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Suitability of *Calamagrostis* x *acutiflora* 'Karl Foerster' and *Filipendula ulmaria* for use in raingardens in Nordic climates

Egnethet for *Calamagrostis* x *acutiflora* 'Karl Foerster' og *Filipendula ulmaria* for bruk i regnbed i nordiske klimaer

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Landscape architecture

Abstract

Global warming and climate change are giving the Nordic countries drier summers with heavier rains over shorter time periods. This has consequences for urban areas that are vulnerable for flooding. Raingardens are a part of many cities' stormwater management strategies to prevent flooding. A raingarden is a sunken area covered in vegetation that will delay, infiltrate and clean stormwater run-off from nearby areas. Vegetation is an essential part of a well-functioning raingarden as it uses water, helps with infiltration and prevents clogging as well as it contributes to biodiversity and can be aesthetically pleasing for people. There has been little research on to what species are best suited for use in raingardens in Nordic climates, and where in the raingarden they should be placed. Raingardens typically have three zones of different moisture levels: bottom, slope and margins. Plants suitable for use in raingardens should tolerate both periods of drought and flooding, and in Nordic climates also low winter temperatures and salt from the de-icing of the roads.

This thesis examines the suitability of two species, one native and one cultivar, *Filipendula ulmaria* and *Calamagrostis* x *acutiflora* 'Karl Foerster'. For each species 420 plants were separated into four watertreatments consisting of 'drought' (3 days flooding , 11 days no water), 'flooding' (3 days of flooding, 4 days of no water), 'cycles' (1 day of flooding, 6 days of no water) and 'control' (watering normally twice a week) that lasted for 8 weeks under an open greenhouse in Norway. All plants survived the treatments and results show that both species are suitable candidates for raingardens in Nordic climates, though *C.* x *acutiflora* 'Karl Foerster' should not be used in places where temperatures reach below -15 °C. *Filipendula ulmaria* was more tolerant to flooding than *C.* x *acutiflora* 'Karl Foerster', and *C.* x *acutiflora* 'Karl Foerster' more tolerant to drought than *F. ulmaria*. Both species are suitable for use in slope and bottom while *C.* x *acutiflora* 'Karl Foerster' is also suitable for use in margins of raingardens.

Sammendrag

Global oppvarming og klimaendringer vil gi nordiske land tørrere somre med flere ekstreme nedbørseventer. Dette får konsekvenser for urbane områder som er sårbare for oversvømmelser. Regnbed er en del av mange byers overvannshåndteringstiltak for å unngå oversvømmelser. Regnbed er en vegetasjonsdekket forsenkning i terrenget som infiltrerer, fordrøyer, renser og forsinker overvannet fra omkringliggende områder. Vegetasjon er en essensiell del av et velfungerende regnbed da den forbruker vann, hjelper med infiltrasjon og forhindrer tetting av jorda, i tillegg til at det bidrar til biologisk mangfold og kan være estetisk vakkert for mennesker. Det har vært lite forskning på hvilke arter som er best egnet til bruk i regnbed i nordiske klimaer, og hvor i regnbedet de bør plasseres. Regnbed har vanligvis tre soner med forskjellige fuktighetsnivåer: bunn, skråning og kant. Planter som er egnet for bruk i regnbed bør tåle både perioder med tørke og oversvømmelse, og i nordiske klimaer også lave vintertemperaturer og salt fra vintervedlikehold av veiene.

Denne oppgaven undersøker egnetheten til to arter, en stedegen og en kultivar, *Filipendula ulmaria* og *Calamagrostis* x *acutiflora* ‘Karl Foerster’. Fra hver av artene ble 420 planter utsatt for fire ulike vannbehandlinger som består av 'tørke' (3 dager stående i vann, 11 dager uten vann), 'flom' (3 dager stående i vann, 4 dager uten vann), 'sykluser' (1 dag stående i vann, 6 dager uten vann) og 'kontroll' (vanning normalt to ganger i uken) i 8 uker under et åpent drivhus i Norge. Alle plantene overlevde behandlingene og resultatene viser at begge artene er egnede kandidater til regnbed i nordiske klimaer, selv om *C.* x *acutiflora* ' Karl Foerster ' ikke bør brukes på steder der temperaturen når under -15 ° C. *Filipendula ulmaria* var mer tolerant mot lengre perioder med oversvømmelse enn *C.* x *acutiflora* 'Karl Foerster ', og *C.* x *acutiflora* 'Karl Foerster' mer tolerant mot tørke enn *F. ulmaria.* Begge artene er egnet for bruk i skråning og bunn, mens *C.* x *acutiflora* 'Karl Foerster' også er egnet til bruk i kantsone i regnbed.

Table of contents

List of Figures

List of Tables

Appendix

Abbreviations

The following abbreviations are used in this thesis:

NBS	nature-based solution
RDW	root dry weight
SDW	shoot dry weight
TDB	total dry biomass

Foreword

This thesis marks the end of a 5-year degree in Landscape Architecture at the faculty of Landscape and Society at the Norwegian University of Life Sciences (NMBU). The topic was chosen because of a strong interest in nature-based solutions to urban problems, specifically urban flooding. This has come more and more in focus recently in Landscape Architecture, as well as ‘sustainable’ design.

It is only just now that more people have realized that restoring nature and natural functions also benefit humans and can create more resilient cities. The urgency for mitigating for climate change has prompted a political will for a “green-shift” and a preference of nature-based solutions over others. Where restoring to a “pre-disturbed” state is not possible, such as in highly urban areas, restoring natural functions to a degree is still possible and this is exactly what nature-based solutions show.

Nature-based solutions, hereafter NBS, have many benefits. Trees and vegetation can improve air quality which in turn allows savings in healthcare, as well as increase carbon sequestration and reducing temperatures (climate change mitigation). NBS can reduce cost and risk of damage of flooding by increasing permeability and infiltration. Examples of NBS can be everything from planting trees, to restoring meanders to a river, restoring a catchment area, recreating old habitat for an endangered species or recreating permeable surface where there was previously asphalt. Naturally the making of rain gardens falls under this category and it mimics the way nature stores and retains water for infiltration through sunken vegetated areas.

Raingardens have become more widely popular in the last 2 decades and are a part of many cities’ stormwater management strategies. A variety of vegetation types can be used in raingardens if they are tolerant to the specific climate and moisture dynamics on site: trees, shrubs, flowering perennials, ferns and grasses. This thesis examines two plant species, a grass *Calamagrostis* x *Acutiflora* ‘Karl Foerster’ and a flowering perennial *Filipendula ulmaria*, for use in raingardens in Nordic climates.

The thesis work was supported by several people. I want to thank my supervisor associate professor Line Rosef and Ph.D candidate Marina Bakhtina for allowing me to join their experiment set-up of a larger study of plants for raingardens in Nordic climate. There were many late nights of cleaning soil from roots and weighing dry material together. I also want to thank Dr. Evert-Jan Bakker, from Wageningen University and Research and Marina Bakhtina for help and advice on statistics. And a thanks to NMBU and SKP, for use of their facilities and equipment’s.

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1 Introduction

1.1 A wetter climate

The Earth’s climate is changing, and the concentration of greenhouse gasses in the atmosphere is higher than it has been for 25 million years. The CO_2 concentration is now 405 ppm (2018), caused mainly by the release of fossil carbon, land-use change and population growth (Allen et al., 2019). Higher concentrations of greenhouse gasses lead to increase in global temperatures, which have already risen approximately 1°C (± 0.2 °C) and is increasing 0.2°C per decade (Allen et al., 2019). For the Earth this has consequences for both the natural systems and the human systems both on land and at sea. Consequences include changes in precipitation cycles, sea-level rise, ocean acidification, increase in drought in arid regions and increased risk of flooding and natural disasters (IPCC, 2013). This creates challenges concerning food-security, drinking water availability, biodiversity and infrastructure security, which we humans depend on.

For Nordic climates (Denmark, Finland, Iceland, Norway and Sweden) predicted climate changes include more intense precipitation events, which we have already been seeing. In the western part of Norway, the risk of flood inducing precipitation events are expected to be more than doubled, and the total yearly precipitation amounts expected to increase by 18% (City of Oslo Agency for Climate, 2020). And on the eastern part, intense precipitation events are expected to increase, while the total yearly precipitation stays the same. Generally, the summer months are expected to become dryer with more intense precipitation events leading to floods (City of Oslo Agency for Climate, 2020; Iversen et al., 2005; Lindholm et al., 2008; SMHI, 2015).

In addition, urbanization has led to a decrease in permeable surfaces that allow for the natural infiltration of rainwater, leading to more surface run-off, higher peak floods and even more frequent flooding events. Most cities water- and drainage systems are not built to handle all the excess water that comes with these extreme precipitation events, leading to extensive damages on infrastructure and the surrounding environment as pipes overflow and discharge of untreated sewage water is released, which negatively impact the urban rivers and streams. The dangers of landslides and debris flows also increases with the increase in precipitation. Increased bank erosion and increase in river flow can also trigger quicksand collapses (City of Oslo Agency for Climate, 2020).

Examples of extreme rainfall events in Nordic countries and their material costs:

> **2011:** Copenhagen was hit by an extreme event in which 150 mm rain fell in 2 hours, which corresponds to the average rainfall of three summer months and damages costing 7 million Danish kroner (TT, 2011).
> **2014:** 100 mm rain fell on two hours in Malmö, with infrastructure damages of 600 million Swedish kroner (Elfstöm, 2015; SMHI, 2014).
> **2016:** 47.8 mm rain fell in 2 hour in Oslo, 80 mm in 19 hours, infrastructure damages costing around 150 million Norwegian kroner (YR).

