	0.1972	(-0.5411, 0.2731)	-0.68	0.5034
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.4660	0.1972	(-0.8731, -0.0589)	-2.36	0.0266
Watering Lane mix-bulb fibre + kaolinite	0.7260	0.1972	(0.3189, 1.1331)	3.68	0.0012
Watering Lane mix + kaolinite-bulb fibre + kaolinite	0.3980	0.1972	(-0.0091, 0.8051)	2.02	0.0549
John Innes no.2 + kaolinite-John Innes no.2	-0.3320	0.1972	(-0.7391, 0.0751)	-1.68	0.1053
Watering Lane mix-John Innes no.2	0.8600	0.1972	(0.4529, 1.2671)	4.36	0.0002
Watering Lane mix + kaolinite-John Innes no.2	0.5320	0.1972	(0.1249, 0.9391)	2.70	0.0126
Watering Lane mix-John Innes no.2 + kaolinite	1.1920	0.1972	(0.7849, 1.5991)	6.04	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	0.8640	0.1972	(0.4569, 1.2711)	4.38	0.0002
Watering Lane mix + kaolinite-Watering Lane mix	-0.3280	0.1972	(-0.7351, 0.0791)	-1.66	0.1093

Simultaneous confidence level = 66.17%

One-Way ANOVA: total dry g versus Treatment

```
Method

Null hypothesis         H0: All means are equal
Alternative hypothesis  H1: At least one mean is different

Equal variances were assumed for the analysis.


Factor Information

Factor     Levels  Values
Treatment       6  bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite


Analysis of Variance

Source     DF   Adj SS   Adj MS  F-Value  P-Value
Treatment   5  31.1739  6.23478    11.06  <0.0001
Error      24  13.5271  0.56363
Total      29  44.7010


Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0.750753  69.74%     63.43%      52.72%


Means

Treatment                     N    Mean  StDev          95% CI
bulb fibre                    5  1.0160  0.3773  (0.3231, 1.7089)
bulb fibre + kaolinite        5  4.0640  0.6567  (3.3711, 4.7569)
John Innes no.2               5  3.8300  1.1096  (3.1371, 4.5229)
John Innes no.2 + kaolinite   5  3.5340  0.7092  (2.8411, 4.2269)
Watering Lane mix             5  3.6580  1.0049  (2.9651, 4.3509)
Watering Lane mix + kaolinite 5  3.1680  0.2531  (2.4751, 3.8609)

Pooled StDev = 0.750753


Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment                     N    Mean  Grouping
bulb fibre + kaolinite        5  4.0640  A
John Innes no.2               5  3.8300  A
Watering Lane mix             5  3.6580  A
John Innes no.2 + kaolinite   5  3.5340  A
Watering Lane mix + kaolinite 5  3.1680  A
bulb fibre                    5  1.0160      B

Means that do not share a letter are significantly different.
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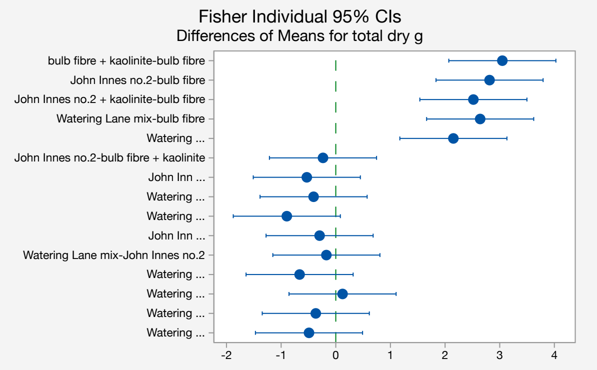
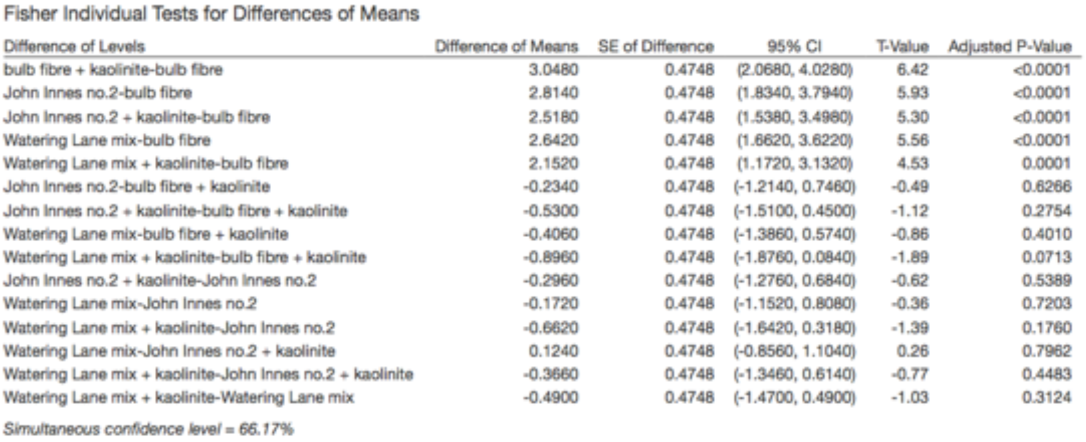


If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	3.0480	0.4748	(2.0680, 4.0280)	6.42	<0.0001
John Innes no.2-bulb fibre	2.8140	0.4748	(1.8340, 3.7940)	5.93	<0.0001
John Innes no.2 + kaolinite-bulb fibre	2.5180	0.4748	(1.5380, 3.4980)	5.30	<0.0001
Watering Lane mix-bulb fibre	2.6420	0.4748	(1.6620, 3.6220)	5.56	<0.0001
Watering Lane mix + kaolinite-bulb fibre	2.1520	0.4748	(1.1720, 3.1320)	4.53	0.0001
John Innes no.2-bulb fibre + kaolinite	-0.2340	0.4748	(-1.2140, 0.7460)	-0.49	0.6266
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.5300	0.4748	(-1.5100, 0.4500)	-1.12	0.2754
Watering Lane mix-bulb fibre + kaolinite	-0.4060	0.4748	(-1.3860, 0.5740)	-0.86	0.4010
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-0.8960	0.4748	(-1.8760, 0.0840)	-1.89	0.0713
John Innes no.2 + kaolinite-John Innes no.2	-0.2960	0.4748	(-1.2760, 0.6840)	-0.62	0.5389
Watering Lane mix-John Innes no.2	-0.1720	0.4748	(-1.1520, 0.8080)	-0.36	0.7203
Watering Lane mix + kaolinite-John Innes no.2	-0.6620	0.4748	(-1.6420, 0.3180)	-1.39	0.1760
Watering Lane mix-John Innes no.2 + kaolinite	0.1240	0.4748	(-0.8560, 1.1040)	0.26	0.7962
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-0.3660	0.4748	(-1.3460, 0.6140)	-0.77	0.4483
Watering Lane mix + kaolinite-Watering Lane mix	-0.4900	0.4748	(-1.4700, 0.4900)	-1.03	0.3124

Simultaneous confidence level = 66.17%

One-Way ANOVA: total % moisture versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	97.794	19.5587	9.24	<0.0001
Error	24	50.824	2.1177		
Total	29	148.618			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.45522	65.80%	58.68%	46.57%

Means

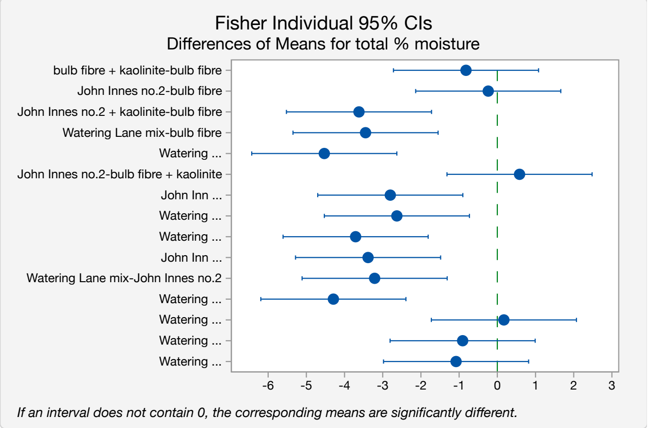
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	93.9440	1.5504	(92.6008, 95.2872)
bulb fibre + kaolinite	5	93.1240	0.8136	(91.7808, 94.4672)
John Innes no.2	5	93.7060	0.5996	(92.3628, 95.0492)
John Innes no.2 + kaolinite	5	90.322	2.680	(88.979, 91.665)
Watering Lane mix	5	90.4940	1.0202	(89.1508, 91.8372)
Watering Lane mix + kaolinite	5	89.4140	1.0280	(88.0708, 90.7572)

Pooled StDev = 1.45522

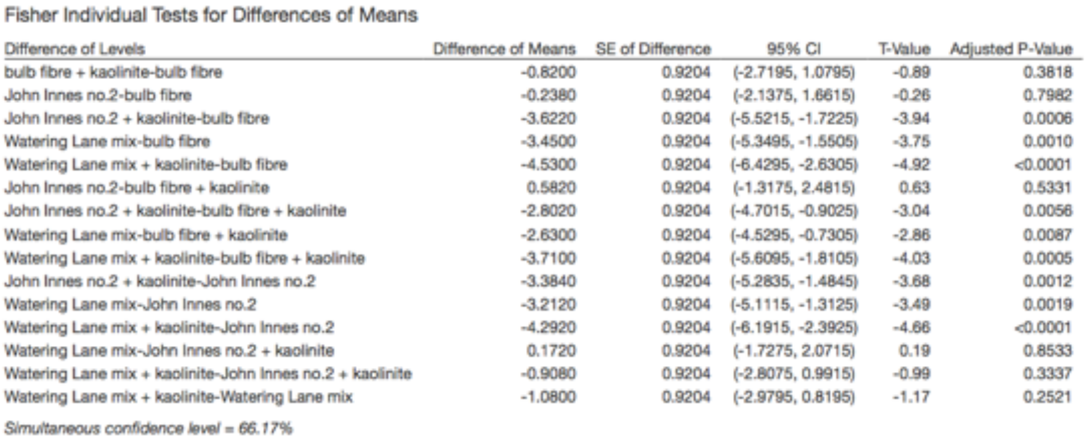
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
bulb fibre	5	93.9440	A	
John Innes no.2	5	93.7060	A	
bulb fibre + kaolinite	5	93.1240	A	
Watering Lane mix	5	90.4940		B
John Innes no.2 + kaolinite	5	90.322		B
Watering Lane mix + kaolinite	5	89.4140		B

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-0.8200	0.9204	(-2.7195, 1.0795)	-0.89	0.3818
John Innes no.2-bulb fibre	-0.2380	0.9204	(-2.1375, 1.6615)	-0.26	0.7982
John Innes no.2 + kaolinite-bulb fibre	-3.6220	0.9204	(-5.5215, -1.7225)	-3.94	0.0006
Watering Lane mix-bulb fibre	-3.4500	0.9204	(-5.3495, -1.5505)	-3.75	0.0010
Watering Lane mix + kaolinite-bulb fibre	-4.5300	0.9204	(-6.4295, -2.6305)	-4.92	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.5820	0.9204	(-1.3175, 2.4815)	0.63	0.5331
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-2.8020	0.9204	(-4.7015, -0.9025)	-3.04	0.0056
Watering Lane mix-bulb fibre + kaolinite	-2.6300	0.9204	(-4.5295, -0.7305)	-2.86	0.0087
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-3.7100	0.9204	(-5.6095, -1.8105)	-4.03	0.0005
John Innes no.2 + kaolinite-John Innes no.2	-3.3840	0.9204	(-5.2835, -1.4845)	-3.68	0.0012
Watering Lane mix-John Innes no.2	-3.2120	0.9204	(-5.1115, -1.3125)	-3.49	0.0019
Watering Lane mix + kaolinite-John Innes no.2	-4.2920	0.9204	(-6.1915, -2.3925)	-4.66	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	0.1720	0.9204	(-1.7275, 2.0715)	0.19	0.8533
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-0.9080	0.9204	(-2.8075, 0.9915)	-0.99	0.3337
Watering Lane mix + kaolinite-Watering Lane mix	-1.0800	0.9204	(-2.9795, 0.8195)	-1.17	0.2521

Simultaneous confidence level = 66.17%

One-Way ANOVA: shoot/root ratio versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	bulb fibre, bulb fibre + kaolinite, John Innes no.2, John Innes no.2 + kaolinite, Watering Lane mix, Watering Lane mix + kaolinite

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	462.237	92.4473	6.23	0.0008
Error	24	356.274	14.8448		
Total	29	818.511			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.85289	56.47%	47.40%	31.99%

Means

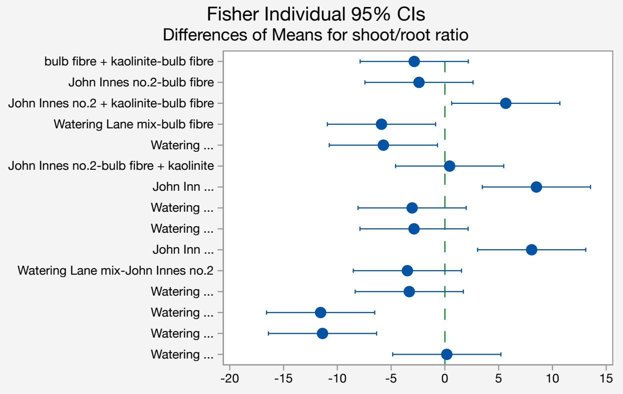
Treatment	N	Mean	StDev	95% CI
bulb fibre	5	7.316	4.269	(3.760, 10.872)
bulb fibre + kaolinite	5	4.4660	1.8181	(0.9098, 8.0222)
John Innes no.2	5	4.9080	1.1941	(1.3518, 8.4642)
John Innes no.2 + kaolinite	5	12.976	8.124	(9.420, 16.532)
Watering Lane mix	5	1.4220	0.2703	(-2.1342, 4.9782)
Watering Lane mix + kaolinite	5	1.59800	0.19383	(-1.95823, 5.15423)

Pooled StDev = 3.85289

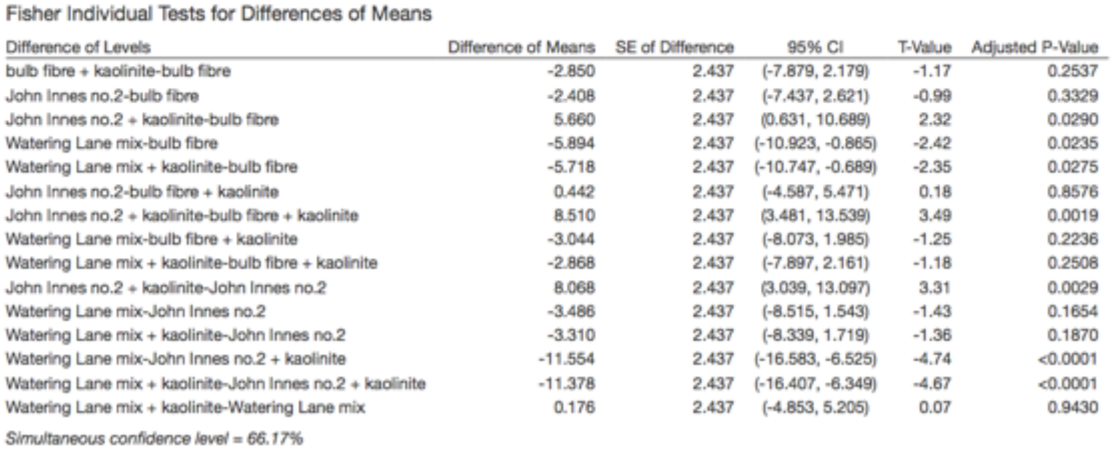
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
John Innes no.2 + kaolinite	5	12.976	A	
bulb fibre	5	7.316	B	
John Innes no.2	5	4.9080	B	C
bulb fibre + kaolinite	5	4.4660	B	C
Watering Lane mix + kaolinite	5	1.59800		C
Watering Lane mix	5	1.4220		C

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-2.850	2.437	(-7.879, 2.179)	-1.17	0.2537
John Innes no.2-bulb fibre	-2.408	2.437	(-7.437, 2.621)	-0.99	0.3329
John Innes no.2 + kaolinite-bulb fibre	5.660	2.437	(0.631, 10.689)	2.32	0.0290
Watering Lane mix-bulb fibre	-5.894	2.437	(-10.923, -0.865)	-2.42	0.0235
Watering Lane mix + kaolinite-bulb fibre	-5.718	2.437	(-10.747, -0.689)	-2.35	0.0275
John Innes no.2-bulb fibre + kaolinite	0.442	2.437	(-4.587, 5.471)	0.18	0.8576
John Innes no.2 + kaolinite-bulb fibre + kaolinite	8.510	2.437	(3.481, 13.539)	3.49	0.0019
Watering Lane mix-bulb fibre + kaolinite	-3.044	2.437	(-8.073, 1.985)	-1.25	0.2236
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-2.868	2.437	(-7.897, 2.161)	-1.18	0.2508
John Innes no.2 + kaolinite-John Innes no.2	8.068	2.437	(3.039, 13.097)	3.31	0.0029
Watering Lane mix-John Innes no.2	-3.486	2.437	(-8.515, 1.543)	-1.43	0.1654
Watering Lane mix + kaolinite-John Innes no.2	-3.310	2.437	(-8.339, 1.719)	-1.36	0.1870
Watering Lane mix-John Innes no.2 + kaolinite	-11.554	2.437	(-16.583, -6.525)	-4.74	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-11.378	2.437	(-16.407, -6.349)	-4.67	<0.0001
Watering Lane mix + kaolinite-Watering Lane mix	0.176	2.437	(-4.853, 5.205)	0.07	0.9430

Simultaneous confidence level = 66.17%

A4.1.3 Full-term Destructive harvest

A4.1.4 Full term harvest statistics

One-Way ANOVA: Stem Length versus

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	3576199	715240	73.16	<0.0001
Error	54	527917	9776		
Total	59	4104115			

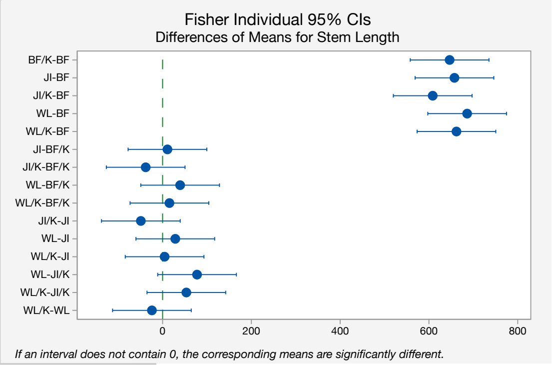
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
98.8748	87.14%	85.95%	84.12%

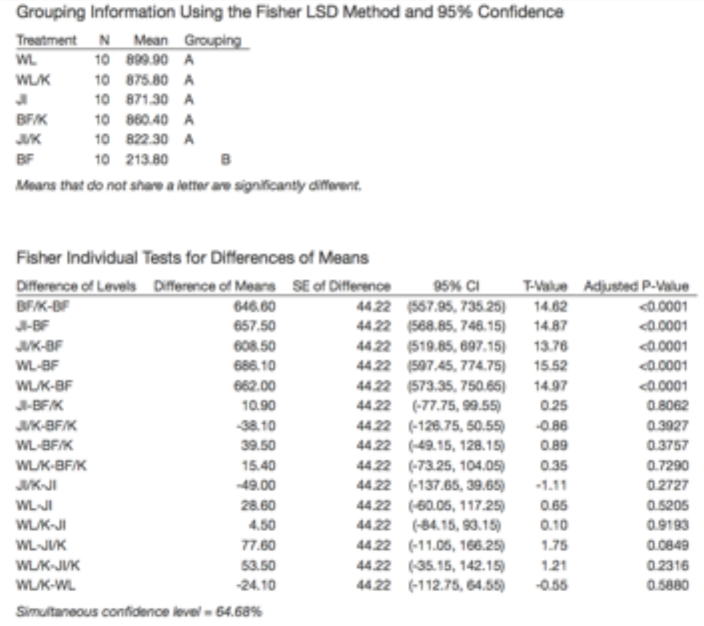
Means

Treatment	N	Mean	StDev	95% CI
BF	10	213.80	88.48	(151.11, 276.49)
BF/K	10	860.40	133.04	(797.71, 923.09)
JI	10	871.30	55.39	(808.61, 933.99)
JI/K	10	822.30	129.29	(759.61, 884.99)
WL	10	899.90	96.27	(837.21, 962.59)
WL/K	10	875.80	63.83	(813.11, 938.49)

Pooled StDev = 98.8748



If an interval does not contain 0, the corresponding means are significantly different.



Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
WL	10	899.90	A	
WL/K	10	875.80	A	
JI	10	871.30	A	
BF/K	10	860.40	A	
JI/K	10	822.30	A	
BF	10	213.80		B

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF/K-BF	646.60	44.22	(557.95, 735.25)	14.62	<0.0001
JI-BF	657.50	44.22	(568.85, 746.15)	14.87	<0.0001
JI/K-BF	608.50	44.22	(519.85, 697.15)	13.76	<0.0001
WL-BF	686.10	44.22	(597.45, 774.75)	15.52	<0.0001
WL/K-BF	662.00	44.22	(573.35, 750.65)	14.97	<0.0001
JI-BF/K	10.90	44.22	(-77.75, 99.55)	0.25	0.8062
JI/K-BF/K	-38.10	44.22	(-126.75, 50.55)	-0.86	0.3927
WL-BF/K	39.50	44.22	(-49.15, 128.15)	0.89	0.3757
WL/K-BF/K	15.40	44.22	(-73.25, 104.05)	0.35	0.7290
JI/K-JI	-49.00	44.22	(-137.65, 39.65)	-1.11	0.2727
WL-JI	28.60	44.22	(-60.05, 117.25)	0.65	0.5205
WL/K-JI	4.50	44.22	(-84.15, 93.15)	0.10	0.9193
WL-JI/K	77.60	44.22	(-11.05, 166.25)	1.75	0.0849
WL/K-JI/K	53.50	44.22	(-35.15, 142.15)	1.21	0.2316
WL/K-WL	-24.10	44.22	(-112.75, 64.55)	-0.55	0.5880

Simultaneous confidence level = 64.68%

One-Way ANOVA: Leaf no. versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	3971.5	794.297	5.38	0.0004
Error	54	7965.5	147.509		
Total	59	11937.0			

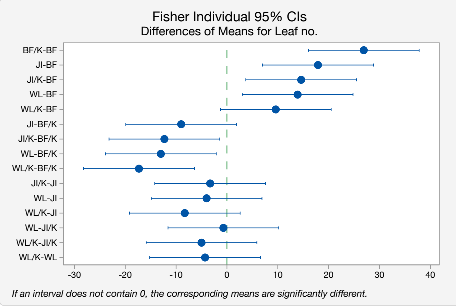
Model Summary

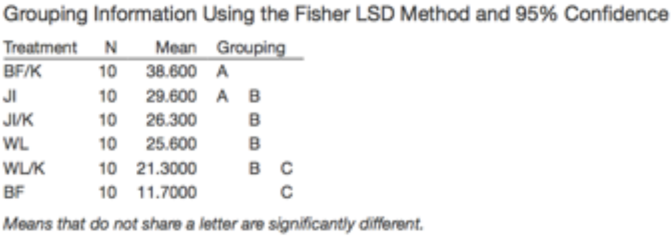
S	R-sq	R-sq(adj)	R-sq(pred)
12.1453	33.27%	27.09%	17.62%

Means

Treatment	N	Mean	StDev	95% CI
BF	10	11.7000	1.6364	(3.9999, 19.4001)
BF/K	10	38.600	28.648	(30.900, 46.300)
JI	10	29.600	4.088	(21.900, 37.300)
JI/K	10	26.300	5.397	(18.600, 34.000)
WL	10	25.600	3.565	(17.900, 33.300)
WL/K	10	21.3000	1.7670	(13.5999, 29.0001)

Pooled StDev = 12.1453

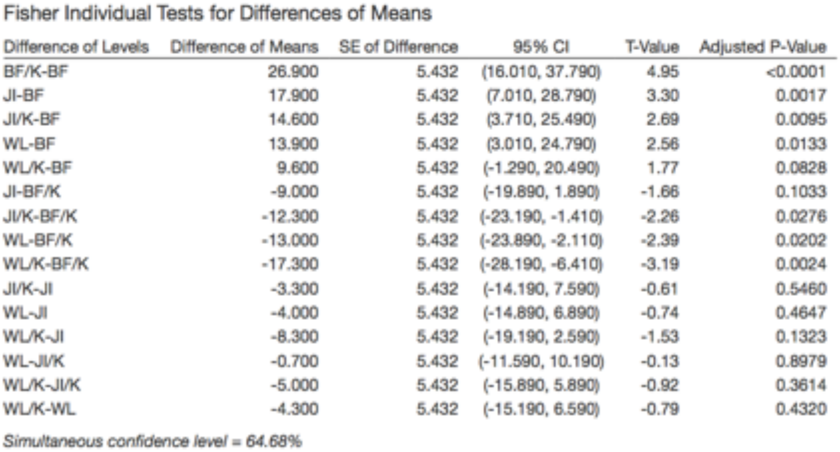




Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping		
BF/K	10	38.600	A		
JI	10	29.600	A	B	
JI/K	10	26.300		B	
WL	10	25.600		B	
WL/K	10	21.3000		B	C
BF	10	11.7000			C

Means that do not share a letter are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF/K-BF	26.900	5.432	(16.010, 37.790)	4.95	<0.0001
JI-BF	17.900	5.432	(7.010, 28.790)	3.30	0.0017
JI/K-BF	14.600	5.432	(3.710, 25.490)	2.69	0.0095
WL-BF	13.900	5.432	(3.010, 24.790)	2.56	0.0133
WL/K-BF	9.600	5.432	(-1.290, 20.490)	1.77	0.0828
JI-BF/K	-9.000	5.432	(-19.890, 1.890)	-1.66	0.1033
JI/K-BF/K	-12.300	5.432	(-23.190, -1.410)	-2.26	0.0276
WL-BF/K	-13.000	5.432	(-23.890, -2.110)	-2.39	0.0202
WL/K-BF/K	-17.300	5.432	(-28.190, -6.410)	-3.19	0.0024
JI/K-JI	-3.300	5.432	(-14.190, 7.590)	-0.61	0.5460
WL-JI	-4.000	5.432	(-14.890, 6.890)	-0.74	0.4647
WL/K-JI	-8.300	5.432	(-19.190, 2.590)	-1.53	0.1323
WL-JI/K	-0.700	5.432	(-11.590, 10.190)	-0.13	0.8979
WL/K-JI/K	-5.000	5.432	(-15.890, 5.890)	-0.92	0.3614
WL/K-WL	-4.300	5.432	(-15.190, 6.590)	-0.79	0.4320

Simultaneous confidence level = 64.68%

One-Way ANOVA: Leaf length versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	78844	15768.7	11.78	<0.0001
Error	54	72271	1338.4		
Total	59	151115			

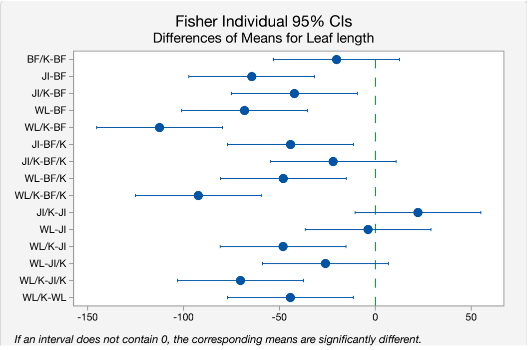
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
36.5836	52.17%	47.75%	40.96%

Means

Treatment	N	Mean	StDev	95% CI
BF	10	264.700	24.404	(241.506, 287.894)
BF/K	10	244.500	24.614	(221.306, 267.694)
JI	10	200.30	58.85	(177.11, 223.49)
JI/K	10	222.50	36.43	(199.31, 245.69)
WL	10	196.500	27.581	(173.306, 219.694)
WL/K	10	152.20	35.75	(129.01, 175.39)

Pooled StDev = 36.5836



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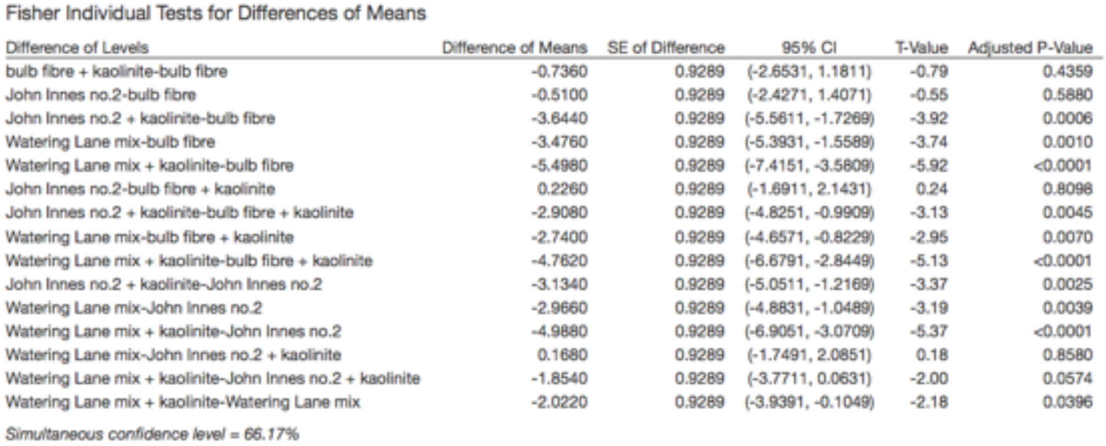


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-0.7360	0.9289	(-2.6531, 1.1811)	-0.79	0.4359
John Innes no.2-bulb fibre	-0.5100	0.9289	(-2.4271, 1.4071)	-0.55	0.5880
John Innes no.2 + kaolinite-bulb fibre	-3.6440	0.9289	(-5.5611, -1.7269)	-3.92	0.0006
Watering Lane mix-bulb fibre	-3.4760	0.9289	(-5.3931, -1.5589)	-3.74	0.0010
Watering Lane mix + kaolinite-bulb fibre	-5.4980	0.9289	(-7.4151, -3.5809)	-5.92	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.2260	0.9289	(-1.6911, 2.1431)	0.24	0.8098
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-2.9080	0.9289	(-4.8251, -0.9909)	-3.13	0.0045
Watering Lane mix-bulb fibre + kaolinite	-2.7400	0.9289	(-4.6571, -0.8229)	-2.95	0.0070
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-4.7620	0.9289	(-6.6791, -2.8449)	-5.13	<0.0001
John Innes no.2 + kaolinite-John Innes no.2	-3.1340	0.9289	(-5.0511, -1.2169)	-3.37	0.0025
Watering Lane mix-John Innes no.2	-2.9660	0.9289	(-4.8831, -1.0489)	-3.19	0.0039
Watering Lane mix + kaolinite-John Innes no.2	-4.9880	0.9289	(-6.9051, -3.0709)	-5.37	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	0.1680	0.9289	(-1.7491, 2.0851)	0.18	0.8580
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-1.8540	0.9289	(-3.7711, 0.0631)	-2.00	0.0574
Watering Lane mix + kaolinite-Watering Lane mix	-2.0220	0.9289	(-3.9391, -0.1049)	-2.18	0.0396

Simultaneous confidence level = 66.17%

One-Way ANOVA: Leaf width versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	11743.3	2348.66	12.08	<0.0001
Error	54	10495.7	194.36		
Total	59	22239.0			

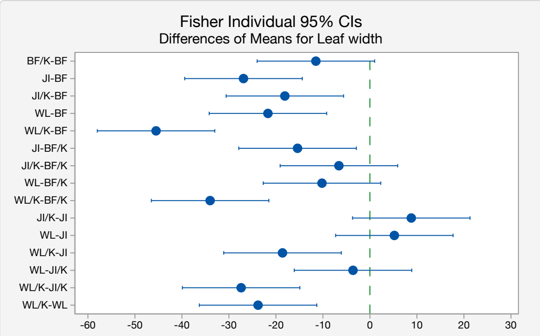
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.9415	52.80%	48.44%	41.73%

Means

Treatment	N	Mean	StDev	95% CI
BF	10	100.300	7.917	(91.461, 109.139)
BF/K	10	88.800	5.846	(79.961, 97.639)
JI	10	73.400	20.839	(64.561, 82.239)
JI/K	10	82.200	12.968	(73.361, 91.039)
WL	10	78.600	14.931	(69.761, 87.439)
WL/K	10	54.800	15.619	(45.961, 63.639)

Pooled StDev = 13.9415



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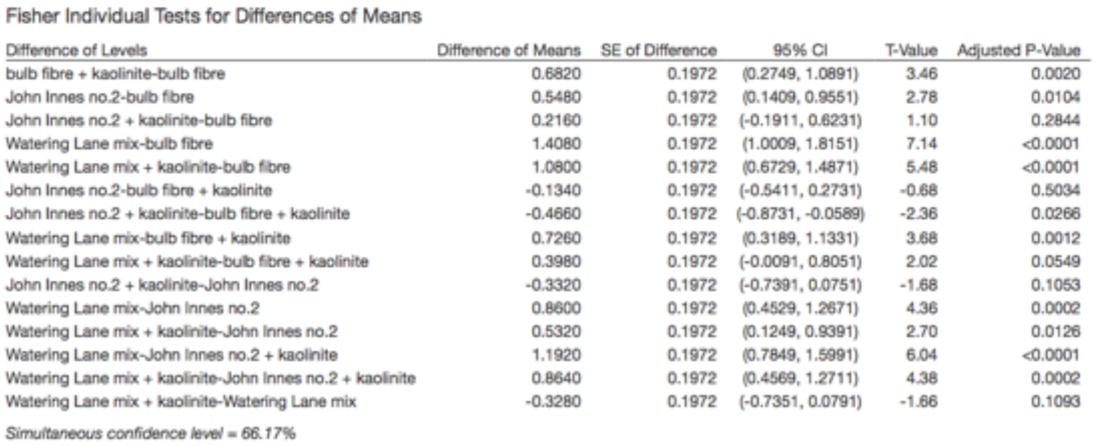


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	0.6820	0.1972	(0.2749, 1.0891)	3.46	0.0020
John Innes no.2-bulb fibre	0.5480	0.1972	(0.1409, 0.9551)	2.78	0.0104
John Innes no.2 + kaolinite-bulb fibre	0.2160	0.1972	(-0.1911, 0.6231)	1.10	0.2844
Watering Lane mix-bulb fibre	1.4080	0.1972	(1.0009, 1.8151)	7.14	<0.0001
Watering Lane mix + kaolinite-bulb fibre	1.0800	0.1972	(0.6729, 1.4871)	5.48	<0.0001
John Innes no.2-bulb fibre + kaolinite	-0.1340	0.1972	(-0.5411, 0.2731)	-0.68	0.5034
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.4660	0.1972	(-0.8731, -0.0589)	-2.36	0.0266
Watering Lane mix-bulb fibre + kaolinite	0.7260	0.1972	(0.3189, 1.1331)	3.68	0.0012
Watering Lane mix + kaolinite-bulb fibre + kaolinite	0.3980	0.1972	(-0.0091, 0.8051)	2.02	0.0549
John Innes no.2 + kaolinite-John Innes no.2	-0.3320	0.1972	(-0.7391, 0.0751)	-1.68	0.1053
Watering Lane mix-John Innes no.2	0.8600	0.1972	(0.4529, 1.2671)	4.36	0.0002
Watering Lane mix + kaolinite-John Innes no.2	0.5320	0.1972	(0.1249, 0.9391)	2.70	0.0126
Watering Lane mix-John Innes no.2 + kaolinite	1.1920	0.1972	(0.7849, 1.5991)	6.04	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	0.8640	0.1972	(0.4569, 1.2711)	4.38	0.0002
Watering Lane mix + kaolinite-Watering Lane mix	-0.3280	0.1972	(-0.7351, 0.0791)	-1.66	0.1093

Simultaneous confidence level = 66.17%

One-Way ANOVA: Algae % versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	42400.9	8480.18	13.36	<0.0001
Error	54	34281.7	634.85		
Total	59	76682.6			

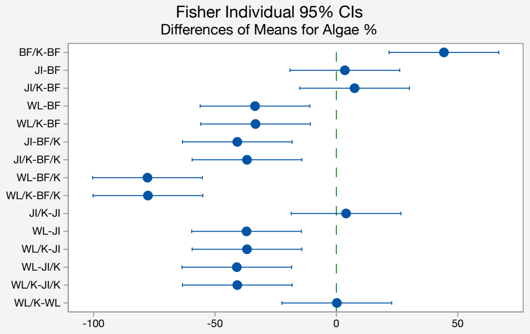
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
25.1962	55.29%	51.15%	44.81%

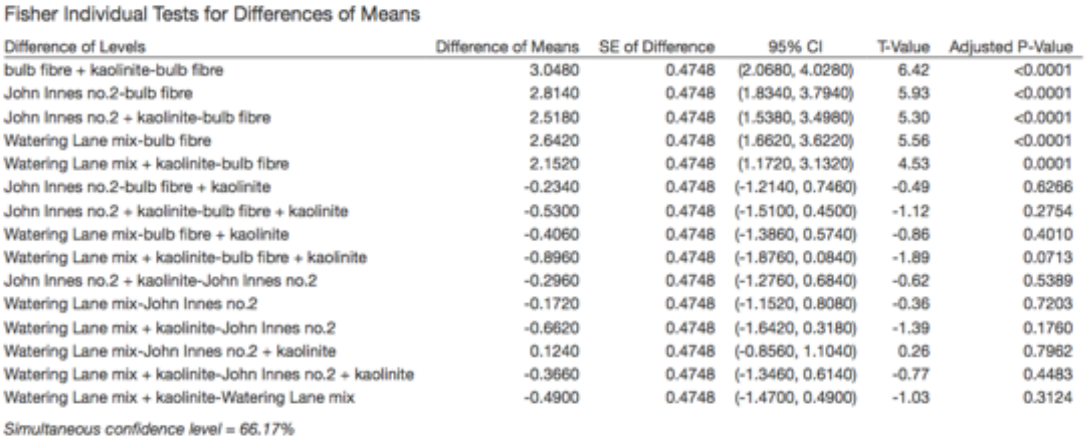
Means

Treatment	N	Mean	StDev	95% CI
BF	10	33.500	29.255	(17.526, 49.474)
BF/K	10	77.800	19.792	(61.826, 93.774)
JI	10	37.000	27.508	(21.026, 52.974)
JI/K	10	41.00	42.48	(25.03, 56.97)
WL	10	0	0	(-15.9743, 15.9743)
WL/K	10	0.2000	0.6325	(-15.7743, 16.1743)

Pooled StDev = 25.1962



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	3.0480	0.4748	(2.0680, 4.0280)	6.42	<0.0001
John Innes no.2-bulb fibre	2.8140	0.4748	(1.8340, 3.7940)	5.93	<0.0001
John Innes no.2 + kaolinite-bulb fibre	2.5180	0.4748	(1.5380, 3.4980)	5.30	<0.0001
Watering Lane mix-bulb fibre	2.6420	0.4748	(1.6620, 3.6220)	5.56	<0.0001
Watering Lane mix + kaolinite-bulb fibre	2.1520	0.4748	(1.1720, 3.1320)	4.53	0.0001
John Innes no.2-bulb fibre + kaolinite	-0.2340	0.4748	(-1.2140, 0.7460)	-0.49	0.6266
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-0.5300	0.4748	(-1.5100, 0.4500)	-1.12	0.2754
Watering Lane mix-bulb fibre + kaolinite	-0.4060	0.4748	(-1.3860, 0.5740)	-0.86	0.4010
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-0.8960	0.4748	(-1.8760, 0.0840)	-1.89	0.0713
John Innes no.2 + kaolinite-John Innes no.2	-0.2960	0.4748	(-1.2760, 0.6840)	-0.62	0.5389
Watering Lane mix-John Innes no.2	-0.1720	0.4748	(-1.1520, 0.8080)	-0.36	0.7203
Watering Lane mix + kaolinite-John Innes no.2	-0.6620	0.4748	(-1.6420, 0.3180)	-1.39	0.1760
Watering Lane mix-John Innes no.2 + kaolinite	0.1240	0.4748	(-0.8560, 1.1040)	0.26	0.7962
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-0.3660	0.4748	(-1.3460, 0.6140)	-0.77	0.4483