1.2 Stormwater management

Urban flooding is nothing new but happening more frequently and the material costs are higher because of denser cities. Most cities have come up with new strategies to handle this Malmö, Stockholm, Copenhagen, Oslo, Trondheim and more all have had extensive plans on how to minimise and prevent urban floods (Lindholm et al., 2008; Stahre, 2008). These strategies go by the name of stormwater management and are a part of nature-based solutions. Nature-based solutions (NBS) is a relatively new term for designs/actions inspired by, supported by, or copied from nature (Cohen-Shacham et al., 2016). Examples of such natural processes can be infiltration, evaporation, transpiration, river migration, mangroves and coastal dunes.

Using NBS can produce ecological benefits, social benefits and well as technical benefits (Figure 1). Examples of the ecological benefits are increased biodiversity and cleaner water as infiltration is a way to purify water (Paus & Braskerud, 2013). Social benefits can be that greener and more diverse environments promote health and physical wellbeing by reducing stress (Bilotta & Evans, 2013; Kaplan, 1995). Technical functions can be carbon sequestration by trees, reduction in flooding as well as purifying water, river meanders slow and spread the peak flow, and coastal dunes can buffer against waves and rising sea-level. As we can see many of these functions overlap and fit into more than category of benetits (Figure 1).

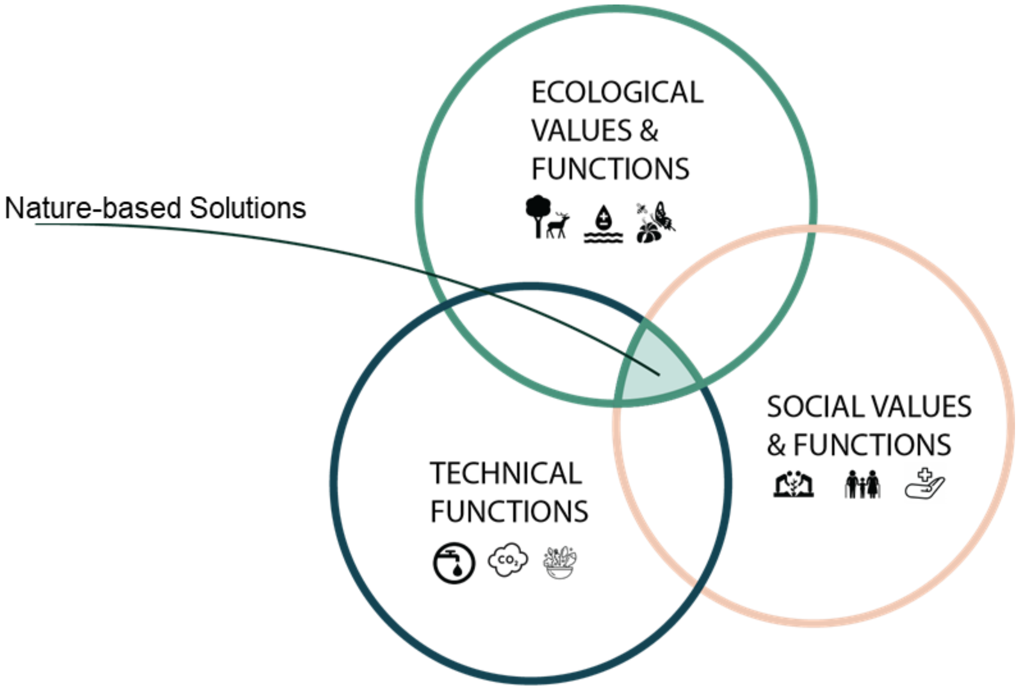


Figure 1 Nature based solutions, the intersection between social, technical and ecological functions. Inspired by Aanderaa and Bothner (2017).

Norway has adopted a three-stage strategy to stormwater management (Lindholm et al., 2008). It refers to three levels of solutions depending on the rainfall intensity and volume (Figure 2). The first stage applies to everyday events (> 20 mm rain), which should be infiltrated locally, the second stage (between 20 and 40 mm) refers to medium size events, and the goal is to detain the water delaying the flood peak and subsequent runoff response. The third stage is for extreme events (> 40 mm), where the aim should be to secure safe flood paths to a recipient with enough space to safely store the excess water.

Figure 2 Three-stages stormwater management strategy inspired by Lindholm et al., 2008.

Raingardens are examples of an intervention for stages one and two in the Norwegian three-stage stormwater management strategy. A they infiltrate, detain and delay rainwater and can store extra run-off, as well as perform important aesthetic, social and ecological functions for the surroundings.

1.3 Rain gardens

Rain gardens are constructed as planted sunken areas that rely on vegetation and soil to infiltrate excess runoff from hard surfaces such as buildings, pavements and roads. Rain gardens are sometimes also referred to as bioswales or bioretention areas. There are many benefits of rain gardens other than infiltration of water and flood protection, they also add aesthetic value, biodiversity and can promote public health. Raingardens also purify the water as well as it can help protect streams from erosion and replenish ground water level. Raingardens are recommended for smaller watersheds of maximum 0.8 ha, if additional water is not being supplied (Paus & Braskerud, 2013). Bigger watersheds can be split into multiple rain gardens. If the supply of water is more continuous other stormwater management practices are more suitable, such as ditches, bioswales and catchment ponds (Braskerud, 2002). The raingardens should be placed at a distance to buildings and infrastructure to avoid water damage on underground construction.

There are two main types of raingardens, one where existing soil is changed to a soil media of choice, and one where the existing media is kept, and the infiltration goes all the way to the groundwater level. A typical raingarden construction where the soil is changed (type 1) includes inlet, retention zone, vegetation, substrate, outflow and drainage layer or pipe (Fridell & Jergmo, 2015) (Figure 3).

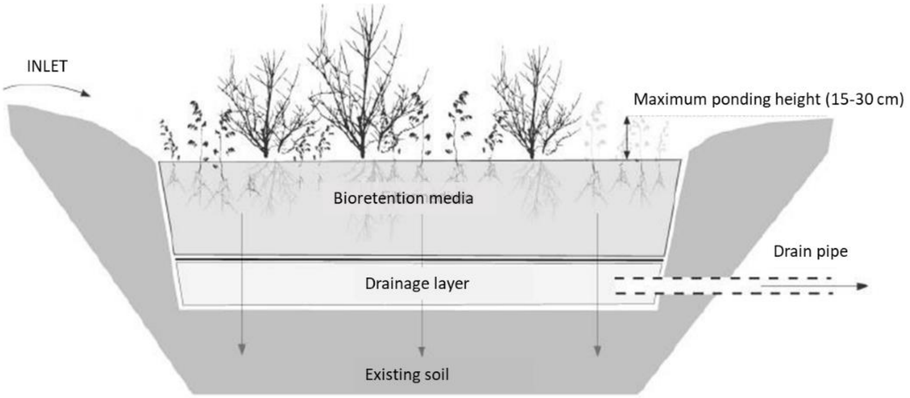


Figure 3 Raingarden construction type 1, where existing soil is changed to bioretention media of choice and drainage layer under (Paus & Braskerud, 2013).

A typical construction of raingarden where the existing soil is kept is much simpler. Here the slope of the raingarden, vegetation, height of the side-slopes and existing soil are the only elements (Figure 4).

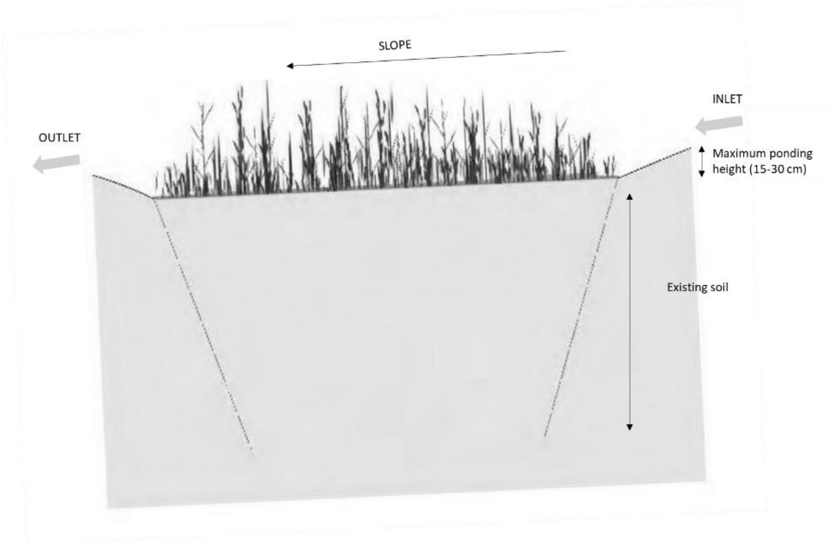


Figure 4 Raingarden construction type 2, where the existing soil is kept and there is no extra drainage (Paus & Braskerud, 2013).

The size of a raingarden is determined by the precipitation amount and should be 5-10% of the watershed area (Minnesota Pollution Control Agency, 2018). As a guide this formula from Paus and Braskerud (2013) can be used.

$$A_{raingarden} = A_{\mathrm{watershead}} * \mathrm{c} * \frac{\mathrm{P}}{\mathrm{h_{max}} + \mathrm{K_h} * \mathrm{h_r}}$$

$A_{raingarden}$ is area in m^2, $A_{watershead}$ is area of watershead in m^2, c is average runoff coefficient of the watershead, P is precipitation amount in the design, h_{maks} is the maximum ponding height, k_h is the saturated hydraulic conductivity of the filtering media (m/h) and h_r is the duration of runoff to the raingarden (h).

1.3.1 Soil for raingardens

Soil for raingardens are very important and depend on the site, amount of rain and what kind of plants are being used. The hydraulic conductivity of the soil should be between 100-300 mm/h, where the higher level is good for fast drainage and lower end is better for a more constant moisture level for the plants. Lower hydraulic conductivity increases the chance of clogging and compaction (Payne et al., 2015). The infiltration speed should be around 50-300 mm/h.