Watering Lane mix + kaolinite-Watering Lane mix	-0.4900	0.4748	(-1.4700, 0.4900)	-1.03	0.3124

Simultaneous confidence level = 66.17%

One-Way ANOVA: aerial dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	565.846	113.169	22.16	<0.0001
Error	54	275.764	5.107		
Total	59	841.611			

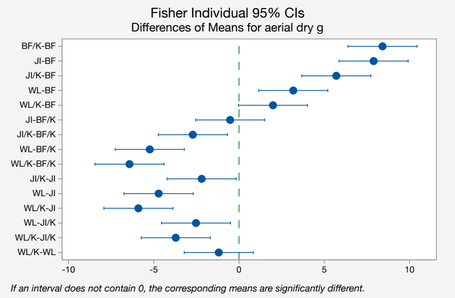
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.25981	67.23%	64.20%	59.55%

Means

Treatment	N	Mean	StDev	95% CI
BF	10	4.3730	3.0954	(2.9403, 5.8057)
BF/K	10	12.7890	3.1307	(11.3563, 14.2217)
JI	10	12.2680	1.2034	(10.8353, 13.7007)
JI/K	10	10.0770	2.1169	(8.6443, 11.5097)
WL	10	7.5540	2.1833	(6.1213, 8.9867)
WL/K	10	6.3650	0.7494	(4.9323, 7.7977)

Pooled StDev = 2.25981



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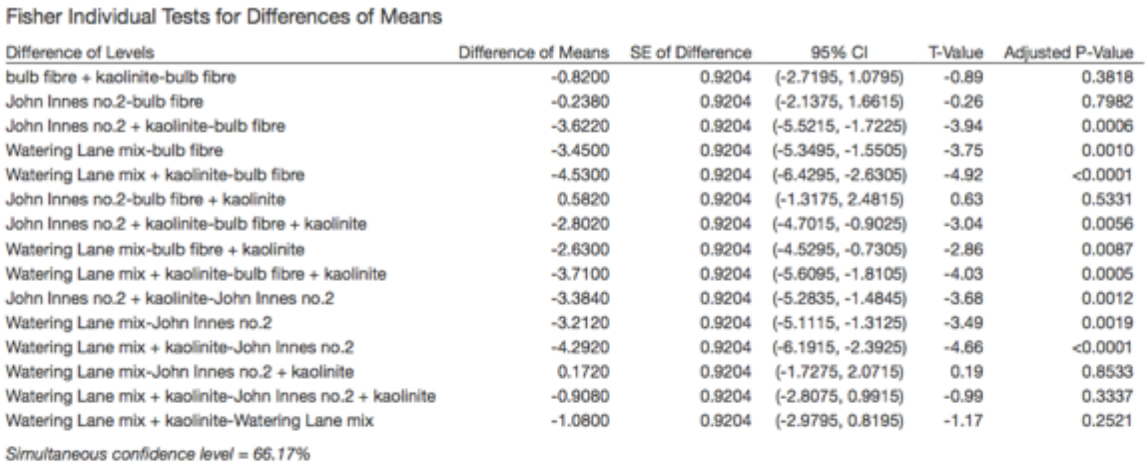


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-0.8200	0.9204	(-2.7195, 1.0795)	-0.89	0.3818
John Innes no.2-bulb fibre	-0.2380	0.9204	(-2.1375, 1.6615)	-0.26	0.7982
John Innes no.2 + kaolinite-bulb fibre	-3.6220	0.9204	(-5.5215, -1.7225)	-3.94	0.0006
Watering Lane mix-bulb fibre	-3.4500	0.9204	(-5.3495, -1.5505)	-3.75	0.0010
Watering Lane mix + kaolinite-bulb fibre	-4.5300	0.9204	(-6.4295, -2.6305)	-4.92	<0.0001
John Innes no.2-bulb fibre + kaolinite	0.5820	0.9204	(-1.3175, 2.4815)	0.63	0.5331
John Innes no.2 + kaolinite-bulb fibre + kaolinite	-2.8020	0.9204	(-4.7015, -0.9025)	-3.04	0.0056
Watering Lane mix-bulb fibre + kaolinite	-2.6300	0.9204	(-4.5295, -0.7305)	-2.86	0.0087
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-3.7100	0.9204	(-5.6095, -1.8105)	-4.03	0.0005
John Innes no.2 + kaolinite-John Innes no.2	-3.3840	0.9204	(-5.2835, -1.4845)	-3.68	0.0012
Watering Lane mix-John Innes no.2	-3.2120	0.9204	(-5.1115, -1.3125)	-3.49	0.0019
Watering Lane mix + kaolinite-John Innes no.2	-4.2920	0.9204	(-6.1915, -2.3925)	-4.66	<0.0001
Watering Lane mix-John Innes no.2 + kaolinite	0.1720	0.9204	(-1.7275, 2.0715)	0.19	0.8533
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-0.9080	0.9204	(-2.8075, 0.9915)	-0.99	0.3337
Watering Lane mix + kaolinite-Watering Lane mix	-1.0800	0.9204	(-2.9795, 0.8195)	-1.17	0.2521

Simultaneous confidence level = 66.17%

One-Way ANOVA: aerial % moisture versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	780.73	156.146	20.82	<0.0001
Error	54	404.94	7.499		
Total	59	1185.66			

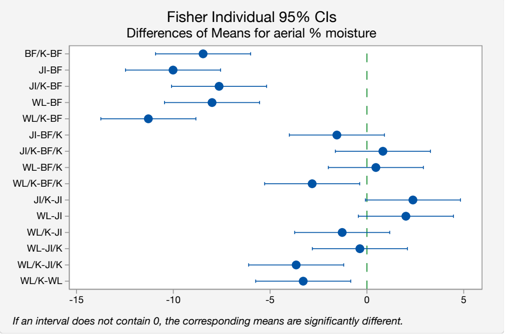
Model Summary

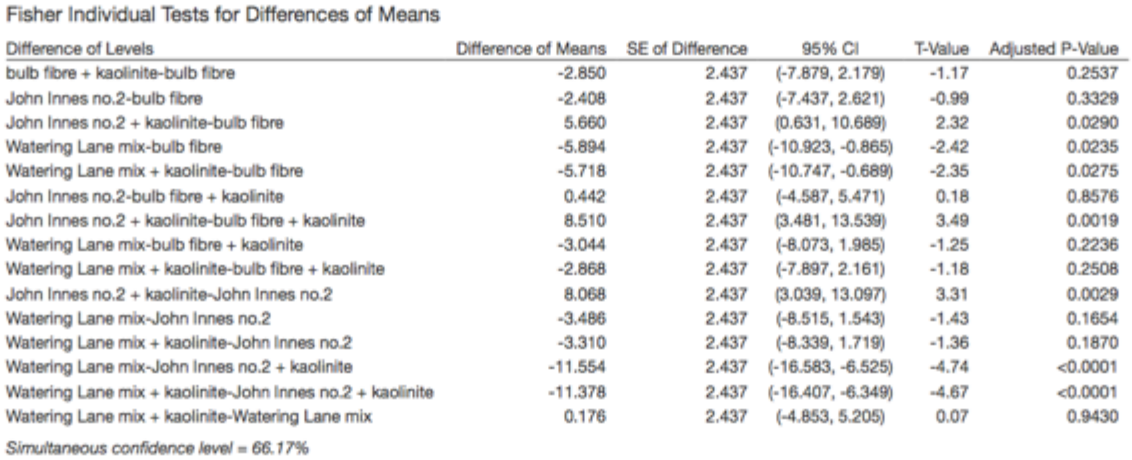
S	R-sq	R-sq(adj)	R-sq(pred)
2.73839	65.85%	62.69%	57.84%

Means

Treatment	N	Mean	StDev	95% CI
BF	10	90.3270	2.4944	(88.5909, 92.0631)
BF/K	10	81.8660	2.7808	(80.1299, 83.6021)
JI	10	80.3150	1.4326	(78.5789, 82.0511)
JI/K	10	82.692	3.192	(80.956, 84.428)
WL	10	82.329	3.823	(80.593, 84.065)
WL/K	10	79.0390	2.0459	(77.3029, 80.7751)

Pooled StDev = 2.73839





Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
bulb fibre + kaolinite-bulb fibre	-2.850	2.437	(-7.879, 2.179)	-1.17	0.2537
John Innes no.2-bulb fibre	-2.408	2.437	(-7.437, 2.621)	-0.99	0.3329
John Innes no.2 + kaolinite-bulb fibre	5.660	2.437	(0.631, 10.689)	2.32	0.0290
Watering Lane mix-bulb fibre	-5.894	2.437	(-10.923, -0.865)	-2.42	0.0235
Watering Lane mix + kaolinite-bulb fibre	-5.718	2.437	(-10.747, -0.689)	-2.35	0.0275
John Innes no.2-bulb fibre + kaolinite	0.442	2.437	(-4.587, 5.471)	0.18	0.8576
John Innes no.2 + kaolinite-bulb fibre + kaolinite	8.510	2.437	(3.481, 13.539)	3.49	0.0019
Watering Lane mix-bulb fibre + kaolinite	-3.044	2.437	(-8.073, 1.985)	-1.25	0.2236
Watering Lane mix + kaolinite-bulb fibre + kaolinite	-2.868	2.437	(-7.897, 2.161)	-1.18	0.2508
John Innes no.2 + kaolinite-John Innes no.2	8.068	2.437	(3.039, 13.097)	3.31	0.0029
Watering Lane mix-John Innes no.2	-3.486	2.437	(-8.515, 1.543)	-1.43	0.1654
Watering Lane mix + kaolinite-John Innes no.2	-3.310	2.437	(-8.339, 1.719)	-1.36	0.1870
Watering Lane mix-John Innes no.2 + kaolinite	-11.554	2.437	(-16.583, -6.525)	-4.74	<0.0001
Watering Lane mix + kaolinite-John Innes no.2 + kaolinite	-11.378	2.437	(-16.407, -6.349)	-4.67	<0.0001
Watering Lane mix + kaolinite-Watering Lane mix	0.176	2.437	(-4.853, 5.205)	0.07	0.9430

Simultaneous confidence level = 66.17%

One-Way ANOVA: roots dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	118.878	23.7755	13.51	<0.0001
Error	54	95.046	1.7601		
Total	59	213.923			

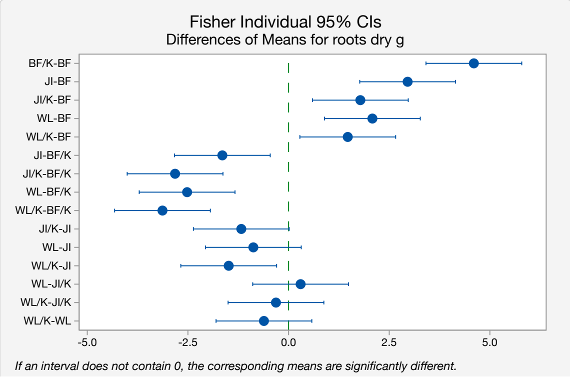
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.32669	55.57%	51.46%	45.15%

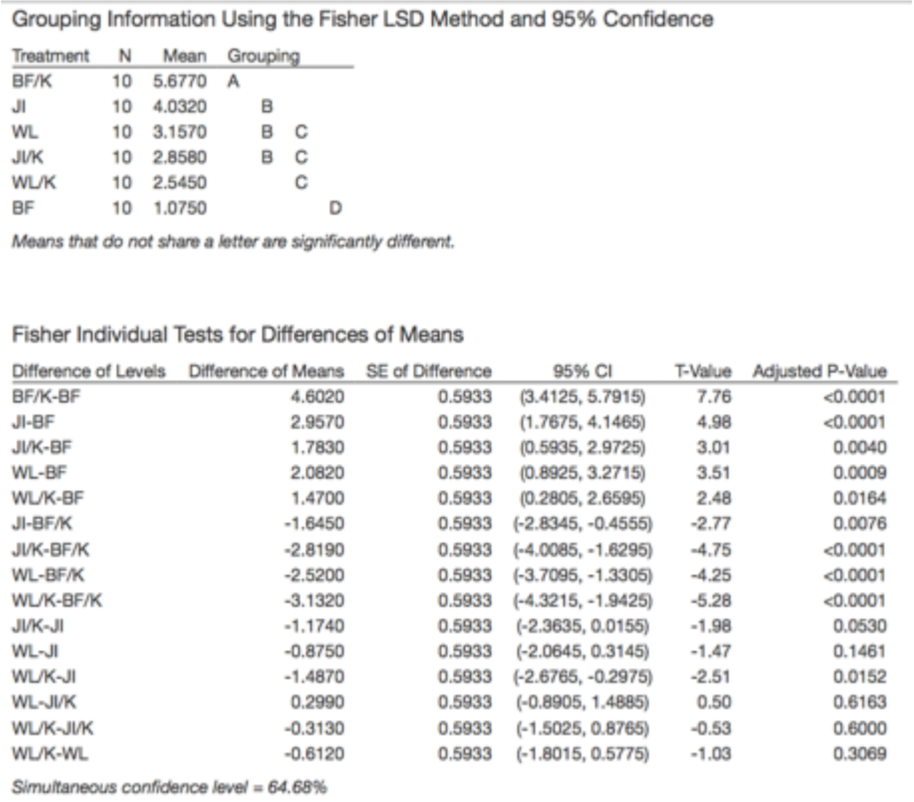
Means

Treatment	N	Mean	StDev	95% CI
BF	10	1.0750	0.8507	(0.2339, 1.9161)
BF/K	10	5.6770	2.2324	(4.8359, 6.5181)
JI	10	4.0320	1.4240	(3.1909, 4.8731)
JI/K	10	2.8580	1.0770	(2.0169, 3.6991)
WL	10	3.1570	0.8701	(2.3159, 3.9981)
WL/K	10	2.5450	0.9533	(1.7039, 3.3861)

Pooled StDev = 1.32669



If an interval does not contain 0, the corresponding means are significantly different.



Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping			
BF/K	10	5.6770	A			
JI	10	4.0320		B		
WL	10	3.1570		B	C	
JI/K	10	2.8580		B	C	
WL/K	10	2.5450			C	
BF	10	1.0750				D

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF/K-BF	4.6020	0.5933	(3.4125, 5.7915)	7.76	<0.0001
JI-BF	2.9570	0.5933	(1.7675, 4.1465)	4.98	<0.0001
JI/K-BF	1.7830	0.5933	(0.5935, 2.9725)	3.01	0.0040
WL-BF	2.0820	0.5933	(0.8925, 3.2715)	3.51	0.0009
WL/K-BF	1.4700	0.5933	(0.2805, 2.6595)	2.48	0.0164
JI-BF/K	-1.6450	0.5933	(-2.8345, -0.4555)	-2.77	0.0076
JI/K-BF/K	-2.8190	0.5933	(-4.0085, -1.6295)	-4.75	<0.0001
WL-BF/K	-2.5200	0.5933	(-3.7095, -1.3305)	-4.25	<0.0001
WL/K-BF/K	-3.1320	0.5933	(-4.3215, -1.9425)	-5.28	<0.0001
JI/K-JI	-1.1740	0.5933	(-2.3635, 0.0155)	-1.98	0.0530
WL-JI	-0.8750	0.5933	(-2.0645, 0.3145)	-1.47	0.1461
WL/K-JI	-1.4870	0.5933	(-2.6765, -0.2975)	-2.51	0.0152
WL-JI/K	0.2990	0.5933	(-0.8905, 1.4885)	0.50	0.6163
WL/K-JI/K	-0.3130	0.5933	(-1.5025, 0.8765)	-0.53	0.6000
WL/K-WL	-0.6120	0.5933	(-1.8015, 0.5775)	-1.03	0.3069

Simultaneous confidence level = 64.68%

One-Way ANOVA: total dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	1152.13	230.426	22.91	<0.0001
Error	54	543.12	10.058		
Total	59	1695.25			

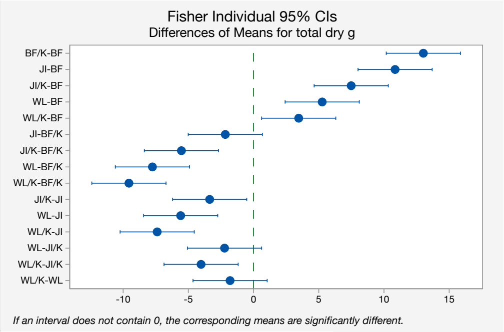
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.17140	67.96%	65.00%	60.45%

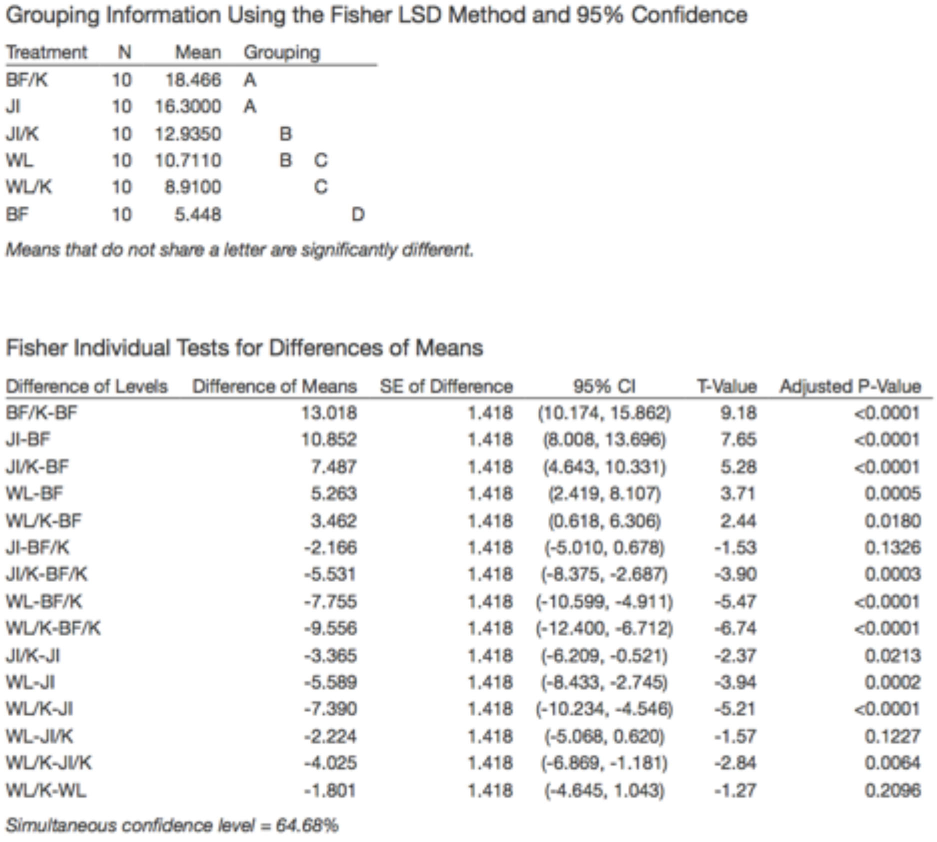
Means

Treatment	N	Mean	StDev	95% CI
BF	10	5.448	3.551	(3.437, 7.459)
BF/K	10	18.466	4.899	(16.455, 20.477)
JI	10	16.3000	2.1870	(14.2893, 18.3107)
JI/K	10	12.9350	2.9762	(10.9243, 14.9457)
WL	10	10.7110	2.7614	(8.7003, 12.7217)
WL/K	10	8.9100	1.5720	(6.8993, 10.9207)

Pooled StDev = 3.17140



If an interval does not contain 0, the corresponding means are significantly different.



Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping			
BF/K	10	18.466	A			
JI	10	16.3000	A			
JI/K	10	12.9350		B		
WL	10	10.7110		B	C	
WL/K	10	8.9100			C	
BF	10	5.448				D

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF/K-BF	13.018	1.418	(10.174, 15.862)	9.18	<0.0001
JI-BF	10.852	1.418	(8.008, 13.696)	7.65	<0.0001
JI/K-BF	7.487	1.418	(4.643, 10.331)	5.28	<0.0001
WL-BF	5.263	1.418	(2.419, 8.107)	3.71	0.0005
WL/K-BF	3.462	1.418	(0.618, 6.306)	2.44	0.0180
JI-BF/K	-2.166	1.418	(-5.010, 0.678)	-1.53	0.1326
JI/K-BF/K	-5.531	1.418	(-8.375, -2.687)	-3.90	0.0003
WL-BF/K	-7.755	1.418	(-10.599, -4.911)	-5.47	<0.0001
WL/K-BF/K	-9.556	1.418	(-12.400, -6.712)	-6.74	<0.0001
JI/K-JI	-3.365	1.418	(-6.209, -0.521)	-2.37	0.0213
WL-JI	-5.589	1.418	(-8.433, -2.745)	-3.94	0.0002
WL/K-JI	-7.390	1.418	(-10.234, -4.546)	-5.21	<0.0001
WL-JI/K	-2.224	1.418	(-5.068, 0.620)	-1.57	0.1227
WL/K-JI/K	-4.025	1.418	(-6.869, -1.181)	-2.84	0.0064
WL/K-WL	-1.801	1.418	(-4.645, 1.043)	-1.27	0.2096

Simultaneous confidence level = 64.68%

One-Way ANOVA: total % moisture versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	6	BF, BF/K, JI, JI/K, WL, WL/K

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	5	745.31	149.061	16.87	<0.0001
Error	54	477.18	8.837		
Total	59	1222.49			

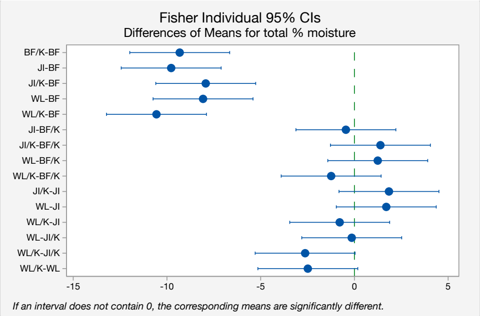
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.97266	60.97%	57.35%	51.81%

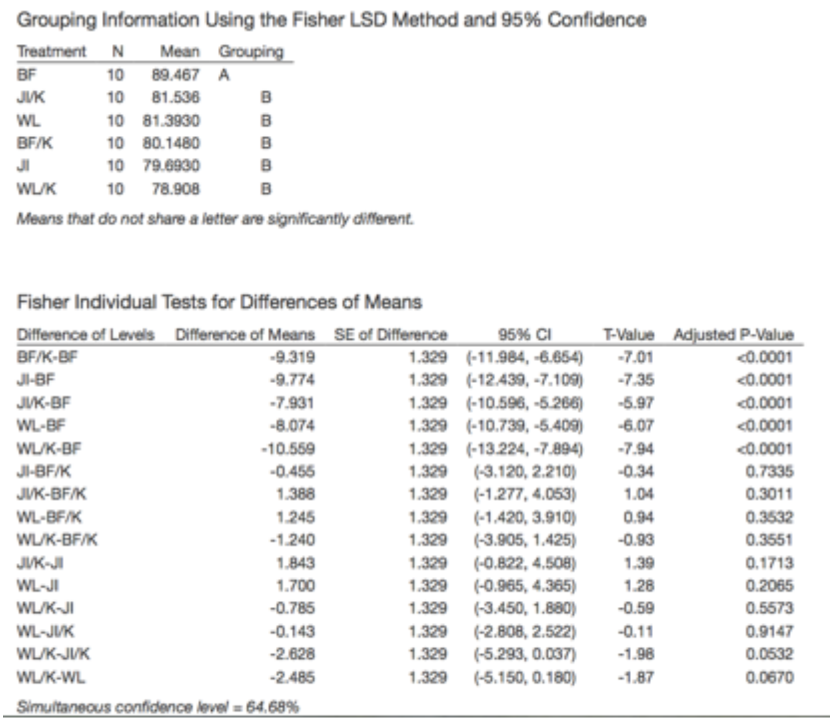
Means

Treatment	N	Mean	StDev	95% CI
BF	10	89.467	3.185	(87.582, 91.352)
BF/K	10	80.1480	2.4473	(78.2633, 82.0327)
JI	10	79.6930	1.8474	(77.8083, 81.5777)
JI/K	10	81.536	3.396	(79.651, 83.421)
WL	10	81.3930	2.8759	(79.5083, 83.2777)
WL/K	10	78.908	3.697	(77.023, 80.793)

Pooled StDev = 2.97266



If an interval does not contain 0, the corresponding means are significantly different.



Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
BF	10	89.467	A	
JI/K	10	81.536		B
WL	10	81.3930		B
BF/K	10	80.1480		B
JI	10	79.6930		B
WL/K	10	78.908		B

Means that do not share a letter are significantly different.