There should not be any leeching of nutrients as one of the main functions is to filtrate and clean run-off. As it needs to have a high hydraulic conductivity, there should not be too much clay or organic matter. Organic content of between 1.5 and 3%, and clay content of less than 5 % is recommended (Commonwealth of Massachusetts, 2008). Furthermore it should suit the plants growing requirements for nutrition and pH (Fridell & Jergmo, 2015; Payne et al., 2015). Recent research has suggested adding biochar to the soil mixture can help with drainage as well as plant growth and prevent leeching of nitrogen from the compost in the soil (Lehmann & Joseph, 2015). However, a study testing this concluded that a mixture of organic and sand was the best soil mixture as preventing leeching and there was no significant difference in adding biochar on the leeching (Iqbal, Garcia-Perez, & Flury, 2015).

European Biochar Certificate (ECB) defines biochar as a heterogeneous product rich in aromatic charcoal and minerals (EBC, 2012). Supplying biochar to the soil can, among other things, bind water, air and nutrients, and the biocarbon in the substrate becomes a carbon sink (Stockholm Stad, 2019; Lehmann & Joseph, 2009). In

Sweden it has become common practice to include biochar in soils for raingardens and along roads (Stockholm Stad, 2019). Biochar has a positive influence on structure and reduces the risk of soil compaction or clogging, and can absorb pollutants (Fridell & Jergmo, 2015).

1.3.2 Rain garden moisture dynamics

Rain gardens rely on natural rainfall as their source of water, and they are normally constructed to drain within a period from 24-72 hours (Dunnett & Clayden, 2007; Uncapher & Woelfle-Erskine, 2012). Therefore, rain gardens undergo cyclical moisture changes, from periodically water inundation to periods of drought. Each rain garden will vary due to construction, soil, climate and geographic location. A rain garden typically contains three moisture zones, the bottom frequently flooded base zone, and occasionally flooded side-slope, and dryer upland buffer (Yuan & Dunnett, 2018)(Figure 5). Different plant species can be planted to suit the different moisture zones.

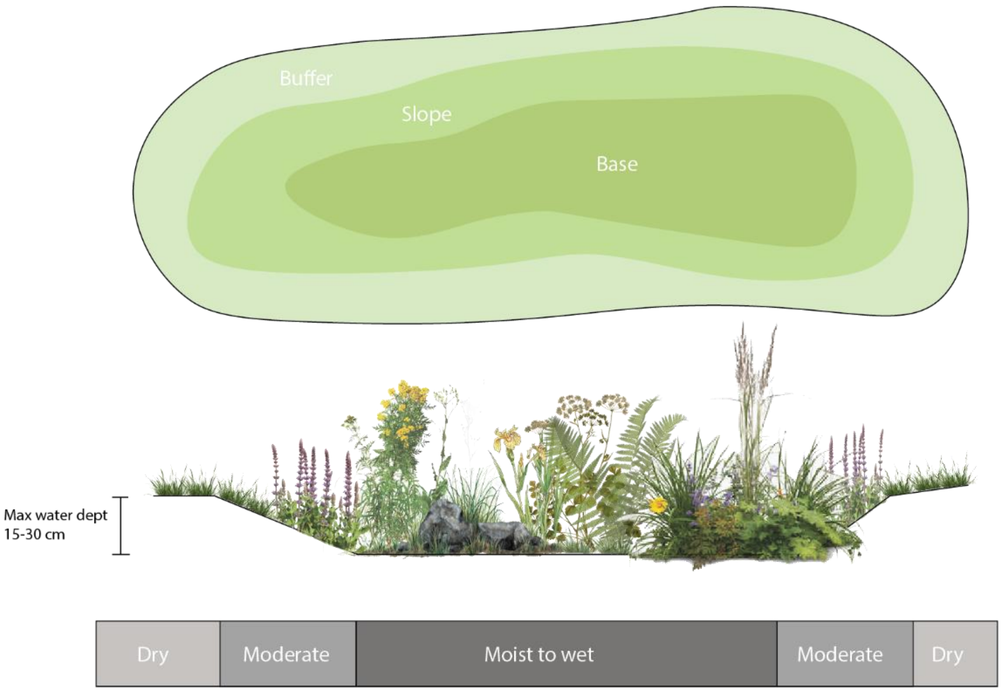


Figure 5 Illustration of raingarden moisture dynamic, based on Dunnett & Yuan (2018).

1.3.3 Rain gardens in cold climates

In cold climates with frost more factors need to be considered when creating a rain garden. Research has shown that coarser soil medium is required to prevent concrete frost from forming (Kratky et al., 2017; Paus & Braskerud, 2013). The coarser soil medium can make sure there is sufficient permeability to drain the system before the frost arrives, this should ensure that peak flow and volume reduction can be maintained. In addition, winter road maintenance salts have been shown to negatively impact the removal of some contaminant in the polluted water while positively impact others. Salts and pollution also can impact plant health, frost tolerance and survival (Amundsen et al., 2008; Paus, 2016; Sæbø et al., 2003). Salt mostly affects aggregated soil types, such as silt or clay, and can decrease porosity and oxygen access. High salt concentrations can lead to dehydration in the roots and soil (Sjöman & Johan, 2016).

1.3.4 Plant selection for rain gardens

The periodic cycles between flooding and drought makes it difficult to find suitable plants for a rain garden. Perennials differ in their tolerance to flooding and drought and identifying a type of suitable plants for rain gardens can be hard. If a plant is not suited it can result in wilting and lead to unpleasing visual effects. The death of a plant can also result in lower contribution to stormwater infiltration as the roots of plants improves soil permeability and porosity. It is therefore important to make planting suggestions based on plant suitability to raingarden moisture dynamics and climate of the site. However, few studies have been conducted in plant response to cyclical flooding and drought, and of those, even fewer potential rain garden plants have been studied with regards to cold climates and frost tolerance.

As per today, most plants for rain gardens in urban areas are chosen based on the sole fact that they have been proven to survive already in an existing rain garden, and by aesthetic appearance. It is popular to mix flowering perennials with ornamental grasses (Yuan & Dunnett, 2018). The combination provides variation in form, flower colours, blooming periods and foliage textures. It is important to consider that if the intention of creating the rain garden is also to promote biodiversity, native species should always be prioritized. Native insect species are often only able to feed on plants that they have co-evolved with, meaning native plants (Tallamy & Darke, 2009). Native species may also be better suited for the climate in the area. Typical native plants that could be suited for use in raingardens are found in naturally moist environments such as along rivers and streams, lakes, swamps and marshes (Dunnett & Clayden, 2007).

Selecting species adapted to Nordic climate with frost is important, because the rain garden should work throughout the year, and the plants should survive until next year. Some few studies have been done to see which plants can survive in raingardens with formation of ice (Meyer et al., 1998; Paus & Braskerud, 2013).

1.4 Plant selection for experiment

In this study *Filipendula ulmaria* and *Calamagrostis* x *acutiflora* 'Karl Foerster' were chosen as species to test out. *Filipendula ulmaria* is a native flowering plant to Norway and *C.* x *acutiflora* 'Karl Foerster' is a hybrid ornamental grass, a cross between *C. arundinacea* and *C. epigejos* who are both native to Norway. The hybrid also occurs naturally some places in Europe. These species were chosen because of a desire to test both a native flowering plant and an ornamental grass. As it wasn't possible to get seed or plants of a native grass in time for the experiment, the hybrid cultivar was chosen as its characteristics will be similar to those of the native Norwegian *Calamagrostis* species. The cultivar was ordered from the Norwegian nursery 'Ljono Stauder'. The *F. ulmaria* plants used in the experiment were raised by seeds collected from a local source near NMBU, the lake Årungen.

1.4.1 *Calamagrostis* x *acutiflora* 'Karl Foerster'

Figure 6 Calamagrostis x acutiflora 'Karl Foerster'. From www.gaissmayer.de/

Calamagrostis, commonly known as reed grass, is a genus consisting of about 250 species of cool season grasses which are primarily native to moist to wet areas in temperate regions of the northern hemisphere. *Calamagrostis* x *acutifolia* is a hybrid between two species native to Europe and Asia, namely *C*. *arundinacea* and *C*. *epigejos* and it is pollen sterile (Lid & Lid, 2005).
Calamagrostis x *acutiflora* 'Karl Foerster' is one of the most popular of the hybrid feather reed grasses sold in commerce today. In 2001 the cultivar won the Perennial Plant of the Year Award. Its cultivar name honours Karl Foerster, a German nurseryman, who discovered this plant in the Hamburg Botanical Garden in the 1930s and later included it in his 1957 garden book: "The Use of Grasses and Ferns in the Garden" (MacCaskey, 2001). It is attractive because of upright growth and ornamental flowering plumes. It usually grows up to 150 cm tall (Missouri Botanical Garden).

Calamagrostis x *acutiflora* 'Karl Foerster' has been found to be tolerant to drought, shade and frost (Meyer et al., 1998; Pudelska, 2012). In an experiment of hardiness of 160 ornamental grasses in Canada, conducted over 3 years, they found the cultivar *C*. x *acutiflora* ‘Karl Foerster’ to be hardy down to us zone 3, equivalent to - 40°C to - 34.5 °C (Davidson & Gobin, 1998).

1.4.2 Filipendula ulmaria

Figure 7 Filipendula ulmaria, Meadowsweet. Pictures from www.nibio.no.

Filipendula ulmaria commonly known as meadowsweet is a perennial herb in the family Rosaceae, native to Norway and other European countries and Western Asia. It is a relatively tall herb, up to 150 cm that flowers from June to August with cream white flowers with a strong sweet odour (Lid & Lid, 2005). The flowers are visited by various insects during flowering period, in particular Musca flies (van der Kooi et al., 2016). Several moths are known to feed on it including *Biston betularia*, *Eupithecia satyrata*, *Neptis rivularis* and *Alcis repandata* (Encyclopedia of Life). Some finches also feed on it including Common Linnet (*Linaria cannabina*), European Goldfinch (*Carduelis carduelis*) (Newton, 1967). In Europe *F. ulmaria* is sometimes referred to as “Queen of the Meadow” for its abilities to dominate a moist to wet meadow. Its flowers contain fruit that are a collection of small nuts that stay afloat and can spread effectively in water. It is looked upon as a “weed” and is thus not commonly planted by home gardeners or professional gardeners/landscape designers (SNL, 2008).

Filipendula ulmaria or ‘mead wort’ has a cultural and historical significance. From the Middle ages through to the 18th century, it was one of the herbs used for strewing in England (Kerr, 2009). The herbs were strewn on the floors in dwelling places to remove unpleasant smells. *Filipendula ulmaria* has also been used for centuries to flavour wine, beer and many vinegars, and its flowers can be added to jams (Larsson, 2013). In Scandinavia *F. ulmaria* was used as a spice in mead, and it’s leaves used for making tea (Høeg, 1974). The plant also holds several medicinal properties, most commonly knows it reduces stomach acidity, it was used to develop the drug aspirin, some studies have shown it can reduce the growth of cancer, it can treat haemorrhoids (Lima et al., 2014; Moro, 2012).

1.5 Objectives

Many of the plants recommended for rain garden use are not based on data from experiments, and there has been little research into the effects of typical rain garden moisture dynamics on the plants, especially in cold climate areas in relation to frost tolerance. This experiment provides quantitative data on two species to help understand their response to different watertreatments that simulate raingarden moisture dynamics.

> The *main objective* of this study is to find out if *Filipendula ulmaria* and *Calamagrostis* x *acutiflora* ‘Karl Foerster’ are suitable for use in raingardens in Nordic climate.

The sub-questions are:

Do *F. ulmaria* and *C. x acutifoila* ‘Karl Foerster’ differ in their response to different water treatment, within species and between species, in relation to:

- Root/shoot growth
- Height and number of leaves/tillers
- Frost tolerance

2 Methods, site and materials

The experiment took place at University of Life Sciences, in Ås, Norway, in an open greenhouse (59°39'49.3"N 10°45'49.4"E). The open greenhouse had a transparent corrugated plastic roof in a triangular shape (Figure 9). Along the north side and east sides of the open greenhouse there were tall hedges giving some protection from wind and sunlight, the south and west sides were open. The area inside the greenhouse was classified as deep shade (300 µmol m-2 s-1). Temperatures registered from the weather station at the university from the time the plants were moved to open greenhouse the 27th of June to when the water treatment experiment ended the 12th of September 2019, were 32°C at the highest and the lowest was 5°C (Figure 8). The plants were left to become established in the open greenhouse from the 27th of June to the 21st of July when treatments started (approximately 4 weeks).

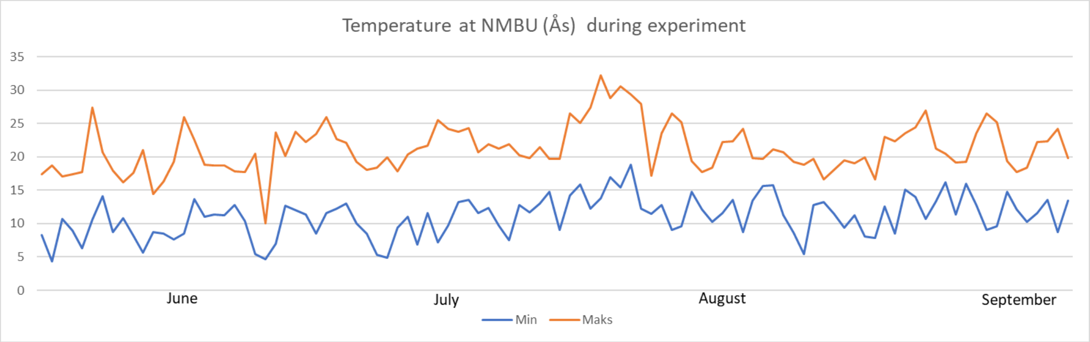


Figure 8 Temperatures at the open greenhouse during experiment

The experiment observed the response of two potential rain garden candidates, *Calamagrostis x Acutiflora* ‘Karl Foerster’ and *Filipendula ulmaria*, to water stress. 420 plants of each species were individually planted in 2L pots. The soil type used was a raingarden soil from Lindum (2% gravel, 92% sand, 4% silt, 1% clay), with a pH of 7.7 and conductivity of 1.7 mS/s.

Figure 9 The open greenhouse with 8 containers, 2 containers of each treatment, with randomly mixed Filipendula ulmaria and Calamagrostis x acutiflora 'Karl Foerster'.

2.1 Simulation of cyclic flooding

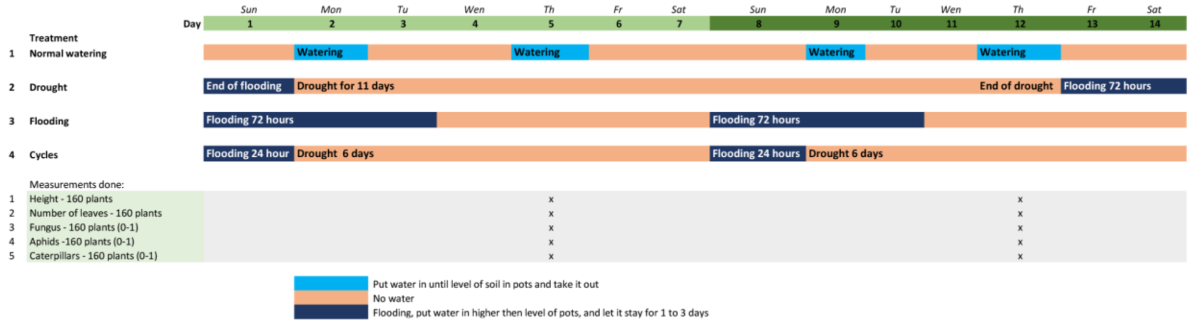
The plants were separated randomly into four different watertreatments: 'cycles', 'flooding', 'drought' and 'normal' (105 individuals per treatment per species).They were put pot-to-pot in large containers, two containers for each treatment, under an open greenhouse (Figure 9). Periodic water baths were used to simulate cyclic flooding that happen in rain gardens in each container.

The different watertreatments consisted of:

1. **Normal (non-flooded control group):** Plants in normal watering were watered twice a week, or when they felt dry so to maintain moisture. When watering the water was put in the container until it reached the top of the pots, around 30 minutes and then let out again.
2. **Drought (+flooding):** Plants in drought were left for 11 days with no water and 3 days (72 hours) of flooding.
3. **Flooding:** Plants in flooding were flooded for 3 days, then 4 days of no watering and then repeated.
4. **Cycles:** Plants in the cycles group experienced 6 days of no water and 1 day (24 hours) of flooding.

When flooding, either for 24 hours or 72 hours, the pots were flooded to cover the entire substrate of the pots in the large container. Plants in 'drought' treatment experienced a total of 3.5 watertreatment cycles, 'flooding' 7 cycles and 'cycles' also 7 cycles (Table 1).

Table 1 The experiment schedule consists of a 14-day period.



		Sun	Mon	Tu	Wen	Th	Fr	Sat	Sun	Mon	Tu	Wen	Th	Fr	Sat
	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Treatment														
1	Normal watering		Watering			Watering				Watering			Watering		
2	Drought	End of flooding	Drought for 11 days										End of drought	Flooding 72 hours	
3	Flooding	Flooding 72 hours							Flooding 72 hours						
4	Cycles	Flooding 24 hour	Drought 6 days						Flooding 24 hours	Drought 6 days					
	Measurements done:														
1	Height - 160 plants					x							x		
2	Number of leaves - 160 plants					x							x		
3	Fungus - 160 plants (0-1)					x							x		
4	Aphids -160 plants (0-1)					x							x		
5	Caterpillars - 160 plants (0-1)					x							x		

🟦 Put water in until level of soil in pots and take it out
🟧 No water
■ Flooding, put water in higher then level of pots, and let it stay for 1 to 3 days

2.2 Growth and survival of plants

20 randomly selected plants from each species in each water treatment were measured weekly from 1st of August 2019 to 12th of September 2019 (7 weeks), for height and number of leaves (in total 160 plants each week). All 840 plants were measured in height and number of leaves before beginning of treatment 21st July 2019, and at the end of treatments 15th September 2019.

When measuring height each plant was measured from bottom (where it touches soil) to the highest leaf apex still alive (meaning green) using a meterstick to nearest 0.5 cm (Figure 10).

Figure 10 Showing to the left, fungus on Filipendula ulmaria, and to the right the measuring of height on Calamagrostis x acutiflora ‘Karl Foerster’.

Number of leaves were counted in *F. ulmaria* as long leaves coming from the main growing point/several growing points, and in *C.* x *acutiflora* ‘Karl Foerster’ as individual tillers coming from the soil. Only tillers or leaves with more than 50% green, and longer than 2 cm were counted. Signs of disease, aphids, caterpillars and fungi was also noted (Figures 10-11).

Figure 11 To the left signs of caterpillar and fungus is visible on Filipendula. To the right 'alive' tillers are separated from the 'dead' (the tiller in the bottom right corner is also counted alive).

2.3 Destructive harvest

Destructive harvest was done both before and at the end of treatments for both species. Before the treatments started it was done on the 23. July 2019, with 20 plants from each species. At the end of treatments, it was done 16-17. September 2019 with 40 plants from each species, 10 for each treatment.

For the destructive harvests the roots were separated from the shoots, by cutting near the soil. The roots were gently hand-washed free of soil in water, immersed in buckets of water and rinsed again to get rid of as much soil as possible.
One picture for the washed roots and one picture of the shoots were then taken of each plant, next to a meterstick as documentation (Figure 12 and 13).

Figure 12 Documentation of roots from destructive harvest at end of experiment.

For each individual, all shoots were gathered in one envelope and all roots in another envelope and put in a drying cabinet of 62°C for at least 48 hours before measuring shoot dry weight (SDW) and root dry weight (RDW). The weighing was done by emptying the envelopes into a tray placed on an accurate laboratory balance. After drying the roots there was still some small rocks and dirt visible in the roots that were not visible when wet, they were manually removed with tweezers before weighing them on the balance (Figure 14).