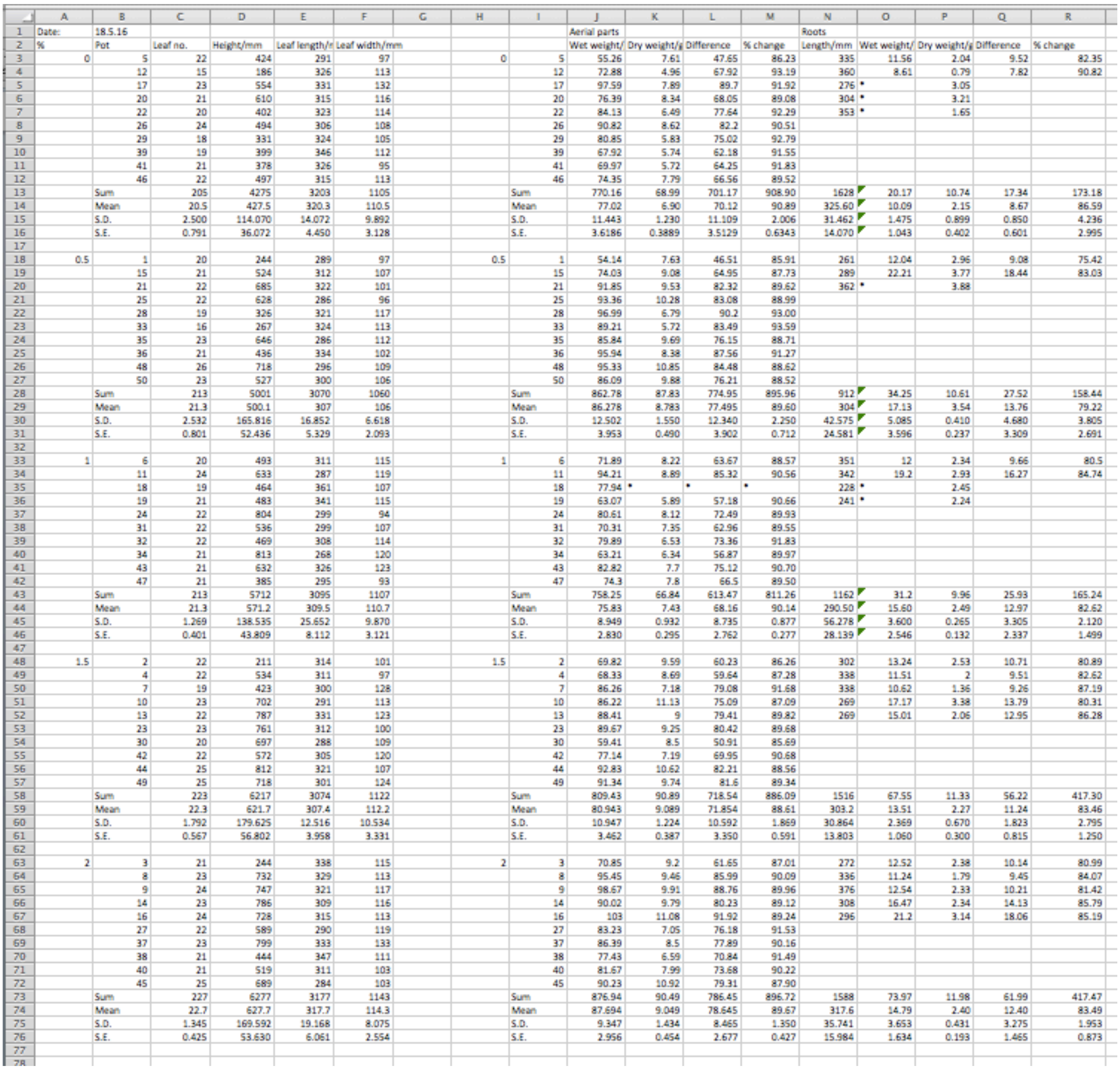
Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
BF/K-BF	-9.319	1.329	(-11.984, -6.654)	-7.01	<0.0001
JI-BF	-9.774	1.329	(-12.439, -7.109)	-7.35	<0.0001
JI/K-BF	-7.931	1.329	(-10.596, -5.266)	-5.97	<0.0001
WL-BF	-8.074	1.329	(-10.739, -5.409)	-6.07	<0.0001
WL/K-BF	-10.559	1.329	(-13.224, -7.894)	-7.94	<0.0001
JI-BF/K	-0.455	1.329	(-3.120, 2.210)	-0.34	0.7335
JI/K-BF/K	1.388	1.329	(-1.277, 4.053)	1.04	0.3011
WL-BF/K	1.245	1.329	(-1.420, 3.910)	0.94	0.3532
WL/K-BF/K	-1.240	1.329	(-3.905, 1.425)	-0.93	0.3551
JI/K-JI	1.843	1.329	(-0.822, 4.508)	1.39	0.1713
WL-JI	1.700	1.329	(-0.965, 4.365)	1.28	0.2065
WL/K-JI	-0.785	1.329	(-3.450, 1.880)	-0.59	0.5573
WL-JI/K	-0.143	1.329	(-2.808, 2.522)	-0.11	0.9147
WL/K-JI/K	-2.628	1.329	(-5.293, 0.037)	-1.98	0.0532
WL/K-WL	-2.485	1.329	(-5.150, 0.180)	-1.87	0.0670

Simultaneous confidence level = 64.68%

Appendix 4.2 Experiment 2 raw data

A4.2.1 Destructive harvest data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Date:	18.5.16								Aerial parts				Roots				
2	%	Pot	Leaf no.	Height/mm	Leaf length/r	Leaf width/mm				Wet weight/	Dry weight/g	Difference	% change	Length/mm	Wet weight/	Dry weight/g	Difference	% change
3	0	5	22	424	291	97		0	5	55.26	7.61	47.65	86.23	335	11.56	2.04	9.52	82.35
4		12	15	186	326	113			12	72.88	4.96	67.92	93.19	360	8.61	0.79	7.82	90.82
5		17	23	554	331	132			17	97.59	7.89	89.7	91.92	276	•	3.05		
6		20	21	610	315	116			20	76.39	8.34	68.05	89.08	304	•	3.21		
7		22	20	402	323	114			22	84.13	6.49	77.64	92.29	353	•	1.65		
8		26	24	494	306	108			26	90.82	8.62	82.2	90.51					
9		29	18	331	324	105			29	80.85	5.83	75.02	92.79					
10		39	19	399	346	112			39	67.92	5.74	62.18	91.55					
11		41	21	378	326	95			41	69.97	5.72	64.25	91.83					
12		46	22	497	315	113			46	74.35	7.79	66.56	89.52					
13		Sum	205	4275	3203	1105			Sum	770.16	68.99	701.17	908.90	1628	20.17	10.74	17.34	173.18
14		Mean	20.5	427.5	320.3	110.5			Mean	77.02	6.90	70.12	90.89	325.60	10.09	2.15	8.67	86.59
15		S.D.	2.500	114.070	14.072	9.892			S.D.	11.443	1.230	11.109	2.006	31.462	1.475	0.899	0.850	4.236
16		S.E.	0.791	36.072	4.450	3.128			S.E.	3.6186	0.3889	3.5129	0.6343	14.070	1.043	0.402	0.601	2.995
17																		
18	0.5	1	20	244	289	97		0.5	1	54.14	7.63	46.51	85.91	261	12.04	2.96	9.08	75.42
19		15	21	524	312	107			15	74.03	9.08	64.95	87.73	289	22.21	3.77	18.44	83.03
20		21	22	685	322	101			21	91.85	9.53	82.32	89.62	362	•	3.88		
21		25	22	628	286	96			25	93.36	10.28	83.08	88.99					
22		28	19	326	321	117			28	96.99	6.79	90.2	93.00					
23		33	16	267	324	113			33	89.21	5.72	83.49	93.59					
24		35	23	646	286	112			35	85.84	9.69	76.15	88.71					
25		36	21	436	334	102			36	95.94	8.38	87.56	91.27					
26		48	26	718	296	109			48	95.33	10.85	84.48	88.62					
27		50	23	527	300	106			50	86.09	9.88	76.21	88.52					
28		Sum	213	5001	3070	1060			Sum	862.78	87.83	774.95	895.96	912	34.25	10.61	27.52	158.44
29		Mean	21.3	500.1	307	106			Mean	86.278	8.783	77.495	89.60	304	17.13	3.54	13.76	79.22
30		S.D.	2.532	165.816	16.852	6.618			S.D.	12.502	1.550	12.340	2.250	42.575	5.085	0.410	4.680	3.805
31		S.E.	0.801	52.436	5.329	2.093			S.E.	3.953	0.490	3.902	0.712	24.581	3.596	0.237	3.309	2.691
32																		
33	1	6	20	493	311	115		1	6	71.89	8.22	63.67	88.57	351	12	2.34	9.66	80.5
34		11	24	633	287	119			11	94.21	8.89	85.32	90.56	342	19.2	2.93	16.27	84.74
35		18	19	464	361	107			18	77.94	•	•	•	228	•	2.45		
36		19	21	483	341	115			19	63.07	5.89	57.18	90.66	241	•	2.24		
37		24	22	804	299	94			24	80.61	8.12	72.49	89.93					
38		31	22	536	299	107			31	70.31	7.35	62.96	89.55					
39		32	22	469	308	114			32	79.89	6.53	73.36	91.83					
40		34	21	813	268	120			34	63.21	6.34	56.87	89.97					
41		43	21	632	326	123			43	82.82	7.7	75.12	90.70					
42		47	21	385	295	93			47	74.3	7.8	66.5	89.50					
43		Sum	213	5712	3095	1107			Sum	758.25	66.84	613.47	811.26	1162	31.2	9.96	25.93	165.24
44		Mean	21.3	571.2	309.5	110.7			Mean	75.83	7.43	68.16	90.14	290.50	15.60	2.49	12.97	82.62
45		S.D.	1.269	138.535	25.652	9.870			S.D.	8.949	0.932	8.735	0.877	56.278	3.600	0.265	3.305	2.120
46		S.E.	0.401	43.809	8.112	3.121			S.E.	2.830	0.295	2.762	0.277	28.139	2.546	0.132	2.337	1.499
47																		
48	1.5	2	22	211	314	101		1.5	2	69.82	9.59	60.23	86.26	302	13.24	2.53	10.71	80.89
49		4	22	534	311	97			4	68.33	8.69	59.64	87.28	338	11.51	2	9.51	82.62
50		7	19	423	300	128			7	86.26	7.18	79.08	91.68	338	10.62	1.36	9.26	87.19
51		10	23	702	291	113			10	86.22	11.13	75.09	87.09	269	17.17	3.38	13.79	80.31
52		13	22	787	331	123			13	88.41	9	79.41	89.82	269	15.01	2.06	12.95	86.28
53		23	23	761	312	100			23	89.67	9.25	80.42	89.68					
54		30	20	697	288	109			30	59.41	8.5	50.91	85.69					
55		42	22	572	305	120			42	77.14	7.19	69.95	90.68					
56		44	25	812	321	107			44	92.83	10.62	82.21	88.56					
57		49	25	718	301	124			49	91.34	9.74	81.6	89.34					
58		Sum	223	6217	3074	1122			Sum	809.43	90.89	718.54	886.09	1516	67.55	11.33	56.22	417.30
59		Mean	22.3	621.7	307.4	112.2			Mean	80.943	9.089	71.854	88.61	303.2	13.51	2.27	11.24	83.46
60		S.D.	1.792	179.625	12.516	10.534			S.D.	10.947	1.224	10.592	1.869	30.864	2.369	0.670	1.823	2.795
61		S.E.	0.567	56.802	3.958	3.331			S.E.	3.462	0.387	3.350	0.591	13.803	1.060	0.300	0.815	1.250
62																		
63	2	3	21	244	338	115		2	3	70.85	9.2	61.65	87.01	272	12.52	2.38	10.14	80.99
64		8	23	732	329	113			8	95.45	9.46	85.99	90.09	336	11.24	1.79	9.45	84.07
65		9	24	747	321	117			9	98.67	9.91	88.76	89.96	376	12.54	2.33	10.21	81.42
66		14	23	786	309	116			14	90.02	9.79	80.23	89.12	308	16.47	2.34	14.13	85.79
67		16	24	728	315	113			16	103	11.08	91.92	89.24	296	21.2	3.14	18.06	85.19
68		27	22	589	290	119			27	83.23	7.05	76.18	91.53					
69		37	23	799	333	133			37	86.39	8.5	77.89	90.16					
70		38	21	444	347	111			38	77.43	6.59	70.84	91.49					
71		40	21	519	311	103			40	81.67	7.99	73.68	90.22					
72		45	25	689	284	103			45	90.23	10.92	79.31	87.90					
73		Sum	227	6277	3177	1143			Sum	876.94	90.49	786.45	896.72	1588	73.97	11.98	61.99	417.47
74		Mean	22.7	627.7	317.7	114.3			Mean	87.694	9.049	78.645	89.67	317.6	14.79	2.40	12.40	83.49
75		S.D.	1.345	169.592	19.168	8.075			S.D.	9.347	1.434	8.465	1.350	35.741	3.653	0.431	3.275	1.953
76		S.E.	0.425	53.630	6.061	2.554			S.E.	2.956	0.454	2.677	0.427	15.984	1.634	0.193	1.465	0.873
77																		
78																		

Data analysis – significant results:

One-Way ANOVA: Height/mm versus Treatment

Method

Null hypothesis H_0: All means are equal
Alternative hypothesis H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0.0, 0.5, 1.0, 1.5, 2.0

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	291232	72808.1	2.71	0.0415
Error	45	1207259	26828.0		
Total	49	1498492			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
163.792	19.44%	12.27%	0.54%

Means

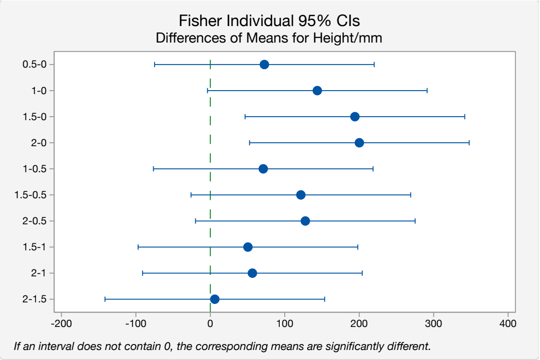
Treatment	N	Mean	StDev	95% CI
0	10	427.50	120.24	(323.18, 531.82)
0.5	10	500.10	174.79	(395.78, 604.42)
1	10	571.20	146.03	(466.88, 675.52)
1.5	10	621.70	189.34	(517.38, 726.02)
2	10	627.70	178.77	(523.38, 732.02)

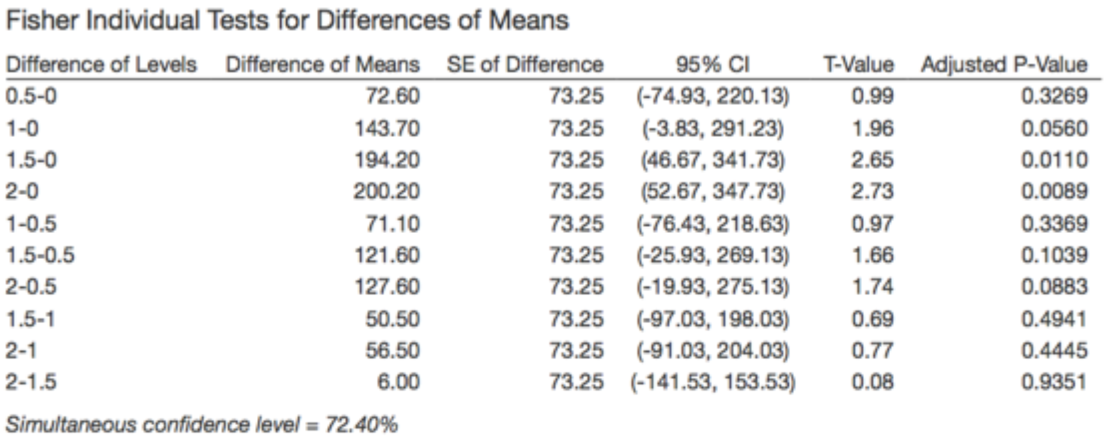
Pooled StDev = 163.792

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
2	10	627.70	A	
1.5	10	621.70	A	
1	10	571.20	A	B
0.5	10	500.10	A	B
0	10	427.50		B

Means that do not share a letter are significantly different.





Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
0.5-0	72.60	73.25	(-74.93, 220.13)	0.99	0.3269
1-0	143.70	73.25	(-3.83, 291.23)	1.96	0.0560
1.5-0	194.20	73.25	(46.67, 341.73)	2.65	0.0110
2-0	200.20	73.25	(52.67, 347.73)	2.73	0.0089
1-0.5	71.10	73.25	(-76.43, 218.63)	0.97	0.3369
1.5-0.5	121.60	73.25	(-25.93, 269.13)	1.66	0.1039
2-0.5	127.60	73.25	(-19.93, 275.13)	1.74	0.0883
1.5-1	50.50	73.25	(-97.03, 198.03)	0.69	0.4941
2-1	56.50	73.25	(-91.03, 204.03)	0.77	0.4445
2-1.5	6.00	73.25	(-141.53, 153.53)	0.08	0.9351

Simultaneous confidence level = 72.40%

One-Way ANOVA: aerial dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different
Rows unused	1

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0.0, 0.5, 1.0, 1.5, 2.0

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	40.604	10.1511	5.41	0.0012
Error	44	82.520	1.8755		
Total	48	123.125			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.36947	32.98%	26.89%	17.06%

Means

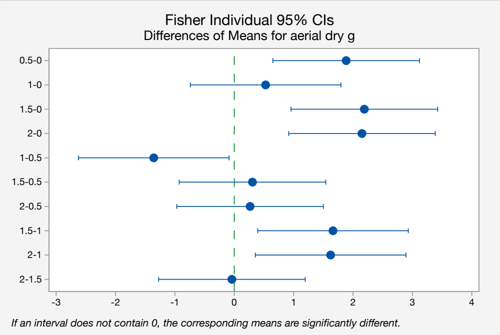
Treatment	N	Mean	StDev	95% CI
0	10	6.8990	1.2963	(6.0262, 7.7718)
0.5	10	8.7830	1.6341	(7.9102, 9.6558)
1	9	7.4267	0.9885	(6.5067, 8.3467)
1.5	10	9.0890	1.2899	(8.2162, 9.9618)
2	10	9.0490	1.5119	(8.1762, 9.9218)

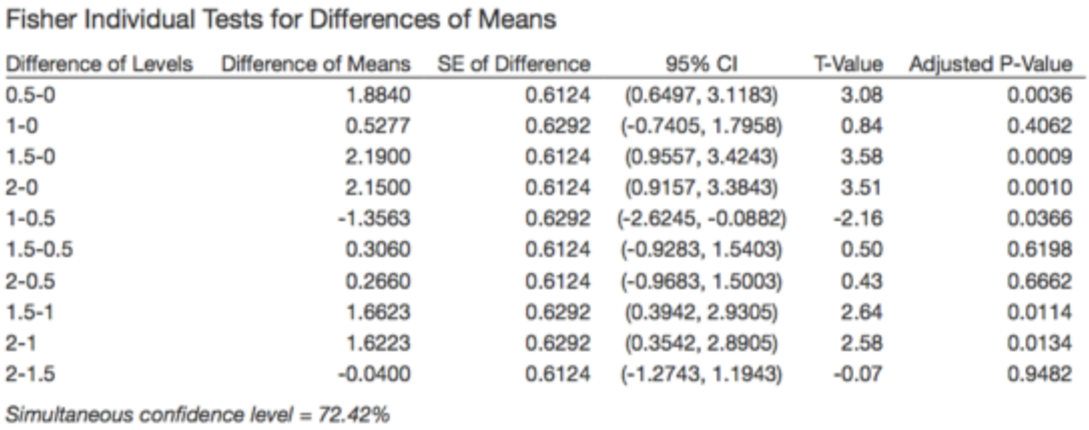
Pooled StDev = 1.36947

Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
1.5	10	9.0890	A	
2	10	9.0490	A	
0.5	10	8.7830	A	
1	9	7.4267		B
0	10	6.8990		B

Means that do not share a letter are significantly different.



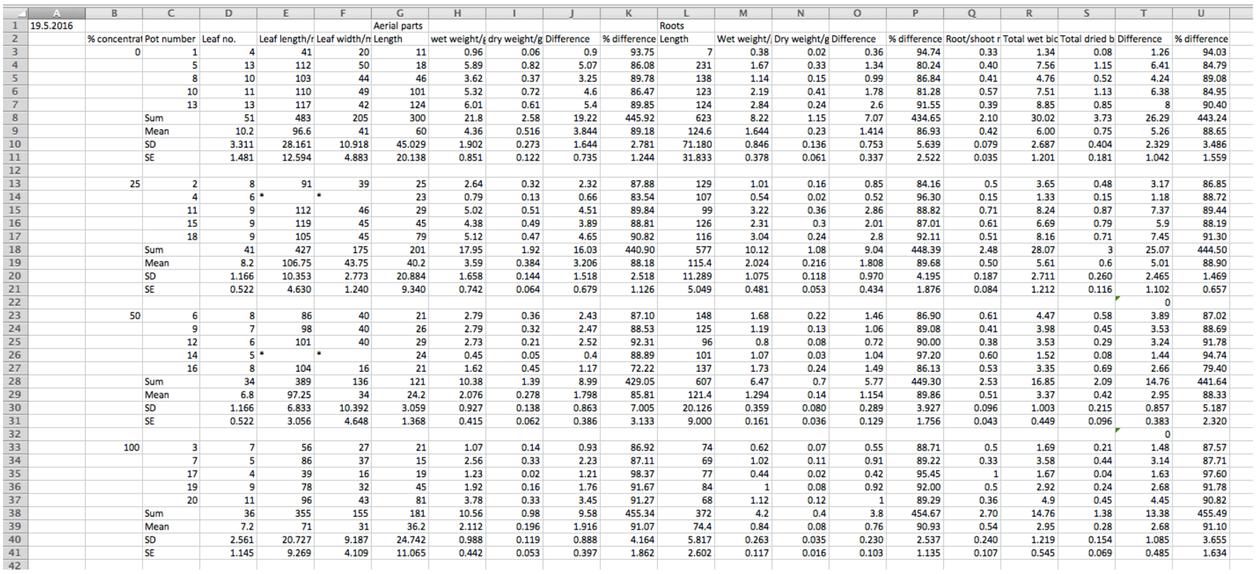


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
0.5-0	1.8840	0.6124	(0.6497, 3.1183)	3.08	0.0036
1-0	0.5277	0.6292	(-0.7405, 1.7958)	0.84	0.4062
1.5-0	2.1900	0.6124	(0.9557, 3.4243)	3.58	0.0009
2-0	2.1500	0.6124	(0.9157, 3.3843)	3.51	0.0010
1-0.5	-1.3563	0.6292	(-2.6245, -0.0882)	-2.16	0.0366
1.5-0.5	0.3060	0.6124	(-0.9283, 1.5403)	0.50	0.6198
2-0.5	0.2660	0.6124	(-0.9683, 1.5003)	0.43	0.6662
1.5-1	1.6623	0.6292	(0.3942, 2.9305)	2.64	0.0114
2-1	1.6223	0.6292	(0.3542, 2.8905)	2.58	0.0134
2-1.5	-0.0400	0.6124	(-1.2743, 1.1943)	-0.07	0.9482

Simultaneous confidence level = 72.42%

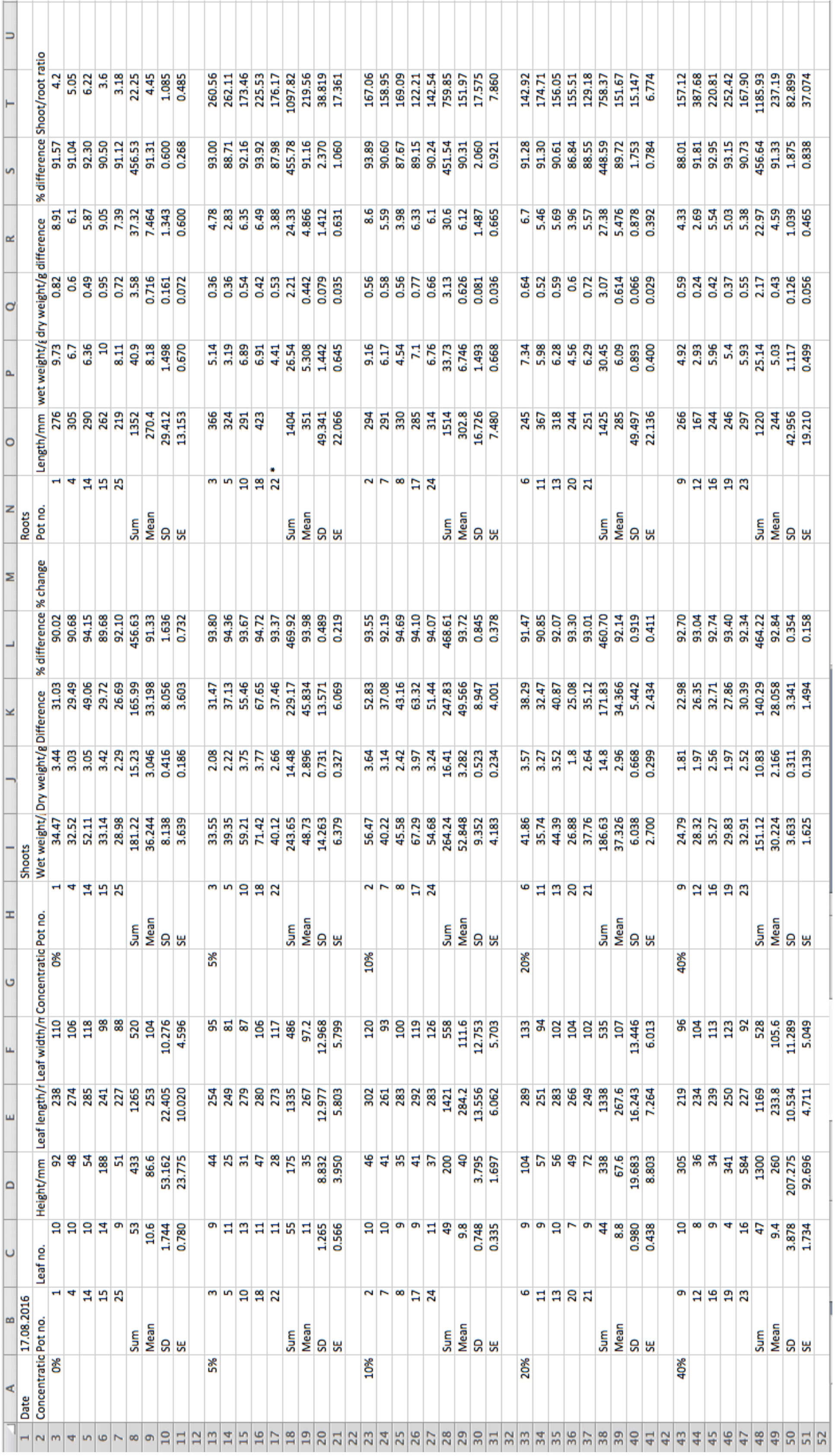
Appendix 4.3 Experiment 3 Raw data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	19.5.2016						Aerial parts					Roots									
2		% concentrat	Pot number	Leaf no.	Leaf length/r	Leaf width/n	Length	wet weight/g	dry weight/g	Difference	% difference	Length	Wet weight/	Dry weight/g	Difference	% difference	Root/shoot r	Total wet bic	Total dried b	Difference	% difference
3		0	1	4	41	20	11	0.96	0.06	0.9	93.75	7	0.38	0.02	0.36	94.74	0.33	1.34	0.08	1.26	94.03
4			5	13	112	50	18	5.89	0.82	5.07	86.08	231	1.67	0.33	1.34	80.24	0.40	7.56	1.15	6.41	84.79
5			8	10	103	44	46	3.62	0.37	3.25	89.78	138	1.14	0.15	0.99	86.84	0.41	4.76	0.52	4.24	89.08
6			10	11	110	49	101	5.32	0.72	4.6	86.47	123	2.19	0.41	1.78	81.28	0.57	7.51	1.13	6.38	84.95
7			13	13	117	42	124	6.01	0.61	5.4	89.85	124	2.84	0.24	2.6	91.55	0.39	8.85	0.85	8	90.40
8			Sum	51	483	205	300	21.8	2.58	19.22	445.92	623	8.22	1.15	7.07	434.65	2.10	30.02	3.73	26.29	443.24
9			Mean	10.2	96.6	41	60	4.36	0.516	3.844	89.18	124.6	1.644	0.23	1.414	86.93	0.42	6.00	0.75	5.26	88.65
10			SD	3.311	28.161	10.918	45.029	1.902	0.273	1.644	2.781	71.180	0.846	0.136	0.753	5.639	0.079	2.687	0.404	2.329	3.486
11			SE	1.481	12.594	4.883	20.138	0.851	0.122	0.735	1.244	31.833	0.378	0.061	0.337	2.522	0.035	1.201	0.181	1.042	1.559
12																					
13		25	2	8	91	39	25	2.64	0.32	2.32	87.88	129	1.01	0.16	0.85	84.16	0.5	3.65	0.48	3.17	86.85
14			4	6	*	*	23	0.79	0.13	0.66	83.54	107	0.54	0.02	0.52	96.30	0.15	1.33	0.15	1.18	88.72
15			11	9	112	46	29	5.02	0.51	4.51	89.84	99	3.22	0.36	2.86	88.82	0.71	8.24	0.87	7.37	89.44
16			15	9	119	45	45	4.38	0.49	3.89	88.81	126	2.31	0.3	2.01	87.01	0.61	6.69	0.79	5.9	88.19
17			18	9	105	45	79	5.12	0.47	4.65	90.82	116	3.04	0.24	2.8	92.11	0.51	8.16	0.71	7.45	91.30
18			Sum	41	427	175	201	17.95	1.92	16.03	440.90	577	10.12	1.08	9.04	448.39	2.48	28.07	3	25.07	444.50
19			Mean	8.2	106.75	43.75	40.2	3.59	0.384	3.206	88.18	115.4	2.024	0.216	1.808	89.68	0.50	5.61	0.6	5.01	88.90
20			SD	1.166	10.353	2.773	20.884	1.658	0.144	1.518	2.518	11.289	1.075	0.118	0.970	4.195	0.187	2.711	0.260	2.465	1.469
21			SE	0.522	4.630	1.240	9.340	0.742	0.064	0.679	1.126	5.049	0.481	0.053	0.434	1.876	0.084	1.212	0.116	1.102	0.657
22																				0	
23		50	6	8	86	40	21	2.79	0.36	2.43	87.10	148	1.68	0.22	1.46	86.90	0.61	4.47	0.58	3.89	87.02
24			9	7	98	40	26	2.79	0.32	2.47	88.53	125	1.19	0.13	1.06	89.08	0.41	3.98	0.45	3.53	88.69
25			12	6	101	40	29	2.73	0.21	2.52	92.31	96	0.8	0.08	0.72	90.00	0.38	3.53	0.29	3.24	91.78
26			14	5	*	*	24	0.45	0.05	0.4	88.89	101	1.07	0.03	1.04	97.20	0.60	1.52	0.08	1.44	94.74
27			16	8	104	16	21	1.62	0.45	1.17	72.22	137	1.73	0.24	1.49	86.13	0.53	3.35	0.69	2.66	79.40
28			Sum	34	389	136	121	10.38	1.39	8.99	429.05	607	6.47	0.7	5.77	449.30	2.53	16.85	2.09	14.76	441.64
29			Mean	6.8	97.25	34	24.2	2.076	0.278	1.798	85.81	121.4	1.294	0.14	1.154	89.86	0.51	3.37	0.42	2.95	88.33
30			SD	1.166	6.833	10.392	3.059	0.927	0.138	0.863	7.005	20.126	0.359	0.080	0.289	3.927	0.096	1.003	0.215	0.857	5.187
31			SE	0.522	3.056	4.648	1.368	0.415	0.062	0.386	3.133	9.000	0.161	0.036	0.129	1.756	0.043	0.449	0.096	0.383	2.320
32																				0	
33		100	3	7	56	27	21	1.07	0.14	0.93	86.92	74	0.62	0.07	0.55	88.71	0.5	1.69	0.21	1.48	87.57
34			7	5	86	37	15	2.56	0.33	2.23	87.11	69	1.02	0.11	0.91	89.22	0.33	3.58	0.44	3.14	87.71
35			17	4	39	16	19	1.23	0.02	1.21	98.37	77	0.44	0.02	0.42	95.45	1	1.67	0.04	1.63	97.60
36			19	9	78	32	45	1.92	0.16	1.76	91.67	84	1	0.08	0.92	92.00	0.5	2.92	0.24	2.68	91.78
37			20	11	96	43	81	3.78	0.33	3.45	91.27	68	1.12	0.12	1	89.29	0.36	4.9	0.45	4.45	90.82
38			Sum	36	355	155	181	10.56	0.98	9.58	455.34	372	4.2	0.4	3.8	454.67	2.70	14.76	1.38	13.38	455.49
39			Mean	7.2	71	31	36.2	2.112	0.196	1.916	91.07	74.4	0.84	0.08	0.76	90.93	0.54	2.95	0.28	2.68	91.10
40			SD	2.561	20.727	9.187	24.742	0.988	0.119	0.888	4.164	5.817	0.263	0.035	0.230	2.537	0.240	1.219	0.154	1.085	3.655
41			SE	1.145	9.269	4.109	11.065	0.442	0.053	0.397	1.862	2.602	0.117	0.016	0.103	1.135	0.107	0.545	0.069	0.485	1.634
42																					

Appendix 4.4 Experiment 4 raw data

A 4.4.1 Experiment 4.0 Destructive harvest raw data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Date	17.08.2016							Shoots					Roots							
2	Concentratic	Pot no.	Leaf no.	Height/mm	Leaf length/r	Leaf width/n	Concentratic	Pot no.	Wet weight/	Dry weight/g	Difference	% difference	% change	Pot no.	Length/mm	wet weight/g	dry weight/g	difference	% difference	Shoot/root ratio	
3	0%	1	10	92	238	110	0%	1	34.47	3.44	31.03	90.02		1	276	9.73	0.82	8.91	91.57	4.2	
4		4	10	48	274	106		4	32.52	3.03	29.49	90.68		4	305	6.7	0.6	6.1	91.04	5.05	
5		14	10	54	285	118		14	52.11	3.05	49.06	94.15		14	290	6.36	0.49	5.87	92.30	6.22	
6		15	14	188	241	98		15	33.14	3.42	29.72	89.68		15	262	10	0.95	9.05	90.50	3.6	
7		25	9	51	227	88		25	28.98	2.29	26.69	92.10		25	219	8.11	0.72	7.39	91.12	3.18	
8		Sum	53	433	1265	520		Sum	181.22	15.23	165.99	456.63		Sum	1352	40.9	3.58	37.32	456.53	22.25	
9		Mean	10.6	86.6	253	104		Mean	36.244	3.046	33.198	91.33		Mean	270.4	8.18	0.716	7.464	91.31	4.45	
10		SD	1.744	53.162	22.405	10.276		SD	8.138	0.416	8.056	1.636		SD	29.412	1.498	0.161	1.343	0.600	1.085	
11		SE	0.780	23.775	10.020	4.596		SE	3.639	0.186	3.603	0.732		SE	13.153	0.670	0.072	0.600	0.268	0.485	
12																					
13	5%	3	9	44	254	95	5%	3	33.55	2.08	31.47	93.80		3	366	5.14	0.36	4.78	93.00	260.56	
14		5	11	25	249	81		5	39.35	2.22	37.13	94.36		5	324	3.19	0.36	2.83	88.71	262.11	
15		10	13	31	279	87		10	59.21	3.75	55.46	93.67		10	291	6.89	0.54	6.35	92.16	173.46	
16		18	11	47	280	106		18	71.42	3.77	67.65	94.72		18	423	6.91	0.42	6.49	93.92	225.53	
17		22	11	28	273	117		22	40.12	2.66	37.46	93.37		22	*	4.41	0.53	3.88	87.98	176.17	
18		Sum	55	175	1335	486		Sum	243.65	14.48	229.17	469.92		Sum	1404	26.54	2.21	24.33	455.78	1097.82	
19		Mean	11	35	267	97.2		Mean	48.73	2.896	45.834	93.98		Mean	351	5.308	0.442	4.866	91.16	219.56	
20		SD	1.265	8.832	12.977	12.968		SD	14.263	0.731	13.571	0.489		SD	49.341	1.442	0.079	1.412	2.370	38.819	
21		SE	0.566	3.950	5.803	5.799		SE	6.379	0.327	6.069	0.219		SE	22.066	0.645	0.035	0.631	1.060	17.361	
22																					
23	10%	2	10	46	302	120	10%	2	56.47	3.64	52.83	93.55		2	294	9.16	0.56	8.6	93.89	167.06	
24		7	10	41	261	93		7	40.22	3.14	37.08	92.19		7	291	6.17	0.58	5.59	90.60	158.95	
25		8	9	35	283	100		8	45.58	2.42	43.16	94.69		8	330	4.54	0.56	3.98	87.67	169.09	
26		17	9	41	292	119		17	67.29	3.97	63.32	94.10		17	285	7.1	0.77	6.33	89.15	122.21	
27		24	11	37	283	126		24	54.68	3.24	51.44	94.07		24	314	6.76	0.66	6.1	90.24	142.54	
28		Sum	49	200	1421	558		Sum	264.24	16.41	247.83	468.61		Sum	1514	33.73	3.13	30.6	451.54	759.85	
29		Mean	9.8	40	284.2	111.6		Mean	52.848	3.282	49.566	93.72		Mean	302.8	6.746	0.626	6.12	90.31	151.97	
30		SD	0.748	3.795	13.556	12.753		SD	9.352	0.523	8.947	0.845		SD	16.726	1.493	0.081	1.487	2.060	17.575	
31		SE	0.335	1.697	6.062	5.703		SE	4.183	0.234	4.001	0.378		SE	7.480	0.668	0.036	0.665	0.921	7.860	
32																					
33	20%	6	9	104	289	133	20%	6	41.86	3.57	38.29	91.47		6	245	7.34	0.64	6.7	91.28	142.92	
34		11	9	57	251	94		11	35.74	3.27	32.47	90.85		11	367	5.98	0.52	5.46	91.30	174.71	
35		13	10	56	283	102		13	44.39	3.52	40.87	92.07		13	318	6.28	0.59	5.69	90.61	156.05	
36		20	7	49	266	104		20	26.88	1.8	25.08	93.30		20	244	4.56	0.6	3.96	86.84	155.51	
37		21	9	72	249	102		21	37.76	2.64	35.12	93.01		21	251	6.29	0.72	5.57	88.55	129.18	
38		Sum	44	338	1338	535		Sum	186.63	14.8	171.83	460.70		Sum	1425	30.45	3.07	27.38	448.59	758.37	
39		Mean	8.8	67.6	267.6	107		Mean	37.326	2.96	34.366	92.14		Mean	285	6.09	0.614	5.476	89.72	151.67	
40		SD	0.980	19.683	16.243	13.446		SD	6.038	0.668	5.442	0.919		SD	49.497	0.893	0.066	0.878	1.753	15.147	
41		SE	0.438	8.803	7.264	6.013		SE	2.700	0.299	2.434	0.411		SE	22.136	0.400	0.029	0.392	0.784	6.774	
42																					
43	40%	9	10	305	219	96	40%	9	24.79	1.81	22.98	92.70		9	266	4.92	0.59	4.33	88.01	157.12	
44		12	8	36	234	104		12	28.32	1.97	26.35	93.04		12	167	2.93	0.24	2.69	91.81	387.68	
45		16	9	34	239	113		16	35.27	2.56	32.71	92.74		16	244	5.96	0.42	5.54	92.95	220.81	
46		19	4	341	250	123		19	29.83	1.97	27.86	93.40		19	246	5.4	0.37	5.03	93.15	252.42	
47		23	16	584	227	92		23	32.91	2.52	30.39	92.34		23	297	5.93	0.55	5.38	90.73	167.90	
48		Sum	47	1300	1169	528		Sum	151.12	10.83	140.29	464.22		Sum	1220	25.14	2.17	22.97	456.64	1185.93	
49		Mean	9.4	260	233.8	105.6		Mean	30.224	2.166	28.058	92.84		Mean	244	5.03	0.43	4.59	91.33	237.19	
50		SD	3.878	207.275	10.534	11.289		SD	3.633	0.311	3.341	0.354		SD	42.956	1.117	0.126	1.039	1.875	82.899	
51		SE	1.734	92.696	4.711	5.049		SE	1.625	0.139	1.494	0.158		SE	19.210	0.499	0.056	0.465	0.838	37.074	
52																					

A4.4.2 Data analysis for significant results (Experiment 4.0)

Kruskal-Wallis: Height/mm versus Treatment

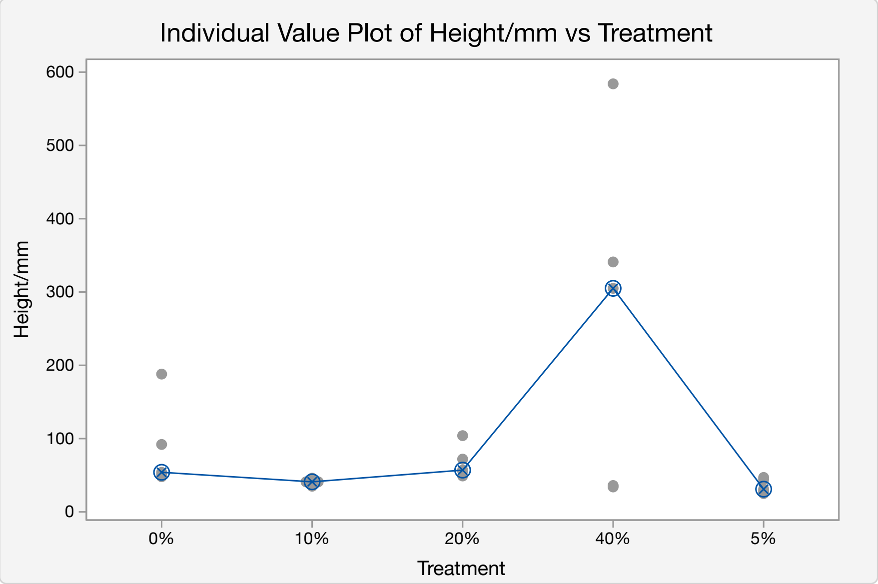
Descriptive Statistics

Treatment	N	Median	Mean Rank	Z-Value
0%	5	54	17.2	1.43
10%	5	41	8.0	-1.70
20%	5	57	17.8	1.63
40%	5	305	16.4	1.15
5%	5	31	5.6	-2.51
Overall	25		13.0	

Test

Null hypothesis	H_0: All medians are equal
Alternative hypothesis	H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	4	12.18	0.0160
Adjusted for ties	4	12.19	0.0160



One-Way ANOVA: Height/mm versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	173155	43288.7	3.74	0.0198
Error	20	231344	11567.2		
Total	24	404499			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
107.551	42.81%	31.37%	10.64%

Means

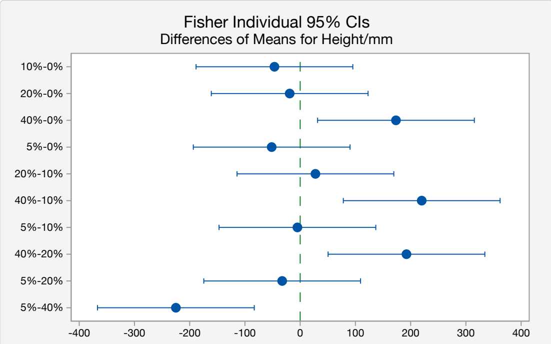
Treatment	N	Mean	StDev	95% CI
0%	5	86.60	59.44	(-13.73, 186.93)
10%	5	40.000	4.243	(-60.331, 140.331)
20%	5	67.600	22.007	(-32.731, 167.931)
40%	5	260.0	231.7	(159.7, 360.3)
5%	5	35.000	9.874	(-65.331, 135.331)

Pooled StDev = 107.551

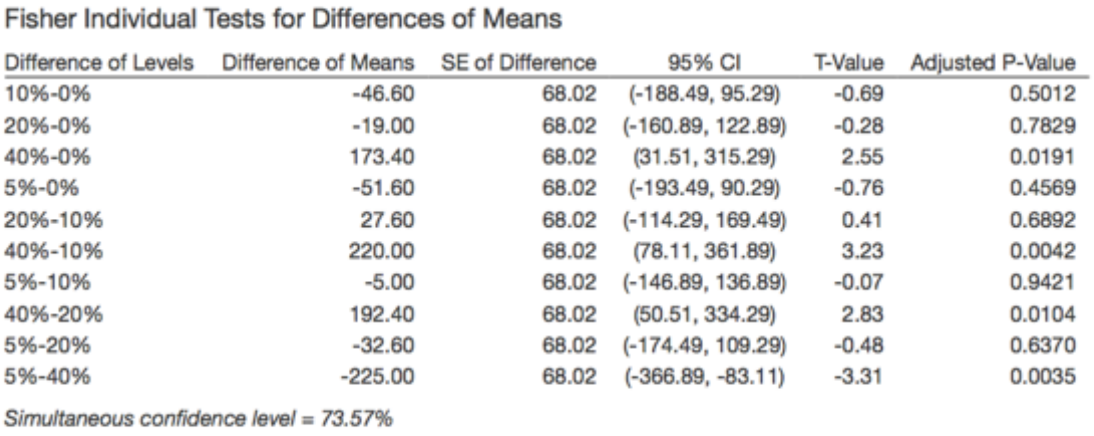
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping
40%	5	260.0	A
0%	5	86.60	B
20%	5	67.600	B
10%	5	40.000	B
5%	5	35.000	B

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.



Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-46.60	68.02	(-188.49, 95.29)	-0.69	0.5012
20%-0%	-19.00	68.02	(-160.89, 122.89)	-0.28	0.7829
40%-0%	173.40	68.02	(31.51, 315.29)	2.55	0.0191
5%-0%	-51.60	68.02	(-193.49, 90.29)	-0.76	0.4569
20%-10%	27.60	68.02	(-114.29, 169.49)	0.41	0.6892
40%-10%	220.00	68.02	(78.11, 361.89)	3.23	0.0042
5%-10%	-5.00	68.02	(-146.89, 136.89)	-0.07	0.9421
40%-20%	192.40	68.02	(50.51, 334.29)	2.83	0.0104
5%-20%	-32.60	68.02	(-174.49, 109.29)	-0.48	0.6370
5%-40%	-225.00	68.02	(-366.89, -83.11)	-3.31	0.0035

Simultaneous confidence level = 73.57%

One-Way ANOVA: roots dry g versus Treatment

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	5	0%, 10%, 20%, 40%, 5%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	4	0.306016	0.076504	5.18	0.0050
Error	20	0.295360	0.014768		
Total	24	0.601376			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.121524	50.89%	41.06%	23.26%

Means

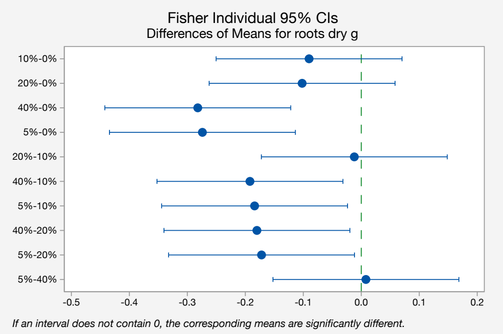
Treatment	N	Mean	StDev	95% CI
0%	5	0.71600	0.18036	(0.60263, 0.82937)
10%	5	0.62600	0.09044	(0.51263, 0.73937)
20%	5	0.61400	0.07335	(0.50063, 0.72737)
40%	5	0.43400	0.14117	(0.32063, 0.54737)
5%	5	0.44200	0.08843	(0.32863, 0.55537)

Pooled StDev = 0.121524

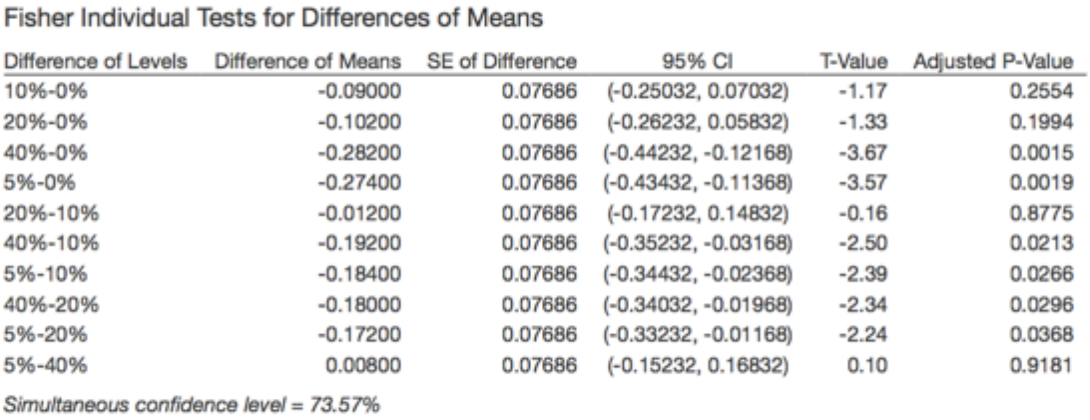
Grouping Information Using the Fisher LSD Method and 95% Confidence

Treatment	N	Mean	Grouping	
0%	5	0.71600	A	
10%	5	0.62600	A	
20%	5	0.61400	A	
5%	5	0.44200		B
40%	5	0.43400		B

Means that do not share a letter are significantly different.



If an interval does not contain 0, the corresponding means are significantly different.

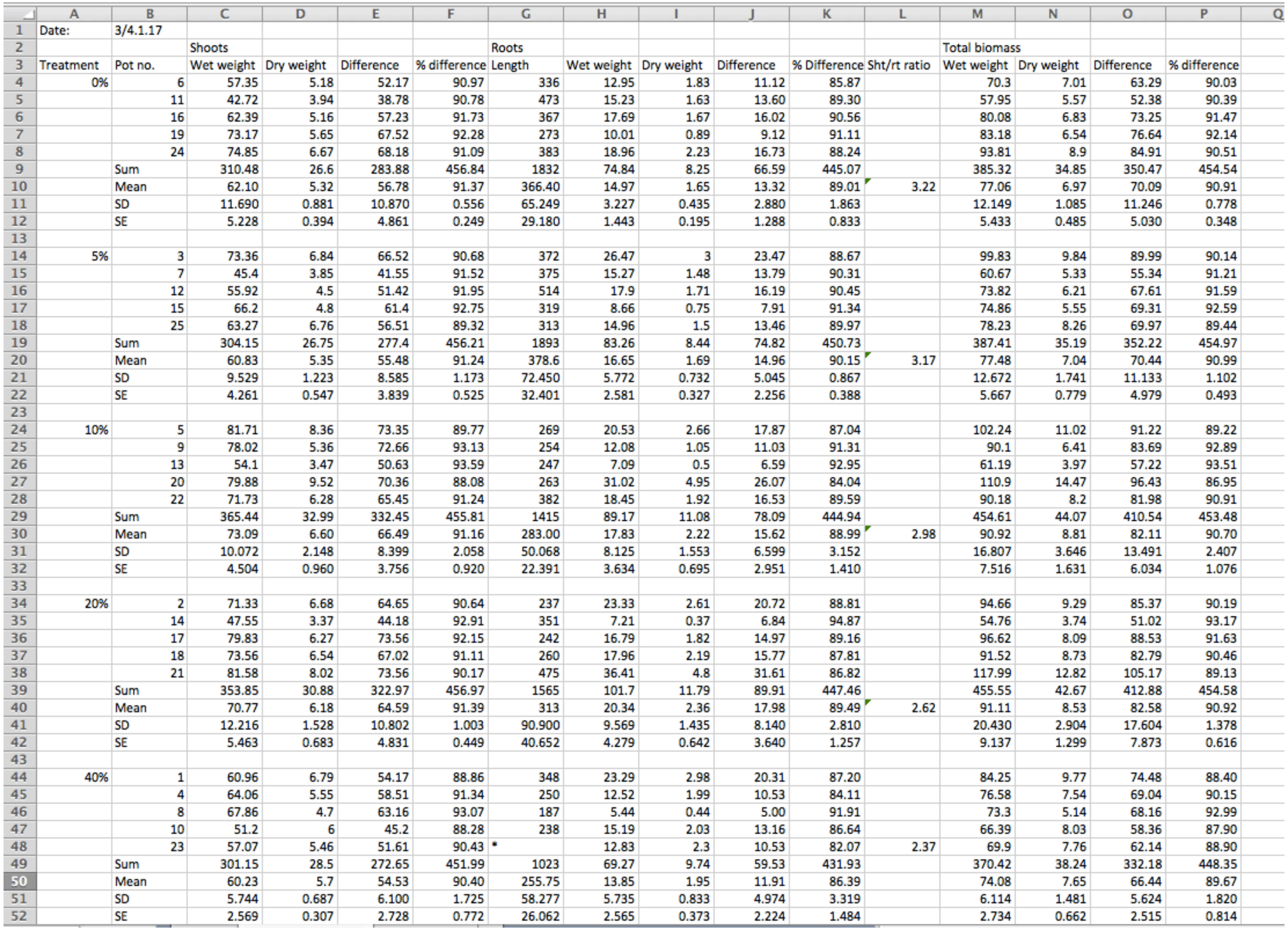


Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
10%-0%	-0.09000	0.07686	(-0.25032, 0.07032)	-1.17	0.2554
20%-0%	-0.10200	0.07686	(-0.26232, 0.05832)	-1.33	0.1994
40%-0%	-0.28200	0.07686	(-0.44232, -0.12168)	-3.67	0.0015
5%-0%	-0.27400	0.07686	(-0.43432, -0.11368)	-3.57	0.0019
20%-10%	-0.01200	0.07686	(-0.17232, 0.14832)	-0.16	0.8775
40%-10%	-0.19200	0.07686	(-0.35232, -0.03168)	-2.50	0.0213
5%-10%	-0.18400	0.07686	(-0.34432, -0.02368)	-2.39	0.0266
40%-20%	-0.18000	0.07686	(-0.34032, -0.01968)	-2.34	0.0296
5%-20%	-0.17200	0.07686	(-0.33232, -0.01168)	-2.24	0.0368
5%-40%	0.00800	0.07686	(-0.15232, 0.16832)	0.10	0.9181

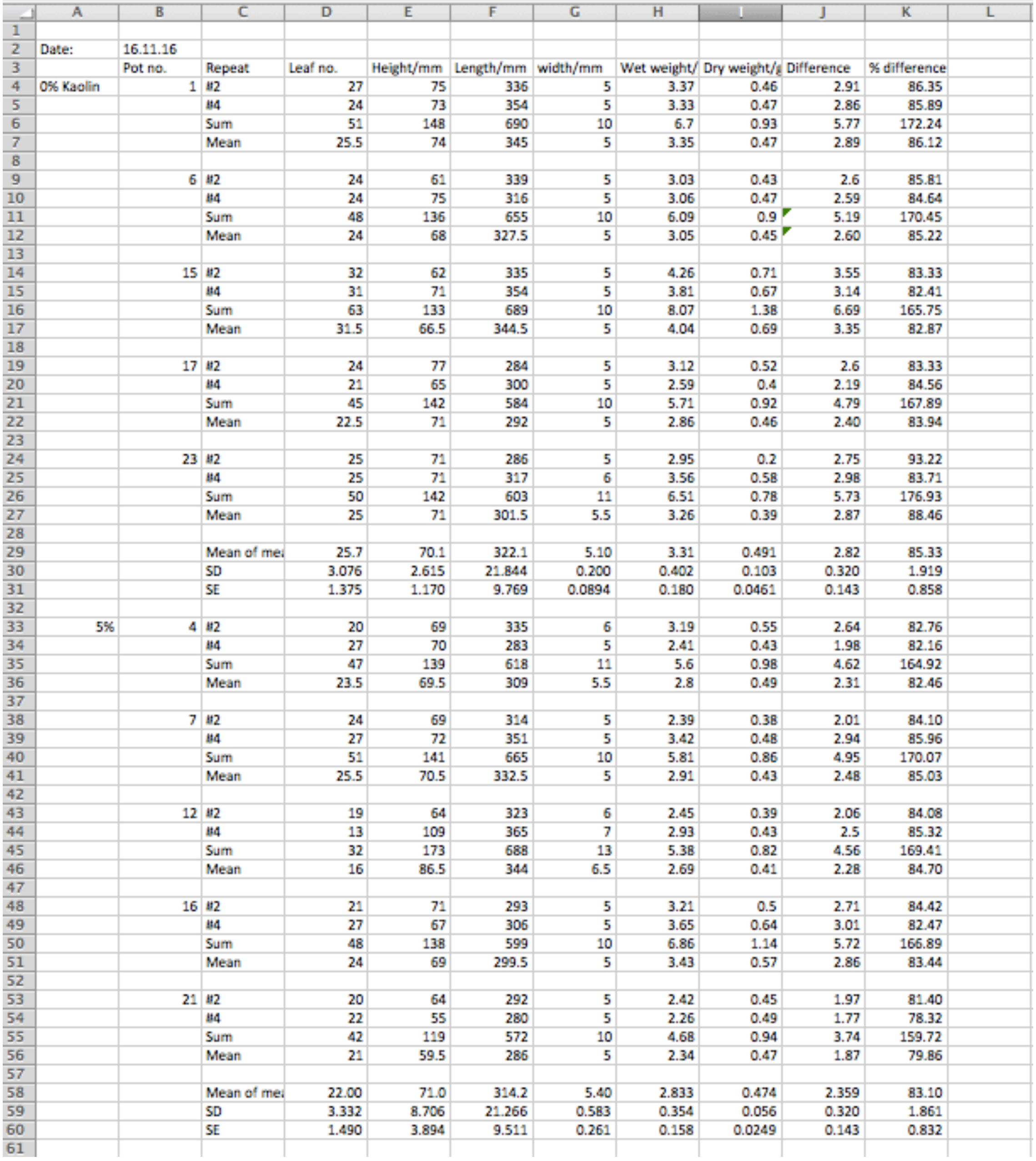
Simultaneous confidence level = 73.57%

A 4.4.3 Experiment 4.1 Destructive harvest raw data



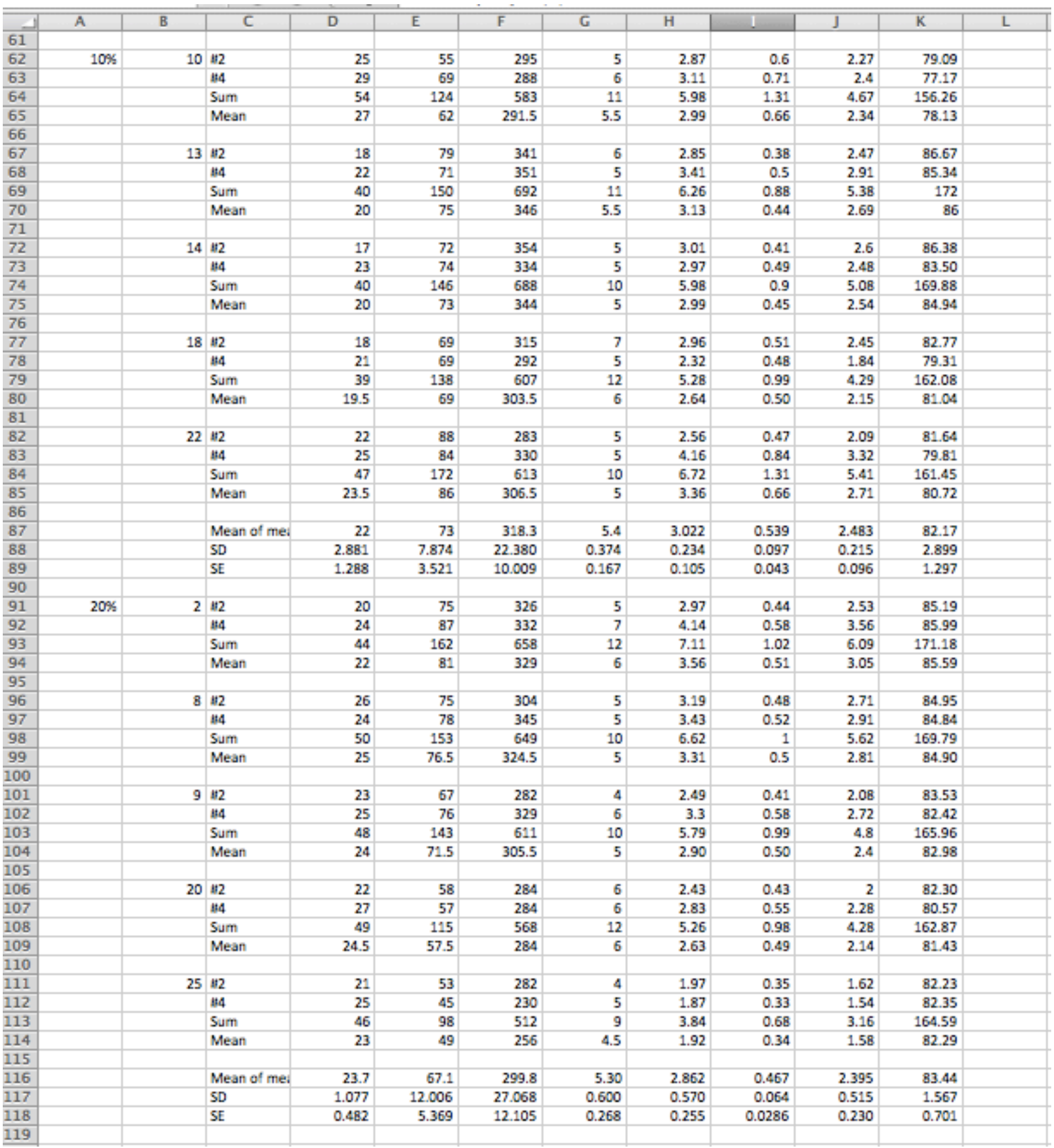
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Date:	3/4.1.17															
2			Shoots				Roots						Total biomass				
3	Treatment	Pot no.	Wet weight	Dry weight	Difference	% difference	Length	Wet weight	Dry weight	Difference	% Difference	Sht/rt ratio	Wet weight	Dry weight	Difference	% difference	
4	0%	6	57.35	5.18	52.17	90.97	336	12.95	1.83	11.12	85.87		70.3	7.01	63.29	90.03	
5		11	42.72	3.94	38.78	90.78	473	15.23	1.63	13.60	89.30		57.95	5.57	52.38	90.39	
6		16	62.39	5.16	57.23	91.73	367	17.69	1.67	16.02	90.56		80.08	6.83	73.25	91.47	
7		19	73.17	5.65	67.52	92.28	273	10.01	0.89	9.12	91.11		83.18	6.54	76.64	92.14	
8		24	74.85	6.67	68.18	91.09	383	18.96	2.23	16.73	88.24		93.81	8.9	84.91	90.51	
9		Sum	310.48	26.6	283.88	456.84	1832	74.84	8.25	66.59	445.07		385.32	34.85	350.47	454.54	
10		Mean	62.10	5.32	56.78	91.37	366.40	14.97	1.65	13.32	89.01	3.22	77.06	6.97	70.09	90.91	
11		SD	11.690	0.881	10.870	0.556	65.249	3.227	0.435	2.880	1.863		12.149	1.085	11.246	0.778	
12		SE	5.228	0.394	4.861	0.249	29.180	1.443	0.195	1.288	0.833		5.433	0.485	5.030	0.348	
13																	
14	5%	3	73.36	6.84	66.52	90.68	372	26.47	3	23.47	88.67		99.83	9.84	89.99	90.14	
15		7	45.4	3.85	41.55	91.52	375	15.27	1.48	13.79	90.31		60.67	5.33	55.34	91.21	
16		12	55.92	4.5	51.42	91.95	514	17.9	1.71	16.19	90.45		73.82	6.21	67.61	91.59	
17		15	66.2	4.8	61.4	92.75	319	8.66	0.75	7.91	91.34		74.86	5.55	69.31	92.59	
18		25	63.27	6.76	56.51	89.32	313	14.96	1.5	13.46	89.97		78.23	8.26	69.97	89.44	
19		Sum	304.15	26.75	277.4	456.21	1893	83.26	8.44	74.82	450.73		387.41	35.19	352.22	454.97	
20		Mean	60.83	5.35	55.48	91.24	378.6	16.65	1.69	14.96	90.15	3.17	77.48	7.04	70.44	90.99	
21		SD	9.529	1.223	8.585	1.173	72.450	5.772	0.732	5.045	0.867		12.672	1.741	11.133	1.102	
22		SE	4.261	0.547	3.839	0.525	32.401	2.581	0.327	2.256	0.388		5.667	0.779	4.979	0.493	
23																	
24	10%	5	81.71	8.36	73.35	89.77	269	20.53	2.66	17.87	87.04		102.24	11.02	91.22	89.22	
25		9	78.02	5.36	72.66	93.13	254	12.08	1.05	11.03	91.31		90.1	6.41	83.69	92.89	
26		13	54.1	3.47	50.63	93.59	247	7.09	0.5	6.59	92.95		61.19	3.97	57.22	93.51	
27		20	79.88	9.52	70.36	88.08	263	31.02	4.95	26.07	84.04		110.9	14.47	96.43	86.95	
28		22	71.73	6.28	65.45	91.24	382	18.45	1.92	16.53	89.59		90.18	8.2	81.98	90.91	
29		Sum	365.44	32.99	332.45	455.81	1415	89.17	11.08	78.09	444.94		454.61	44.07	410.54	453.48	
30		Mean	73.09	6.60	66.49	91.16	283.00	17.83	2.22	15.62	88.99	2.98	90.92	8.81	82.11	90.70	
31		SD	10.072	2.148	8.399	2.058	50.068	8.125	1.553	6.599	3.152		16.807	3.646	13.491	2.407	
32		SE	4.504	0.960	3.756	0.920	22.391	3.634	0.695	2.951	1.410		7.516	1.631	6.034	1.076	
33																	
34	20%	2	71.33	6.68	64.65	90.64	237	23.33	2.61	20.72	88.81		94.66	9.29	85.37	90.19	
35		14	47.55	3.37	44.18	92.91	351	7.21	0.37	6.84	94.87		54.76	3.74	51.02	93.17	
36		17	79.83	6.27	73.56	92.15	242	16.79	1.82	14.97	89.16		96.62	8.09	88.53	91.63	
37		18	73.56	6.54	67.02	91.11	260	17.96	2.19	15.77	87.81		91.52	8.73	82.79	90.46	
38		21	81.58	8.02	73.56	90.17	475	36.41	4.8	31.61	86.82		117.99	12.82	105.17	89.13	
39		Sum	353.85	30.88	322.97	456.97	1565	101.7	11.79	89.91	447.46		455.55	42.67	412.88	454.58	
40		Mean	70.77	6.18	64.59	91.39	313	20.34	2.36	17.98	89.49	2.62	91.11	8.53	82.58	90.92	
41		SD	12.216	1.528	10.802	1.003	90.900	9.569	1.435	8.140	2.810		20.430	2.904	17.604	1.378	
42		SE	5.463	0.683	4.831	0.449	40.652	4.279	0.642	3.640	1.257		9.137	1.299	7.873	0.616	
43																	
44	40%	1	60.96	6.79	54.17	88.86	348	23.29	2.98	20.31	87.20		84.25	9.77	74.48	88.40	
45		4	64.06	5.55	58.51	91.34	250	12.52	1.99	10.53	84.11		76.58	7.54	69.04	90.15	
46		8	67.86	4.7	63.16	93.07	187	5.44	0.44	5.00	91.91		73.3	5.14	68.16	92.99	
47		10	51.2	6	45.2	88.28	238	15.19	2.03	13.16	86.64		66.39	8.03	58.36	87.90	
48		23	57.07	5.46	51.61	90.43	*	12.83	2.3	10.53	82.07	2.37	69.9	7.76	62.14	88.90	
49		Sum	301.15	28.5	272.65	451.99	1023	69.27	9.74	59.53	431.93		370.42	38.24	332.18	448.35	
50		Mean	60.23	5.7	54.53	90.40	255.75	13.85	1.95	11.91	86.39		74.08	7.65	66.44	89.67	
51		SD	5.744	0.687	6.100	1.725	58.277	5.735	0.833	4.974	3.319		6.114	1.481	5.624	1.820	
52		SE	2.569	0.307	2.728	0.772	26.062	2.565	0.373	2.224	1.484		2.734	0.662	2.515	0.814	

A4.5.1 Experiment 5 mid term harvest raw data:

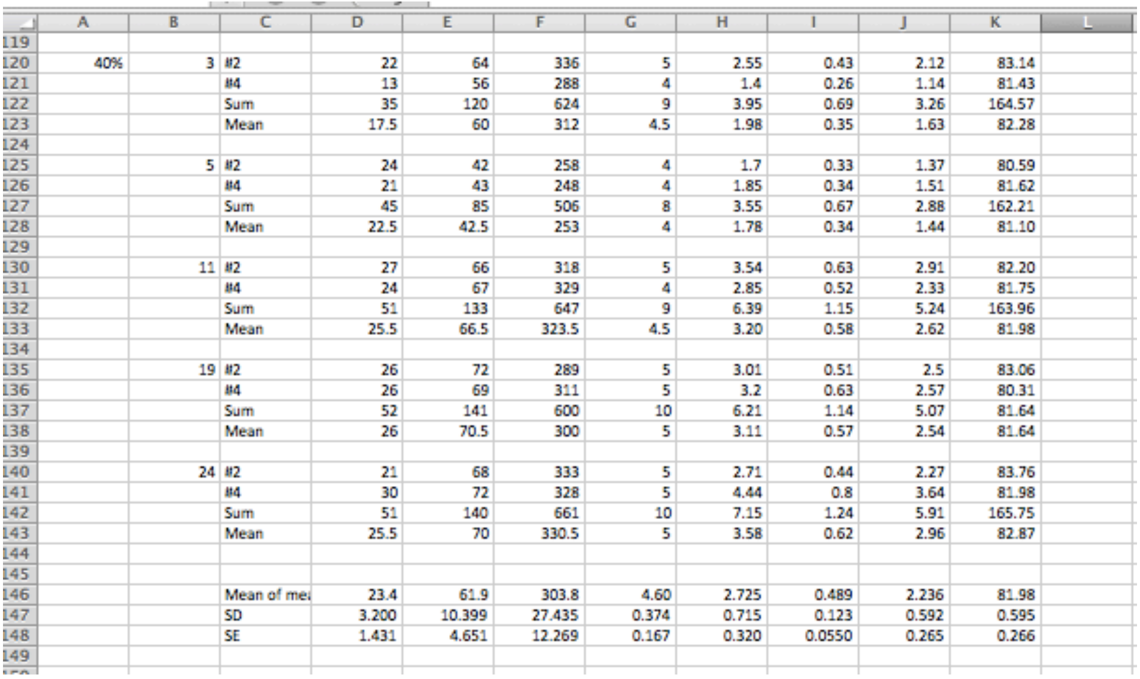


	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Date:	16.11.16										
3		Pot no.	Repeat	Leaf no.	Height/mm	Length/mm	width/mm	Wet weight/	Dry weight/g	Difference	% difference	
4	0% Kaolin	1	#2	27	75	336	5	3.37	0.46	2.91	86.35	
5			#4	24	73	354	5	3.33	0.47	2.86	85.89	
6			Sum	51	148	690	10	6.7	0.93	5.77	172.24	
7			Mean	25.5	74	345	5	3.35	0.47	2.89	86.12	
8												
9		6	#2	24	61	339	5	3.03	0.43	2.6	85.81	
10			#4	24	75	316	5	3.06	0.47	2.59	84.64	
11			Sum	48	136	655	10	6.09	0.9	5.19	170.45	
12			Mean	24	68	327.5	5	3.05	0.45	2.60	85.22	
13												
14		15	#2	32	62	335	5	4.26	0.71	3.55	83.33	
15			#4	31	71	354	5	3.81	0.67	3.14	82.41	
16			Sum	63	133	689	10	8.07	1.38	6.69	165.75	
17			Mean	31.5	66.5	344.5	5	4.04	0.69	3.35	82.87	
18												
19		17	#2	24	77	284	5	3.12	0.52	2.6	83.33	
20			#4	21	65	300	5	2.59	0.4	2.19	84.56	
21			Sum	45	142	584	10	5.71	0.92	4.79	167.89	
22			Mean	22.5	71	292	5	2.86	0.46	2.40	83.94	
23												
24		23	#2	25	71	286	5	2.95	0.2	2.75	93.22	
25			#4	25	71	317	6	3.56	0.58	2.98	83.71	
26			Sum	50	142	603	11	6.51	0.78	5.73	176.93	