Figure 13 Documentation of leaves from destructive harvest at end of experiment

Figure 14 To the left: stones and dirt removed from dried roots. To the right: visible particles in the dried roots.

2.4 Frost tolerance test

Figure 15 Underground storage room to the left and plastic greenhouse to the right.

A freezing test was conducted in the end to see if the different watertreatments impacted the plants’ frost tolerance, after which SDW was measured on the surviving plants.

The plants that did not go into the destructive harvest at the end of watertreatments were left in the open greenhouse until the 22. October 2019, when they were moved a plastic greenhouse with natural light and temperatures slightly warmer than outside

(

Figure 15). On the 5th of November 2019 the plants were then moved to an underground outdoor storage room to acclimate for colder temperatures (

Figure 15). Temperatures in the underground storage room were usually above 0 °C but there were a few nights with frost, and some of the plants' soil was frozen.

On the 2nd and 3rd of December 2019, 10 randomly chosen plants of each species from each treatment were prepared for each of the six temperatures to undergo a frost test (in total 60 individuals from each species).To prepare for the frost tolerance test, for each plant, the shoots were cut from the roots near the soil. The roots were separated from the soil, by shaking and brushing, and when they were clean, cut so that only the top 5 cm of the roots remained.

For *C.* x *acutiflora* 'Karl Foerster' five growing points were isolated and bound together and put in a tray of 2 litres of sand below the bundle and 5 litres of sand on top. In *F. ulmaria,* all growing points were saved, the roots cut to 5 cm and then laid out same way on trays as the previous species. 10 bundles (with five tillers) of *C.* x *acutiflora* 'Karl Foerster' and 10 plant pieces of *F. ulmaria* growing points were put on each tray for each temperature, along with a temperature chip, in total 20 plants in each tray (Figure 16). There were two trays of plants per temperature.

Figure 16 Example of tray mixed with Filipendula ulmaria and Calamagrostis x acutiflora 'Karl Foerster' pieces, before putting in temperature chip and the 5 litres of sand on top. This tray is marked for -5°C.

Freezing was done Centre for Climate Regulated Plant Research (SKP) at NMBU. The temperatures of the Frost chambers were: + 2 °C, -5 °C, -10 °C, -15 °C, -20 °C, -25 °C. The +2 °C was used as the control.

Explanation of steps for the freezing procedure (Table 2):

1. Start from +2 °C and stay for 1.5 hour at this temperature,
2. Then decline per -1°C per hour until -3°C, stay at -3 °C for 18 hours,
3. Decline per -1°C per hour until goal temperature (one of -5, - 10, -15, -20, -25),
4. Stays at the goal temperature for 1 hour,
5. Increase +1°C per hour until +2°C, stay at +2°C for 12 hours
6. Continue to stay at +2°C until time to take out

Table 2 Schedule for the freezing procedure.

#	Temperature group	Duration of frost treatment in hours	Amount of days	Day to put in	Time of start	Day of program finish	Time of program finish	Extra time at +2°C, after program finishes, in hours	Day to take out
1	+ 2°C	66	1D and 18 H	3-Dec	15:00:00	05-Dec	19:00	0	06-Dec
2	- 5°C	46.5	1 D and 22.5 H	3-Dec	15:00:00	05-Dec	15:30	19.5	06-Dec
3	-10°C	56.5	2 D and 8.5 H	3-Dec	15:00:00	05-Dec	23:30	9.5	06-Dec
4	-15 °C	66.5	2D and 18.5 H	2-Dec	15:00:00	05-Dec	09:30	23.5	06-Dec
5	-20 °C	76.5	3D and 4.5 H	2-Dec	15:00:00	05-Dec	19:30	13.5	06-Dec
6	-25°C	86.5	3D and 14.5 H	2-Dec	15:00:00	06-Dec	05:30	3.5	06-Dec

After the freezing test the plants were then planted in individual pots of 0.5 litre soil (normal organic garden mix soil) and put in a greenhouse for 4 weeks to see which had survived and how much they grew (Figure 16). The temperatures in the greenhouse was 18°C in the day, and 15°C in the night. The day length was 16 hours.

The survival count was done at 8th of January, the plants were examined to see which were still alive, any sign of a green leaf was counted as alive. Number of leaves/tillers was also counted as well as number of growing points for *F. ulmaria* (clusters where leaves come out from).

The shoot dry weights (SDW) were taken at the 15th-16th of January 2020. On the plants that were alive the leaves/tillers were cut off, put in envelopes and dried in the same manner as for the destructive harvest. Some of the plants that had been in the most extreme temperatures only had one or two tiny leaves, so a very accurate three-digit scale had to be used when weighing.

Figure 17 The small greenhouse at SKP on the 8th of January. Were plants went after the Frost chambers.

2.5 Summary ranking

For each treatment in *C.* x *acutiflora* 'Karl Foerster' and *F. ulmaria*, a score based on ranking within the measuring category was calculated (Table 3). The categories were the types of measures done, root dry weight (RDW), shoot dry weight (SDW), total dry biomass (TDB), survival, height, number of tillers/leaves and frost tolerance. Ranking in height and number of leaves/tillers was based on all 420 from each species, with 4 being the best, and 1 the worst. Ranking in frost tolerance (frost) was done looking at average shoot dry weights of frost tolerance for -15 °C (as for -20 °C there were no survivors in *C.* x *acutiflora* 'Karl Foerster', and the ranking was the same as in -15 °C as for -20 °C for *F. ulmaria*). So, for each measuring category a 4 is the best, and 1 is the lowest. A summary score is made where highest number indicated best performance, and a ranking in the end was made where 1 is the best and 4 is the worst scoring treatment.

2.6 Data analysis

Data were put into spreadsheets in excel (https://www.microsoft.com/en-us/microsoft-365/excel). Often a variable is more than just the mean (Legendre & Legendre, 1998), therefore I used boxplots and plots that show the spread of the data, produced in excel or SPSS. Before doing any further analysis with the data I first checked for normality and homogeneity of variances using a Q-Q plot and Levene's test for equality of variances in SPSS (https://www.ibm.com/analytics/spss-statistics-software), to see if analysis of variance (ANOVA) was possible. To test for differences between group means I used one-way ANOVA in SPSS, and test level $\alpha = 0.05$, if the test was positive ($p<0.05$) I proceeded to test which groups were different from each other. To see the differences between groups I used Fisher's protected least significant difference (LSD). This test is suitable for experiments with preplanned comparisons (Ott & Longnecker, 2015). If the criteria for using ANOVA were not met (normal distribution, equal variance and independent samples) I used two-way ANOVA through General Linearized Models -> Univariate and included for interaction between factors. This model met the ANOVA criteria and I was able to do the post-hoc LSD test to find which groups were significantly different from each other.

3 Results

3.1 Growth and survival

All plants survived the different watertreatments that took place from the 21st July 2019 to the end of treatments 15th September 2019 (8 weeks) and they have a large spread in both number of leaves and height for both species, for all treatments (Figures 15-18).

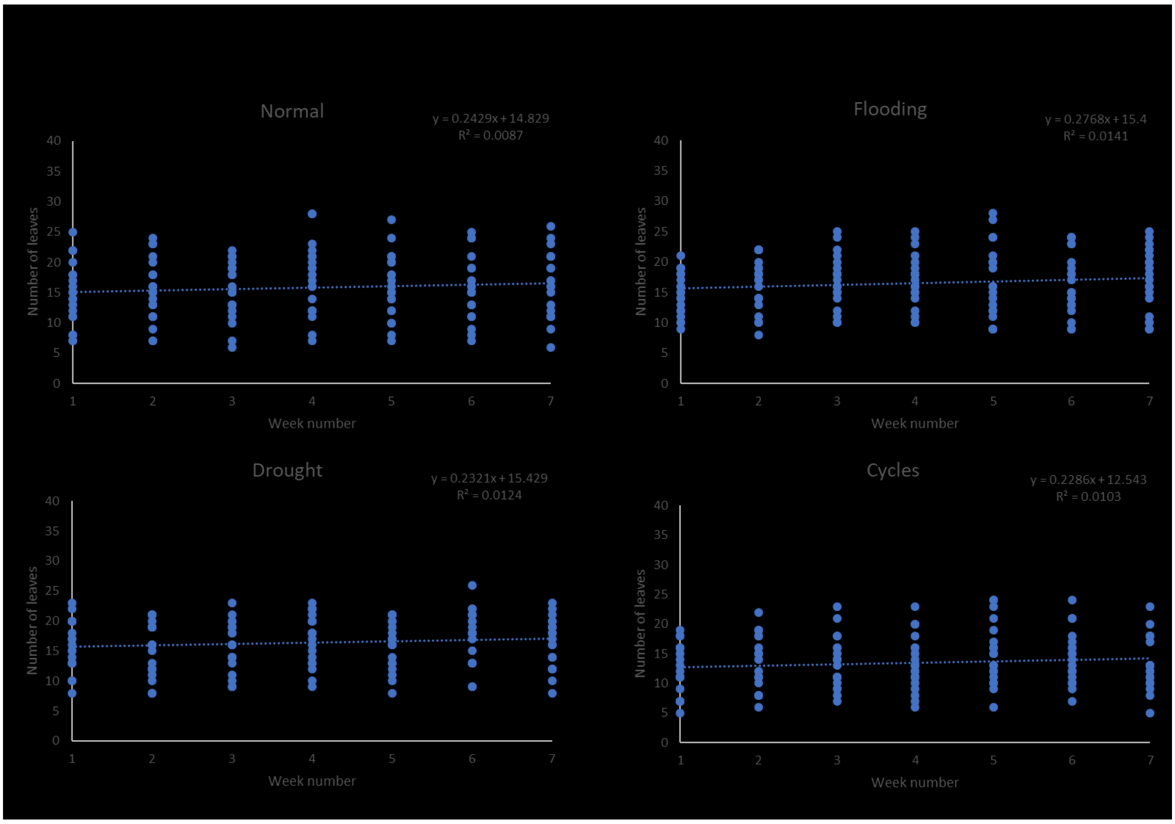


Figure 18 Weekly number of leaves Calamagrostis x acutiflora 'Karl Foerster'. 20 plants in each treatment were measured.

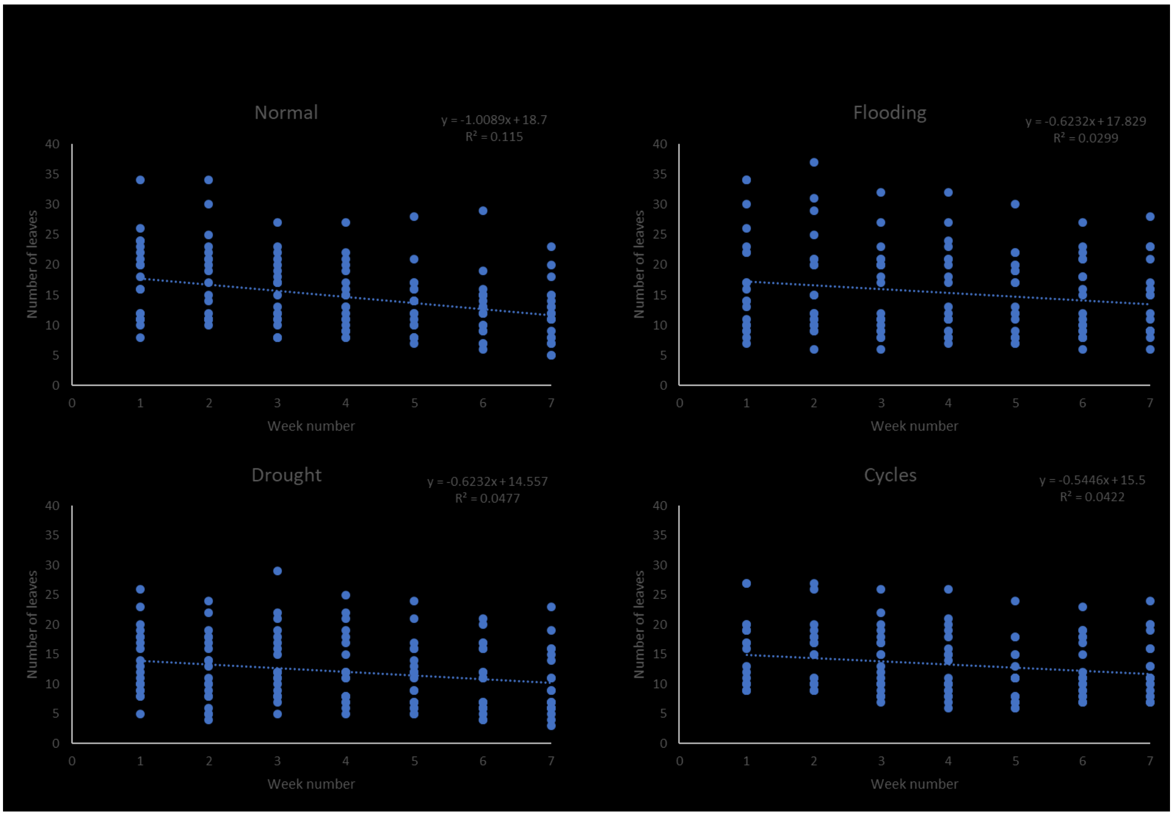


Figure 19 Weekly number of leaves Filipendula ulmaria. 20 plants in each treatment were measured.

When plotting a trendline we can see that *C.* x *acutiflora* 'Karl Foerster' has a slightly positive slope (> 0.228x) for number of leaves for all treatments, while *F. ulmaria* has a negative slope (< -0.545x) for all treatments (Figure 18 and Figure 19). Meaning *C.* x *acutiflora* 'Karl Foerster' is growing in number of leaves per week, in all treatments, while *F. ulmaria* is losing leaves each week across all treatments. *F. ulmaria* goes from around 17 leaves to 13 leaves on average (for all treatments). *C.* x *acutiflora* 'Karl Foerster' goes from around 15 leaves to 17 leaves, on average for all treatments.

For height, *C.* x *acutiflora* 'Karl Foerster' keeping the same height, on average around 60 cm, except for in 'flooding' where it loses leaves steadily throughout the weeks (Figure 20). For *F. ulmaria* height is staying around the same height, around 45 cm, in all treatments for all the weeks, except for in 'drought' where it loses leaves steadily throughout the weeks (Figure 21).

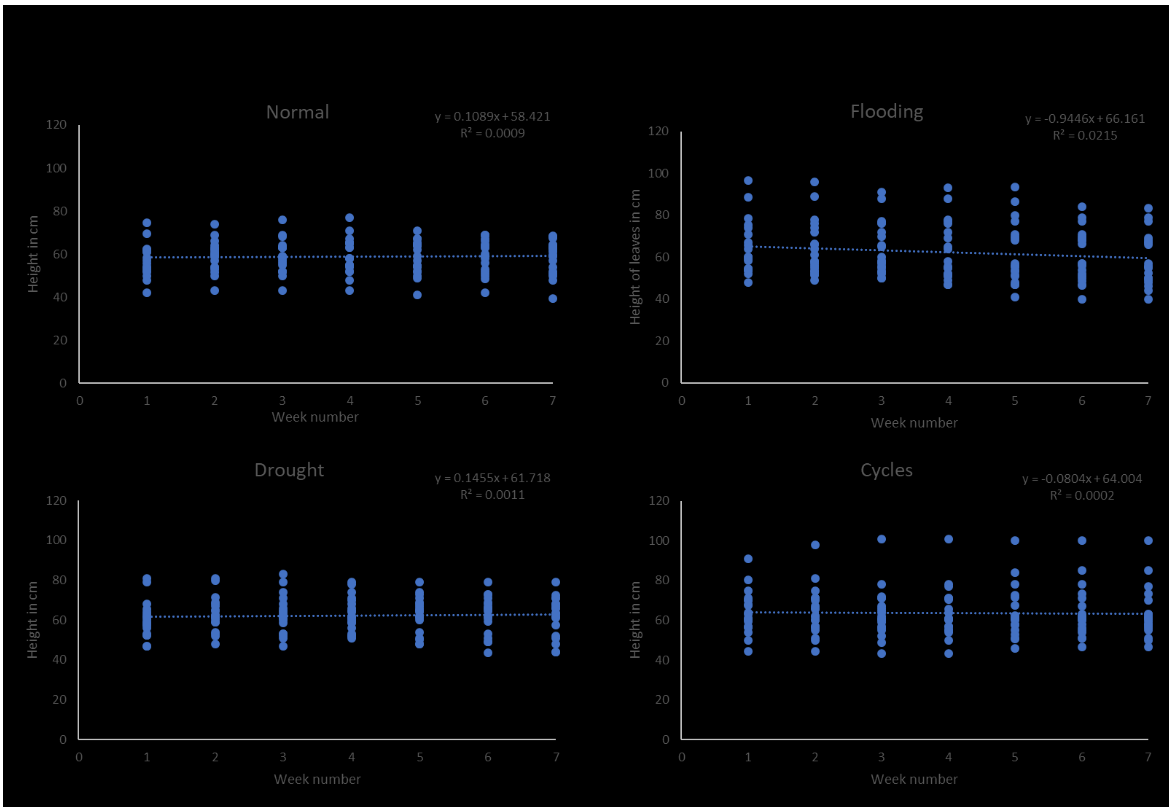


Figure 20 Weekly height for Calamagrostis x acutiflora 'Karl Foerster'. 20 plants in each treatment were measured.

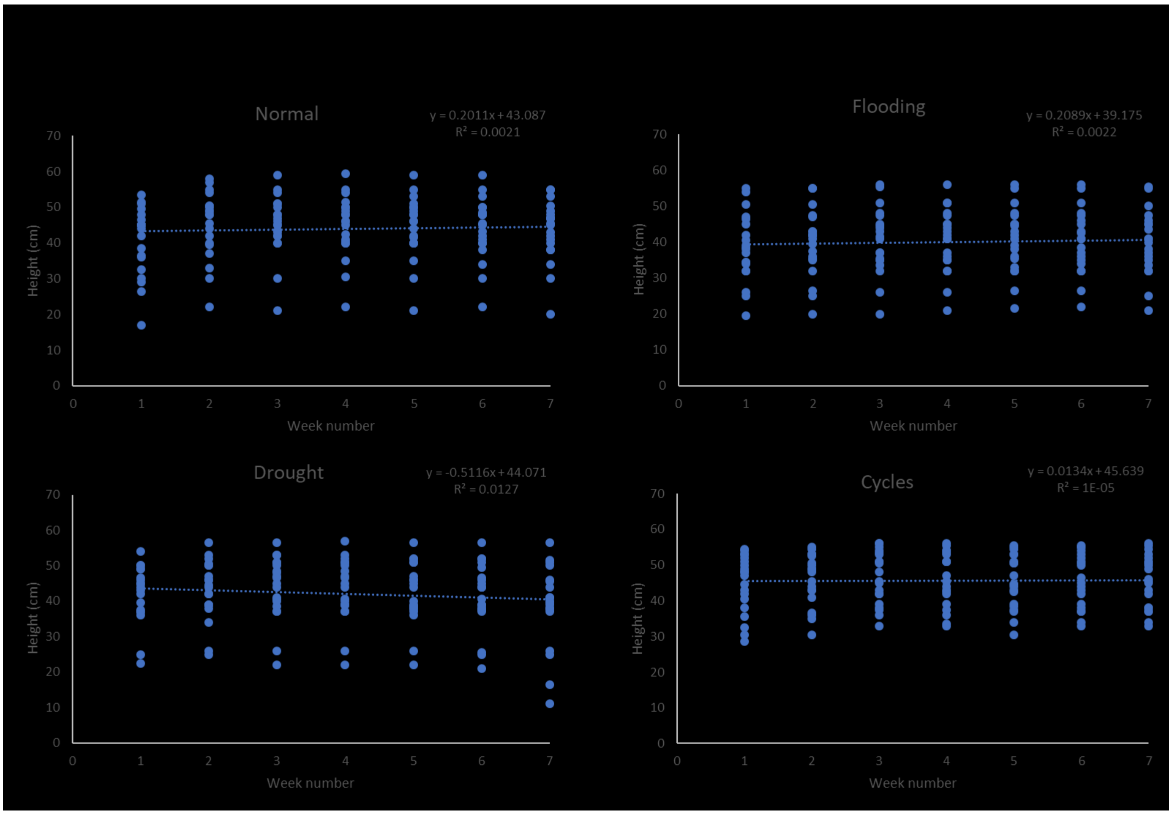


Figure 21 Weekly height for Filipendula ulmaria. 20 plants in each treatment were measured.