27			Mean	25	71	301.5	5.5	3.26	0.39	2.87	88.46	
28												
29			Mean of mea	25.7	70.1	322.1	5.10	3.31	0.491	2.82	85.33	
30			SD	3.076	2.615	21.844	0.200	0.402	0.103	0.320	1.919	
31			SE	1.375	1.170	9.769	0.0894	0.180	0.0461	0.143	0.858	
32												
33	5%	4	#2	20	69	335	6	3.19	0.55	2.64	82.76	
34			#4	27	70	283	5	2.41	0.43	1.98	82.16	
35			Sum	47	139	618	11	5.6	0.98	4.62	164.92	
36			Mean	23.5	69.5	309	5.5	2.8	0.49	2.31	82.46	
37												
38		7	#2	24	69	314	5	2.39	0.38	2.01	84.10	
39			#4	27	72	351	5	3.42	0.48	2.94	85.96	
40			Sum	51	141	665	10	5.81	0.86	4.95	170.07	
41			Mean	25.5	70.5	332.5	5	2.91	0.43	2.48	85.03	
42												
43		12	#2	19	64	323	6	2.45	0.39	2.06	84.08	
44			#4	13	109	365	7	2.93	0.43	2.5	85.32	
45			Sum	32	173	688	13	5.38	0.82	4.56	169.41	
46			Mean	16	86.5	344	6.5	2.69	0.41	2.28	84.70	
47												
48		16	#2	21	71	293	5	3.21	0.5	2.71	84.42	
49			#4	27	67	306	5	3.65	0.64	3.01	82.47	
50			Sum	48	138	599	10	6.86	1.14	5.72	166.89	
51			Mean	24	69	299.5	5	3.43	0.57	2.86	83.44	
52												
53		21	#2	20	64	292	5	2.42	0.45	1.97	81.40	
54			#4	22	55	280	5	2.26	0.49	1.77	78.32	
55			Sum	42	119	572	10	4.68	0.94	3.74	159.72	
56			Mean	21	59.5	286	5	2.34	0.47	1.87	79.86	
57												
58			Mean of mea	22.00	71.0	314.2	5.40	2.833	0.474	2.359	83.10	
59			SD	3.332	8.706	21.266	0.583	0.354	0.056	0.320	1.861	
60			SE	1.490	3.894	9.511	0.261	0.158	0.0249	0.143	0.832	
61												

]

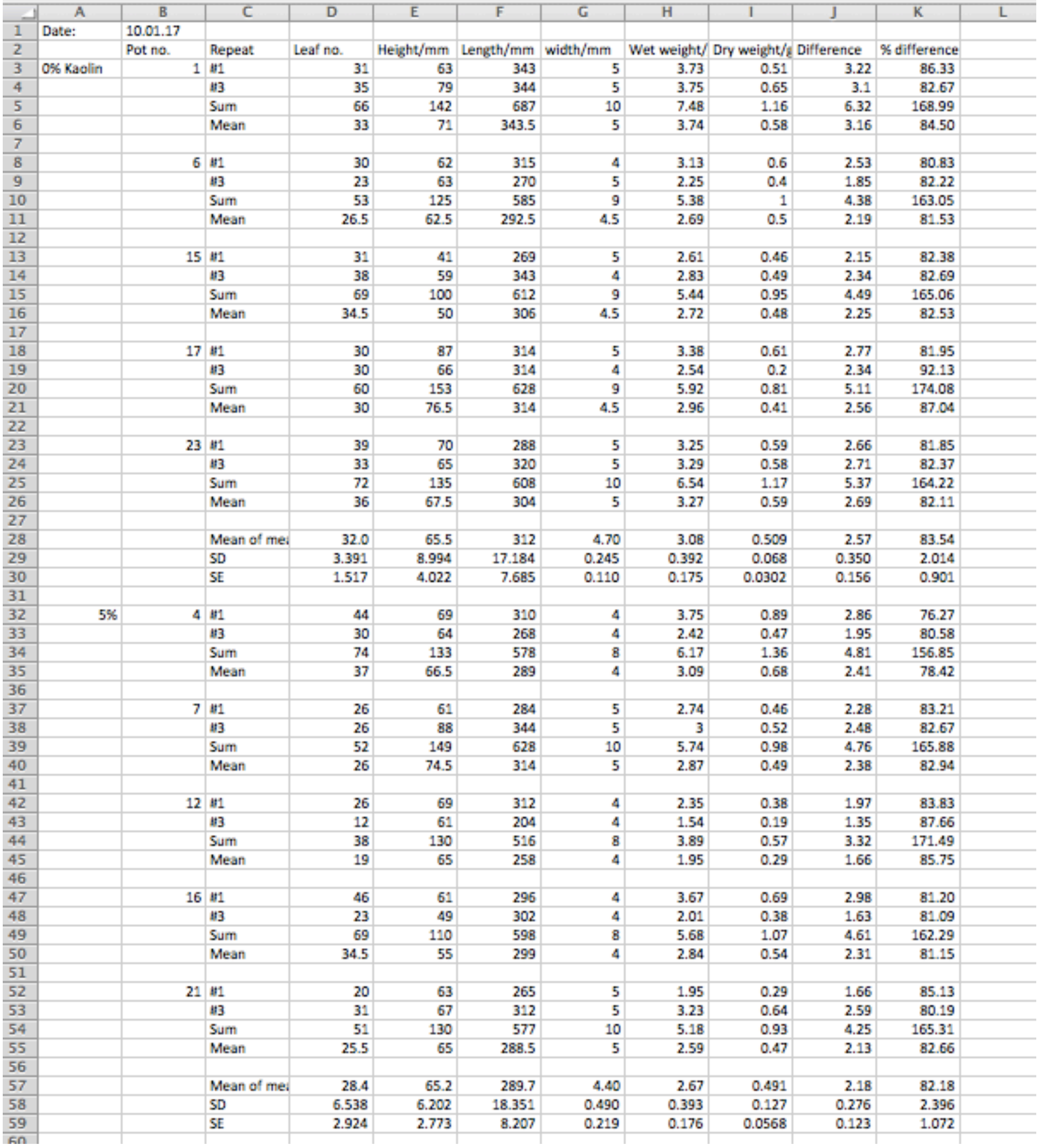


	A	B	C	D	E	F	G	H	I	J	K	L
61												
62	10%	10	#2	25	55	295	5	2.87	0.6	2.27	79.09	
63			#4	29	69	288	6	3.11	0.71	2.4	77.17	
64			Sum	54	124	583	11	5.98	1.31	4.67	156.26	
65			Mean	27	62	291.5	5.5	2.99	0.66	2.34	78.13	
66												
67		13	#2	18	79	341	6	2.85	0.38	2.47	86.67	
68			#4	22	71	351	5	3.41	0.5	2.91	85.34	
69			Sum	40	150	692	11	6.26	0.88	5.38	172	
70			Mean	20	75	346	5.5	3.13	0.44	2.69	86	
71												
72		14	#2	17	72	354	5	3.01	0.41	2.6	86.38	
73			#4	23	74	334	5	2.97	0.49	2.48	83.50	
74			Sum	40	146	688	10	5.98	0.9	5.08	169.88	
75			Mean	20	73	344	5	2.99	0.45	2.54	84.94	
76												
77		18	#2	18	69	315	7	2.96	0.51	2.45	82.77	
78			#4	21	69	292	5	2.32	0.48	1.84	79.31	
79			Sum	39	138	607	12	5.28	0.99	4.29	162.08	
80			Mean	19.5	69	303.5	6	2.64	0.50	2.15	81.04	
81												
82		22	#2	22	88	283	5	2.56	0.47	2.09	81.64	
83			#4	25	84	330	5	4.16	0.84	3.32	79.81	
84			Sum	47	172	613	10	6.72	1.31	5.41	161.45	
85			Mean	23.5	86	306.5	5	3.36	0.66	2.71	80.72	
86												
87			Mean of me	22	73	318.3	5.4	3.022	0.539	2.483	82.17	
88			SD	2.881	7.874	22.380	0.374	0.234	0.097	0.215	2.899	
89			SE	1.288	3.521	10.009	0.167	0.105	0.043	0.096	1.297	
90												
91	20%	2	#2	20	75	326	5	2.97	0.44	2.53	85.19	
92			#4	24	87	332	7	4.14	0.58	3.56	85.99	
93			Sum	44	162	658	12	7.11	1.02	6.09	171.18	
94			Mean	22	81	329	6	3.56	0.51	3.05	85.59	
95												
96		8	#2	26	75	304	5	3.19	0.48	2.71	84.95	
97			#4	24	78	345	5	3.43	0.52	2.91	84.84	
98			Sum	50	153	649	10	6.62	1	5.62	169.79	
99			Mean	25	76.5	324.5	5	3.31	0.5	2.81	84.90	
100												
101		9	#2	23	67	282	4	2.49	0.41	2.08	83.53	
102			#4	25	76	329	6	3.3	0.58	2.72	82.42	
103			Sum	48	143	611	10	5.79	0.99	4.8	165.96	
104			Mean	24	71.5	305.5	5	2.90	0.50	2.4	82.98	
105												
106		20	#2	22	58	284	6	2.43	0.43	2	82.30	
107			#4	27	57	284	6	2.83	0.55	2.28	80.57	
108			Sum	49	115	568	12	5.26	0.98	4.28	162.87	
109			Mean	24.5	57.5	284	6	2.63	0.49	2.14	81.43	
110												
111		25	#2	21	53	282	4	1.97	0.35	1.62	82.23	
112			#4	25	45	230	5	1.87	0.33	1.54	82.35	
113			Sum	46	98	512	9	3.84	0.68	3.16	164.59	
114			Mean	23	49	256	4.5	1.92	0.34	1.58	82.29	
115												
116			Mean of me	23.7	67.1	299.8	5.30	2.862	0.467	2.395	83.44	
117			SD	1.077	12.006	27.068	0.600	0.570	0.064	0.515	1.567	
118			SE	0.482	5.369	12.105	0.268	0.255	0.0286	0.230	0.701	
119												

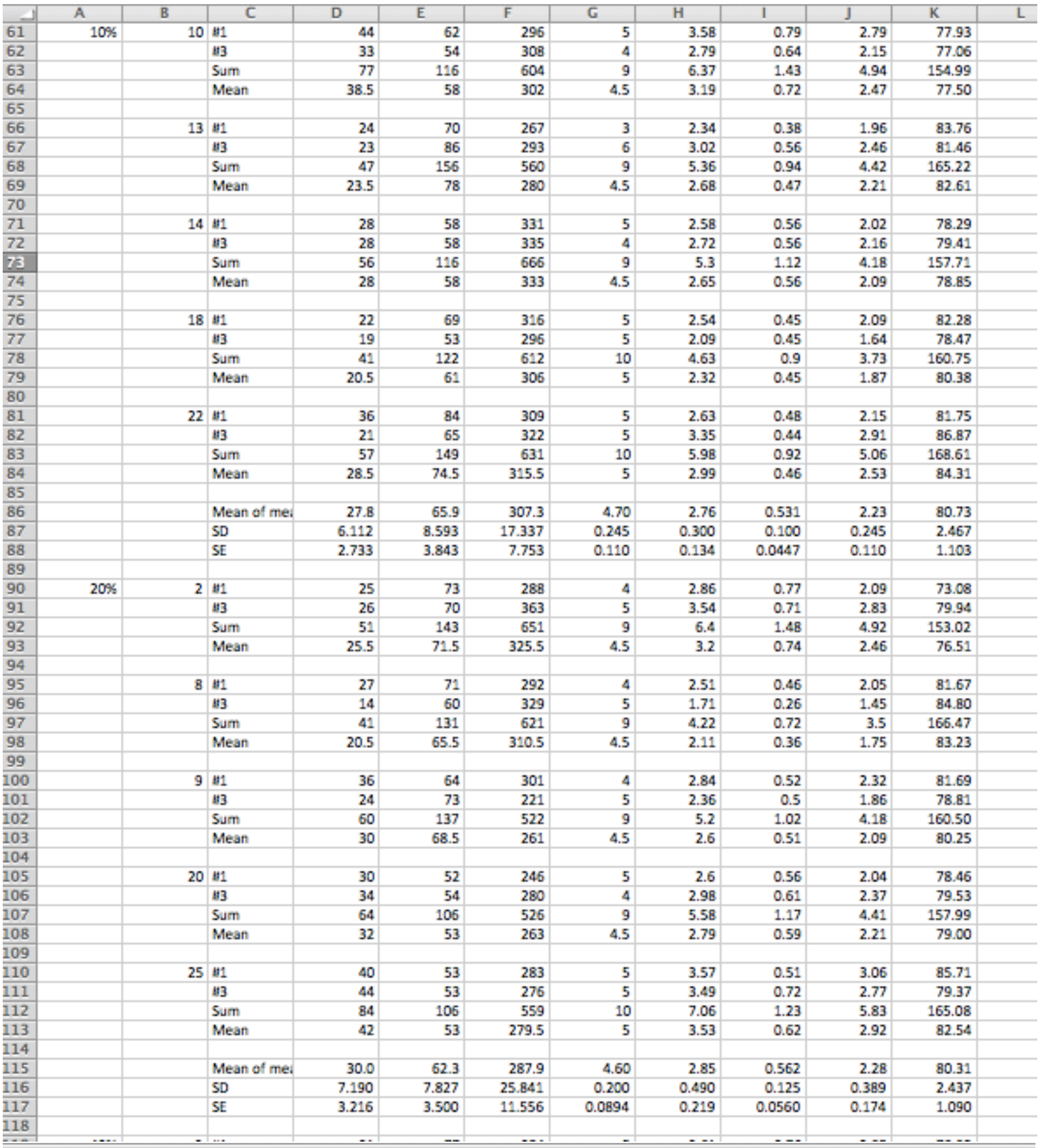


	A	B	C	D	E	F	G	H	I	J	K	L
119												
120	40%	3	#2	22	64	336	5	2.55	0.43	2.12	83.14	
121			#4	13	56	288	4	1.4	0.26	1.14	81.43	
122			Sum	35	120	624	9	3.95	0.69	3.26	164.57	
123			Mean	17.5	60	312	4.5	1.98	0.35	1.63	82.28	
124												
125		5	#2	24	42	258	4	1.7	0.33	1.37	80.59	
126			#4	21	43	248	4	1.85	0.34	1.51	81.62	
127			Sum	45	85	506	8	3.55	0.67	2.88	162.21	
128			Mean	22.5	42.5	253	4	1.78	0.34	1.44	81.10	
129												
130		11	#2	27	66	318	5	3.54	0.63	2.91	82.20	
131			#4	24	67	329	4	2.85	0.52	2.33	81.75	
132			Sum	51	133	647	9	6.39	1.15	5.24	163.96	
133			Mean	25.5	66.5	323.5	4.5	3.20	0.58	2.62	81.98	
134												
135		19	#2	26	72	289	5	3.01	0.51	2.5	83.06	
136			#4	26	69	311	5	3.2	0.63	2.57	80.31	
137			Sum	52	141	600	10	6.21	1.14	5.07	81.64	
138			Mean	26	70.5	300	5	3.11	0.57	2.54	81.64	
139												
140		24	#2	21	68	333	5	2.71	0.44	2.27	83.76	
141			#4	30	72	328	5	4.44	0.8	3.64	81.98	
142			Sum	51	140	661	10	7.15	1.24	5.91	165.75	
143			Mean	25.5	70	330.5	5	3.58	0.62	2.96	82.87	
144												
145												
146			Mean of me	23.4	61.9	303.8	4.60	2.725	0.489	2.236	81.98	
147			SD	3.200	10.399	27.435	0.374	0.715	0.123	0.592	0.595	
148			SE	1.431	4.651	12.269	0.167	0.320	0.0550	0.265	0.266	
149												

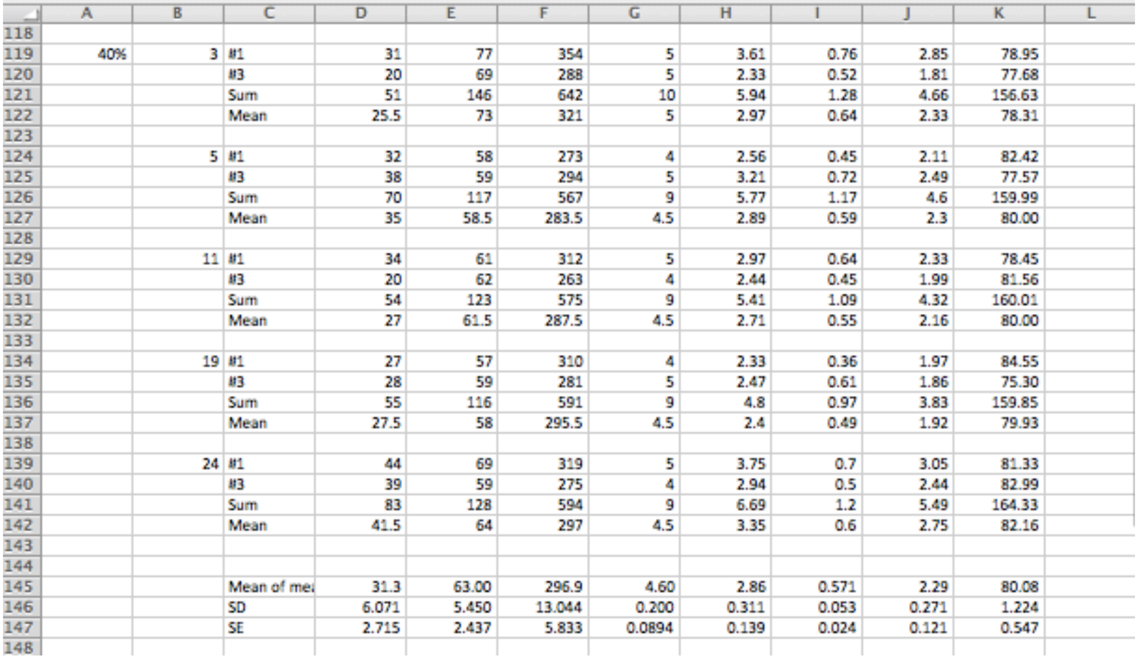
A4.5.2 Experiment 5 full term destructive harvest



	A	B	C	D	E	F	G	H	I	J	K	L
1	Date:	10.01.17										
2		Pot no.	Repeat	Leaf no.	Height/mm	Length/mm	width/mm	Wet weight/	Dry weight/g	Difference	% difference	
3	0% Kaolin	1	#1	31	63	343	5	3.73	0.51	3.22	86.33	
4			#3	35	79	344	5	3.75	0.65	3.1	82.67	
5			Sum	66	142	687	10	7.48	1.16	6.32	168.99	
6			Mean	33	71	343.5	5	3.74	0.58	3.16	84.50	
7												
8		6	#1	30	62	315	4	3.13	0.6	2.53	80.83	
9			#3	23	63	270	5	2.25	0.4	1.85	82.22	
10			Sum	53	125	585	9	5.38	1	4.38	163.05	
11			Mean	26.5	62.5	292.5	4.5	2.69	0.5	2.19	81.53	
12												
13		15	#1	31	41	269	5	2.61	0.46	2.15	82.38	
14			#3	38	59	343	4	2.83	0.49	2.34	82.69	
15			Sum	69	100	612	9	5.44	0.95	4.49	165.06	
16			Mean	34.5	50	306	4.5	2.72	0.48	2.25	82.53	
17												
18		17	#1	30	87	314	5	3.38	0.61	2.77	81.95	
19			#3	30	66	314	4	2.54	0.2	2.34	92.13	
20			Sum	60	153	628	9	5.92	0.81	5.11	174.08	
21			Mean	30	76.5	314	4.5	2.96	0.41	2.56	87.04	
22												
23		23	#1	39	70	288	5	3.25	0.59	2.66	81.85	
24			#3	33	65	320	5	3.29	0.58	2.71	82.37	
25			Sum	72	135	608	10	6.54	1.17	5.37	164.22	
26			Mean	36	67.5	304	5	3.27	0.59	2.69	82.11	
27												
28			Mean of me	32.0	65.5	312	4.70	3.08	0.509	2.57	83.54	
29			SD	3.391	8.994	17.184	0.245	0.392	0.068	0.350	2.014	
30			SE	1.517	4.022	7.685	0.110	0.175	0.0302	0.156	0.901	
31												
32	5%	4	#1	44	69	310	4	3.75	0.89	2.86	76.27	
33			#3	30	64	268	4	2.42	0.47	1.95	80.58	
34			Sum	74	133	578	8	6.17	1.36	4.81	156.85	
35			Mean	37	66.5	289	4	3.09	0.68	2.41	78.42	
36												
37		7	#1	26	61	284	5	2.74	0.46	2.28	83.21	
38			#3	26	88	344	5	3	0.52	2.48	82.67	
39			Sum	52	149	628	10	5.74	0.98	4.76	165.88	
40			Mean	26	74.5	314	5	2.87	0.49	2.38	82.94	
41												
42		12	#1	26	69	312	4	2.35	0.38	1.97	83.83	
43			#3	12	61	204	4	1.54	0.19	1.35	87.66	
44			Sum	38	130	516	8	3.89	0.57	3.32	171.49	
45			Mean	19	65	258	4	1.95	0.29	1.66	85.75	
46												
47		16	#1	46	61	296	4	3.67	0.69	2.98	81.20	
48			#3	23	49	302	4	2.01	0.38	1.63	81.09	
49			Sum	69	110	598	8	5.68	1.07	4.61	162.29	
50			Mean	34.5	55	299	4	2.84	0.54	2.31	81.15	
51												
52		21	#1	20	63	265	5	1.95	0.29	1.66	85.13	
53			#3	31	67	312	5	3.23	0.64	2.59	80.19	
54			Sum	51	130	577	10	5.18	0.93	4.25	165.31	
55			Mean	25.5	65	288.5	5	2.59	0.47	2.13	82.66	
56												
57			Mean of me	28.4	65.2	289.7	4.40	2.67	0.491	2.18	82.18	
58			SD	6.538	6.202	18.351	0.490	0.393	0.127	0.276	2.396	
59			SE	2.924	2.773	8.207	0.219	0.176	0.0568	0.123	1.072	

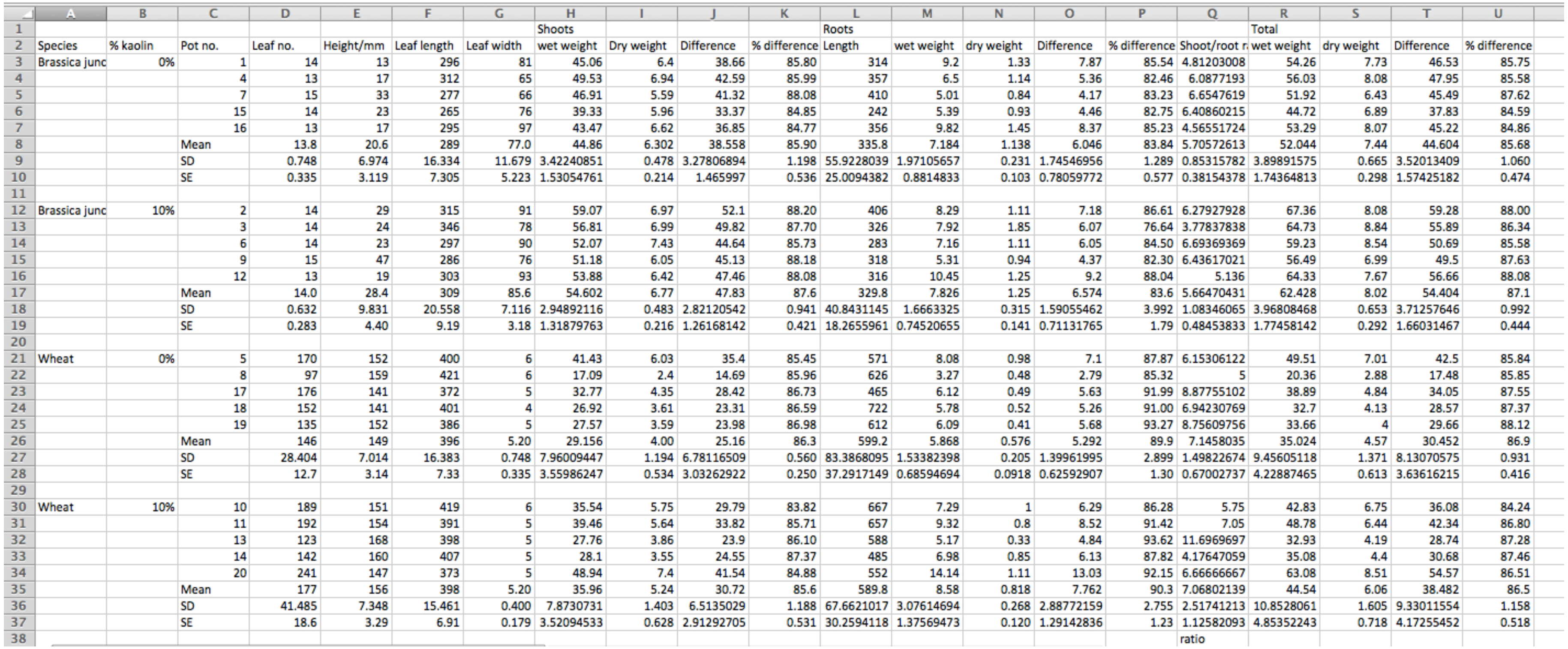


	A	B	C	D	E	F	G	H	I	J	K	L
61	10%	10	#1	44	62	296	5	3.58	0.79	2.79	77.93	
62			#3	33	54	308	4	2.79	0.64	2.15	77.06	
63			Sum	77	116	604	9	6.37	1.43	4.94	154.99	
64			Mean	38.5	58	302	4.5	3.19	0.72	2.47	77.50	
65												
66		13	#1	24	70	267	3	2.34	0.38	1.96	83.76	
67			#3	23	86	293	6	3.02	0.56	2.46	81.46	
68			Sum	47	156	560	9	5.36	0.94	4.42	165.22	
69			Mean	23.5	78	280	4.5	2.68	0.47	2.21	82.61	
70												
71		14	#1	28	58	331	5	2.58	0.56	2.02	78.29	
72			#3	28	58	335	4	2.72	0.56	2.16	79.41	
73			Sum	56	116	666	9	5.3	1.12	4.18	157.71	
74			Mean	28	58	333	4.5	2.65	0.56	2.09	78.85	
75												
76		18	#1	22	69	316	5	2.54	0.45	2.09	82.28	
77			#3	19	53	296	5	2.09	0.45	1.64	78.47	
78			Sum	41	122	612	10	4.63	0.9	3.73	160.75	
79			Mean	20.5	61	306	5	2.32	0.45	1.87	80.38	
80												
81		22	#1	36	84	309	5	2.63	0.48	2.15	81.75	
82			#3	21	65	322	5	3.35	0.44	2.91	86.87	
83			Sum	57	149	631	10	5.98	0.92	5.06	168.61	
84			Mean	28.5	74.5	315.5	5	2.99	0.46	2.53	84.31	
85												
86			Mean of me	27.8	65.9	307.3	4.70	2.76	0.531	2.23	80.73	
87			SD	6.112	8.593	17.337	0.245	0.300	0.100	0.245	2.467	
88			SE	2.733	3.843	7.753	0.110	0.134	0.0447	0.110	1.103	
89												
90	20%	2	#1	25	73	288	4	2.86	0.77	2.09	73.08	
91			#3	26	70	363	5	3.54	0.71	2.83	79.94	
92			Sum	51	143	651	9	6.4	1.48	4.92	153.02	
93			Mean	25.5	71.5	325.5	4.5	3.2	0.74	2.46	76.51	
94												
95		8	#1	27	71	292	4	2.51	0.46	2.05	81.67	
96			#3	14	60	329	5	1.71	0.26	1.45	84.80	
97			Sum	41	131	621	9	4.22	0.72	3.5	166.47	
98			Mean	20.5	65.5	310.5	4.5	2.11	0.36	1.75	83.23	
99												
100		9	#1	36	64	301	4	2.84	0.52	2.32	81.69	
101			#3	24	73	221	5	2.36	0.5	1.86	78.81	
102			Sum	60	137	522	9	5.2	1.02	4.18	160.50	
103			Mean	30	68.5	261	4.5	2.6	0.51	2.09	80.25	
104												
105		20	#1	30	52	246	5	2.6	0.56	2.04	78.46	
106			#3	34	54	280	4	2.98	0.61	2.37	79.53	
107			Sum	64	106	526	9	5.58	1.17	4.41	157.99	
108			Mean	32	53	263	4.5	2.79	0.59	2.21	79.00	
109												
110		25	#1	40	53	283	5	3.57	0.51	3.06	85.71	
111			#3	44	53	276	5	3.49	0.72	2.77	79.37	
112			Sum	84	106	559	10	7.06	1.23	5.83	165.08	
113			Mean	42	53	279.5	5	3.53	0.62	2.92	82.54	
114												
115			Mean of me	30.0	62.3	287.9	4.60	2.85	0.562	2.28	80.31	
116			SD	7.190	7.827	25.841	0.200	0.490	0.125	0.389	2.437	
117			SE	3.216	3.500	11.556	0.0894	0.219	0.0560	0.174	1.090	
118												



	A	B	C	D	E	F	G	H	I	J	K	L
118												
119	40%	3	#1	31	77	354	5	3.61	0.76	2.85	78.95	
120			#3	20	69	288	5	2.33	0.52	1.81	77.68	
121			Sum	51	146	642	10	5.94	1.28	4.66	156.63	
122			Mean	25.5	73	321	5	2.97	0.64	2.33	78.31	
123												
124		5	#1	32	58	273	4	2.56	0.45	2.11	82.42	
125			#3	38	59	294	5	3.21	0.72	2.49	77.57	
126			Sum	70	117	567	9	5.77	1.17	4.6	159.99	
127			Mean	35	58.5	283.5	4.5	2.89	0.59	2.3	80.00	
128												
129		11	#1	34	61	312	5	2.97	0.64	2.33	78.45	
130			#3	20	62	263	4	2.44	0.45	1.99	81.56	
131			Sum	54	123	575	9	5.41	1.09	4.32	160.01	
132			Mean	27	61.5	287.5	4.5	2.71	0.55	2.16	80.00	
133												
134		19	#1	27	57	310	4	2.33	0.36	1.97	84.55	
135			#3	28	59	281	5	2.47	0.61	1.86	75.30	
136			Sum	55	116	591	9	4.8	0.97	3.83	159.85	
137			Mean	27.5	58	295.5	4.5	2.4	0.49	1.92	79.93	
138												
139		24	#1	44	69	319	5	3.75	0.7	3.05	81.33	
140			#3	39	59	275	4	2.94	0.5	2.44	82.99	
141			Sum	83	128	594	9	6.69	1.2	5.49	164.33	
142			Mean	41.5	64	297	4.5	3.35	0.6	2.75	82.16	
143												
144												
145			Mean of me	31.3	63.00	296.9	4.60	2.86	0.571	2.29	80.08	
146			SD	6.071	5.450	13.044	0.200	0.311	0.053	0.271	1.224	
147			SE	2.715	2.437	5.833	0.0894	0.139	0.024	0.121	0.547	
148												

A4.6 Experiment 6 Destructive harvest



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1								Shoots				Roots						Total			
2	Species	% kaolin	Pot no.	Leaf no.	Height/mm	Leaf length	Leaf width	wet weight	Dry weight	Difference	% difference	Length	wet weight	dry weight	Difference	% difference	Shoot/root r	wet weight	dry weight	Difference	% difference
3	Brassica junc	0%	1	14	13	296	81	45.06	6.4	38.66	85.80	314	9.2	1.33	7.87	85.54	4.81203008	54.26	7.73	46.53	85.75
4			4	13	17	312	65	49.53	6.94	42.59	85.99	357	6.5	1.14	5.36	82.46	6.0877193	56.03	8.08	47.95	85.58
5			7	15	33	277	66	46.91	5.59	41.32	88.08	410	5.01	0.84	4.17	83.23	6.6547619	51.92	6.43	45.49	87.62
6			15	14	23	265	76	39.33	5.96	33.37	84.85	242	5.39	0.93	4.46	82.75	6.40860215	44.72	6.89	37.83	84.59
7			16	13	17	295	97	43.47	6.62	36.85	84.77	356	9.82	1.45	8.37	85.23	4.56551724	53.29	8.07	45.22	84.86
8			Mean	13.8	20.6	289	77.0	44.86	6.302	38.558	85.90	335.8	7.184	1.138	6.046	83.84	5.70572613	52.044	7.44	44.604	85.68
9			SD	0.748	6.974	16.334	11.679	3.42240851	0.478	3.27806894	1.198	55.9228039	1.97105657	0.231	1.74546956	1.289	0.85315782	3.89891575	0.665	3.52013409	1.060
10			SE	0.335	3.119	7.305	5.223	1.53054761	0.214	1.465997	0.536	25.0094382	0.8814833	0.103	0.78059772	0.577	0.38154378	1.74364813	0.298	1.57425182	0.474
11																					
12	Brassica junc	10%	2	14	29	315	91	59.07	6.97	52.1	88.20	406	8.29	1.11	7.18	86.61	6.27927928	67.36	8.08	59.28	88.00
13			3	14	24	346	78	56.81	6.99	49.82	87.70	326	7.92	1.85	6.07	76.64	3.77837838	64.73	8.84	55.89	86.34
14			6	14	23	297	90	52.07	7.43	44.64	85.73	283	7.16	1.11	6.05	84.50	6.69369369	59.23	8.54	50.69	85.58
15			9	15	47	286	76	51.18	6.05	45.13	88.18	318	5.31	0.94	4.37	82.30	6.43617021	56.49	6.99	49.5	87.63
16			12	13	19	303	93	53.88	6.42	47.46	88.08	316	10.45	1.25	9.2	88.04	5.136	64.33	7.67	56.66	88.08
17			Mean	14.0	28.4	309	85.6	54.602	6.77	47.83	87.6	329.8	7.826	1.25	6.574	83.6	5.66470431	62.428	8.02	54.404	87.1
18			SD	0.632	9.831	20.558	7.116	2.94892116	0.483	2.82120542	0.941	40.8431145	1.6663325	0.315	1.59055462	3.992	1.08346065	3.96808468	0.653	3.71257646	0.992
19			SE	0.283	4.40	9.19	3.18	1.31879763	0.216	1.26168142	0.421	18.2655961	0.74520655	0.141	0.71131765	1.79	0.48453833	1.77458142	0.292	1.66031467	0.444
20																					
21	Wheat	0%	5	170	152	400	6	41.43	6.03	35.4	85.45	571	8.08	0.98	7.1	87.87	6.15306122	49.51	7.01	42.5	85.84
22			8	97	159	421	6	17.09	2.4	14.69	85.96	626	3.27	0.48	2.79	85.32	5	20.36	2.88	17.48	85.85
23			17	176	141	372	5	32.77	4.35	28.42	86.73	465	6.12	0.49	5.63	91.99	8.87755102	38.89	4.84	34.05	87.55
24			18	152	141	401	4	26.92	3.61	23.31	86.59	722	5.78	0.52	5.26	91.00	6.94230769	32.7	4.13	28.57	87.37
25			19	135	152	386	5	27.57	3.59	23.98	86.98	612	6.09	0.41	5.68	93.27	8.75609756	33.66	4	29.66	88.12
26			Mean	146	149	396	5.20	29.156	4.00	25.16	86.3	599.2	5.868	0.576	5.292	89.9	7.1458035	35.024	4.57	30.452	86.9
27			SD	28.404	7.014	16.383	0.748	7.96009447	1.194	6.78116509	0.560	83.3868095	1.53382398	0.205	1.39961995	2.899	1.49822674	9.45605118	1.371	8.13070575	0.931
28			SE	12.7	3.14	7.33	0.335	3.55986247	0.534	3.03262922	0.250	37.2917149	0.68594694	0.0918	0.62592907	1.30	0.67002737	4.22887465	0.613	3.63616215	0.416
29																					
30	Wheat	10%	10	189	151	419	6	35.54	5.75	29.79	83.82	667	7.29	1	6.29	86.28	5.75	42.83	6.75	36.08	84.24
31			11	192	154	391	5	39.46	5.64	33.82	85.71	657	9.32	0.8	8.52	91.42	7.05	48.78	6.44	42.34	86.80
32			13	123	168	398	5	27.76	3.86	23.9	86.10	588	5.17	0.33	4.84	93.62	11.6969697	32.93	4.19	28.74	87.28
33			14	142	160	407	5	28.1	3.55	24.55	87.37	485	6.98	0.85	6.13	87.82	4.17647059	35.08	4.4	30.68	87.46
34			20	241	147	373	5	48.94	7.4	41.54	84.88	552	14.14	1.11	13.03	92.15	6.66666667	63.08	8.51	54.57	86.51
35			Mean	177	156	398	5.20	35.96	5.24	30.72	85.6	589.8	8.58	0.818	7.762	90.3	7.06802139	44.54	6.06	38.482	86.5
36			SD	41.485	7.348	15.461	0.400	7.8730731	1.403	6.5135029	1.188	67.6621017	3.07614694	0.268	2.88772159	2.755	2.51741213	10.8528061	1.605	9.33011554	1.158
37			SE	18.6	3.29	6.91	0.179	3.52094533	0.628	2.91292705	0.531	30.2594118	1.37569473	0.120	1.29142836	1.23	1.12582093	4.85352243	0.718	4.17255452	0.518
38																	ratio				

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[References with a star refer to Appendix 1 as well as or instead of the main text]

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