When plotting the averages of all treatments for each species in the same graph, we can clearly see the differences between the treatments.

For average weekly number of leaves, *C.* x *acutiflora* ‘Karl Foerster’ is increasing in leaves until around week 5 in all treatments, before it starts losing leaves from week 5 to week 7. The plants in ‘flooding’ have the most leaves, then ‘drought’, then ‘normal’ and ‘cycles’ at the lowest. For *F. ulmaria,* it loses leaves steadily from week 1 to week 7. ‘Flooding’ has the highest number of leaves, then ‘normal’, then ‘cycles’ and ‘drought’ being at the lowest (Figure 22).

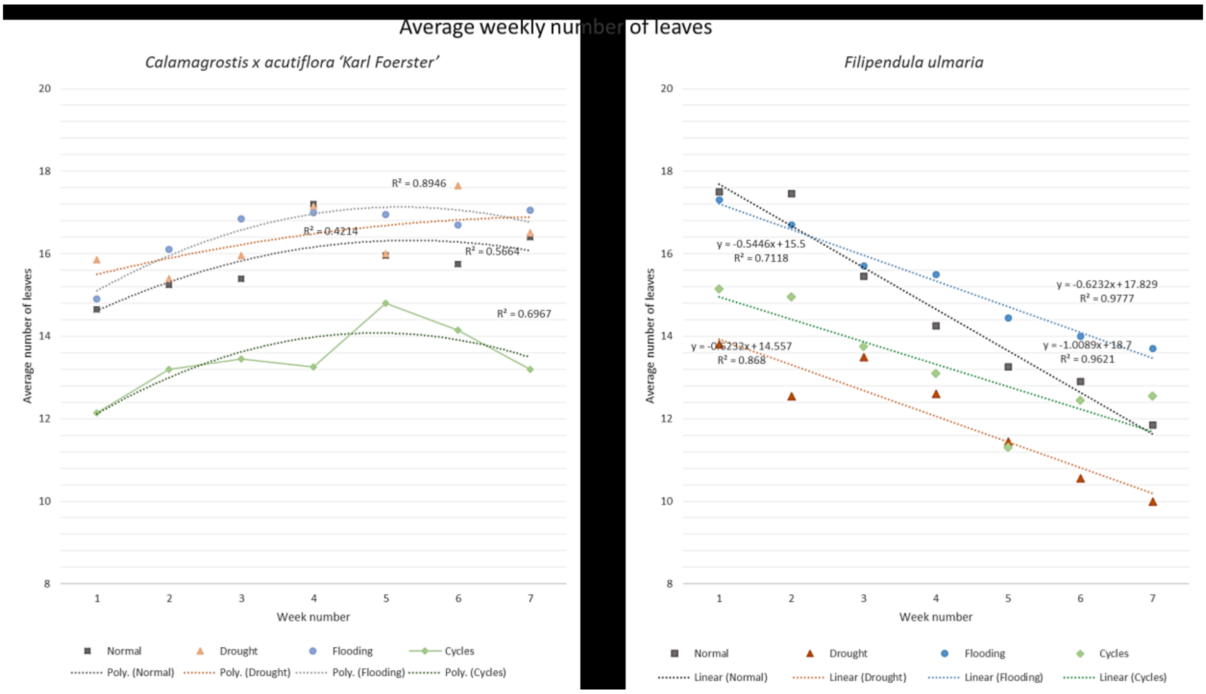


Figure 22 Average weekly number of leaves for all treatments combined, per species. 20 plants were measured each week for each species.

For average weekly height, in *C.* x *acutiflora* ‘Karl Foerster’ it stays around the same height of around 60-63 cm, except for ‘flooding’ where there is a constant decrease in height per week. ‘Cycles’ has the highest average height throughout, then ‘drought’, then ‘flooding’ and ‘normal’ being the lowest average height. In *F. ulmaria*, average weekly height stays around 40-43 cm throughout. Plants in ‘cycles’ having the highest average weekly height, then ‘normal’, then ‘drought’ and ‘flooding’ having the lowest average height per week (Figure 23).

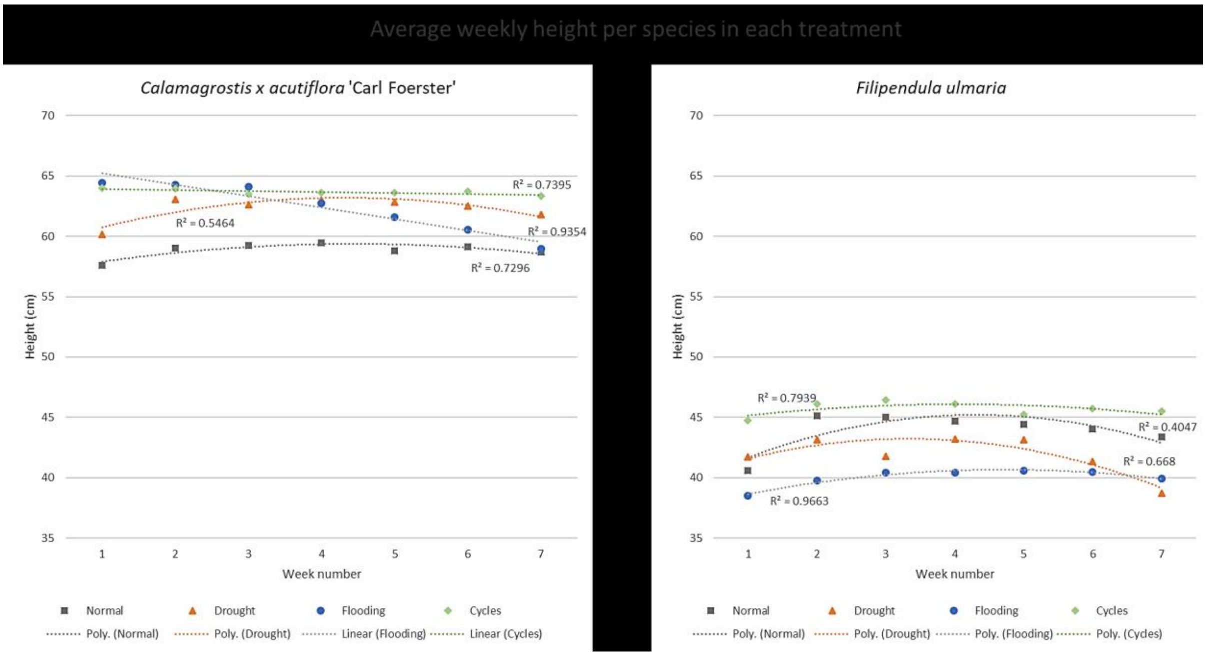


Figure 23 Average weekly height for all treatments combined, per species.

The height before and after treatments were measured on all 840 plants, 420 for each species. In *F. ulmaria* the average height before treatments started was smaller than at the end, with before mean being 32.54 cm, and the after treatments average mean being 42.83 cm. Between the end treatments there were differences between height in treatments ‘control (45.15 ± 1.56 cm) and ‘drought’ (40.60 ± 1.54 cm), and between ‘control’ and ‘flooding’ (40.76 ± 1.55 cm), with both p-values of p= 0.000. There were also significant differences in height between ‘cycles’ (44.49 ± 1.59 cm) and ‘flooding’, and between ‘cycles’ and ‘drought’, with p-values of p= 0.001 and p=0.000 respectively. There were no differences in height between ‘control’ and ‘cycles’, p=0.551, or between ‘drought’ and flooding’, p=0.880. (Figure 24)

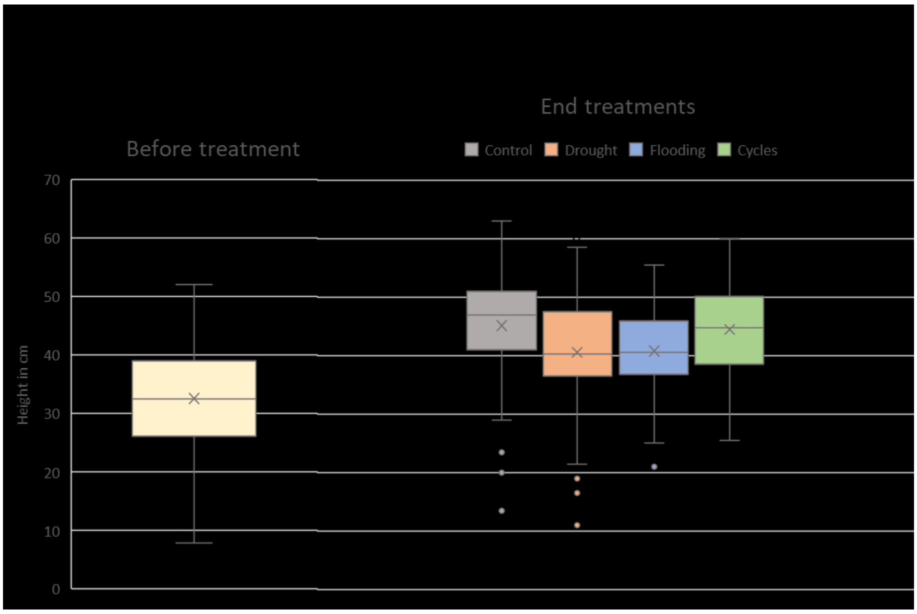


Figure 24 All 420 Filipendula ulmaria plants measured for height before and after treatments. A post-hoc LSD from two-way ANOVA revealed differences between end treatments. Statistically significant differences are indicated with different lower-case letters.

For height in *C.* x *acutiflora* ‘Karl Foerster’ he difference between before treatment height and after treatment height was not that big, with before average being 59.95 cm and after treatment average 61.30 cm. Between the end treatments there were significant differences in height between ‘flooding’ (59.06 ± 1.91 cm) and ‘drought’ (62.59 ± 1.92 cm), and between ‘flooding’ and ‘cycles’ (62.84 ± 1.94 cm), with p-values of p=0.011 and p=0.007 respectively. There was no significant difference between heights from ‘normal’ (60.84 ± 1.93 cm) and any other end treatment, nor between ‘drought’ and ‘cycles’. (Figure 25).

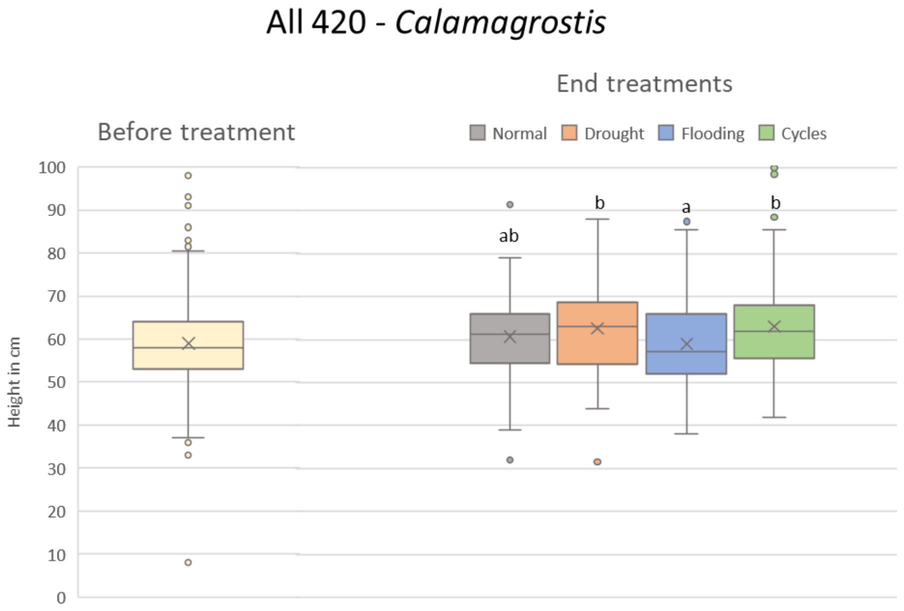


Figure 25 All 420 Calamagrostis x acutiflora 'Karl Foerster' plants measured for height before and after treatments. A post-hoc LDS from two-way ANOVA revealed differences between end treatments. Differences is indicated with different lower-case letters

In number of tillers for *C*. x *acutiflora* 'Karl Foerster' the difference between before treatment number of tillers and end of treatments number of tillers was not big, with before treatment average of 12.15 and the end of treatments average of 14.52. Between the end treatments there were significant differences in number of tillers between 'normal' (15.05 ± 0.90) and 'drought' (13.75 ± 0.89), with p-value of p=0.030. There were no significant differences between number of tillers in any other end treatments, 'flooding' (14.84 ± 0.90) and 'cycles' (14.45 ± 0.91), p-values all above 0.050. (Figure 26).

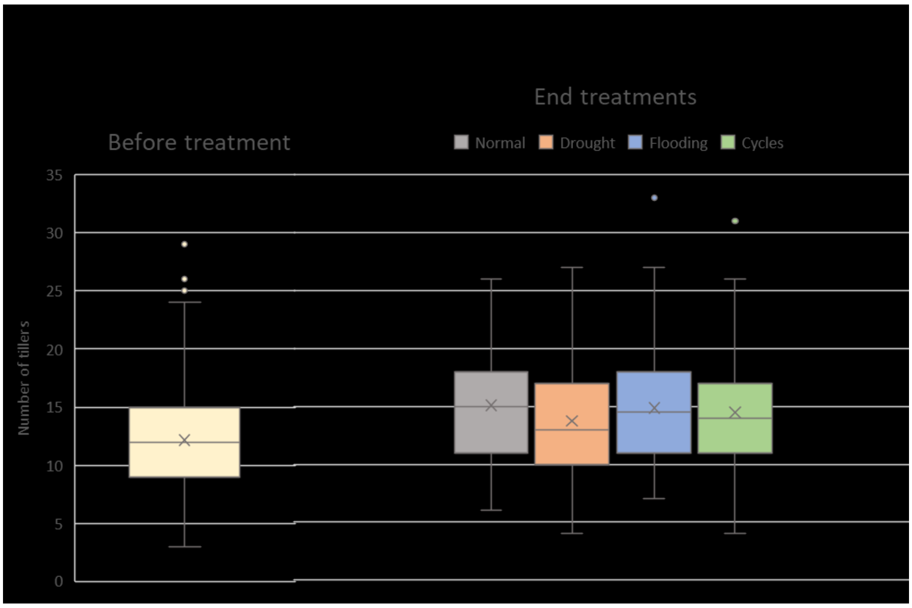


Figure 26 All 420 Calamagrostis x acutiflora 'Karl Foerster' plants measured for number of tillers before and after treatments. A post-hoc LDS from two-way ANOVA revealed differences between end treatments. Differences is indicated with different lower-case letters.

In number of leaves for *F. ulmaria*, the before treatment average number of leaves was 12.34 and the end treatment average number of leaves is a little lower at 11.33. Between the end treatments, there is significant differences in number of leaves between 'flooding' (13.32 ± 1.00) and 'normal' (10.52 ± 1.01), 'drought' (9.58 ± 0.99) and 'cycles' (11.88 ± 0.99) with p-values of p=0.000, p=0.000 and p=0.046, respectively. There was also significant difference between number of leaves in treatments 'cycles' and 'drought' at p=0.001. There was no significant difference in number of leaves between treatments 'normal' and 'drought', or between 'normal' and 'cycles' (p-values of p=0.193 and p=0.057). (Figure 27).

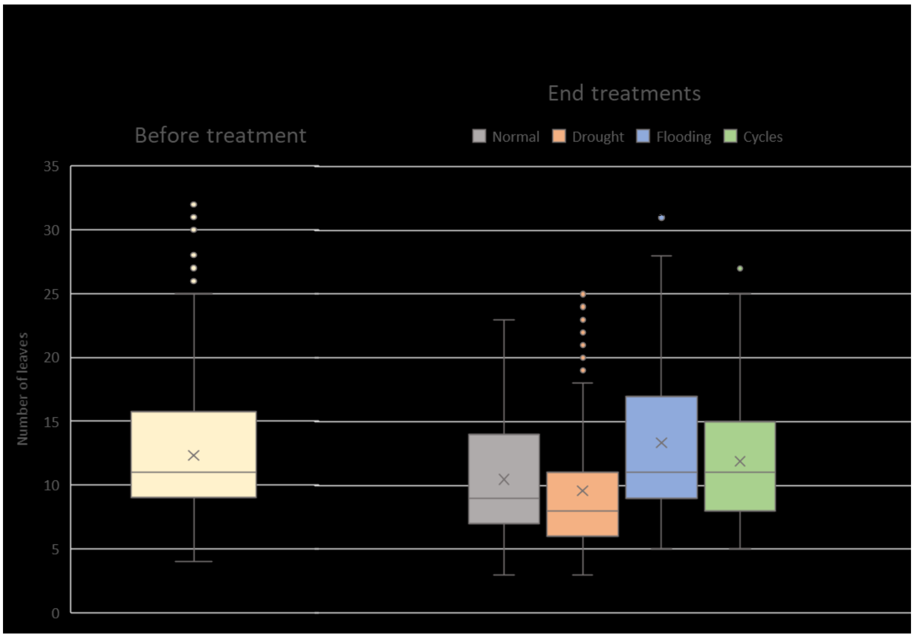


Figure 27 All 420 Filipendula ulmaria plants measured for number of leaves before and after treatments. A post-hoc LDS from two-way ANOVA revealed differences between end treatments. Differences is indicated with different lower-case letters.

3.2 Destructive harvest

Dry weights from destructive harvest was compared between start and end of treatments, as well as between treatments. For total dry biomass (TDB) in *F. ulmaria* there was a statistically significant difference between start of destructive harvest in TDB and end of treatment destructive harvest for TDB, determined by one-way ANOVA (F(4,59) = 2.805, p = .034).

There was a significant difference between 'before treatments' TDB (9.11 ± 5.80 grams) and end treatment 'control' TDB (13.45 ± 5.81 grams) at p = 0.029. There were no statistically significant differences between 'before treatments' TDB and the end treatments TDB for 'drought', 'flooding' and 'cycles', with respectively p = 0.151, p= 0.470 and p = 0.382.

Within the end treatments, there were significant differences between TDB in 'control' (13.45 ± 5.81 grams) and 'drought' (6.28 ± 2.88 grams) at p = 0.002, and between 'cycles' (10.82 ± 4.18 grams) and 'drought' (6.28 ± 2.88 grams) at p = 0.048. There were no differences in TDB between 'flooding' (10.52 ± 4.73) and any other treatments, p-values of 0.470, 0.197, 0.064 and 0.894. (Figure 28).

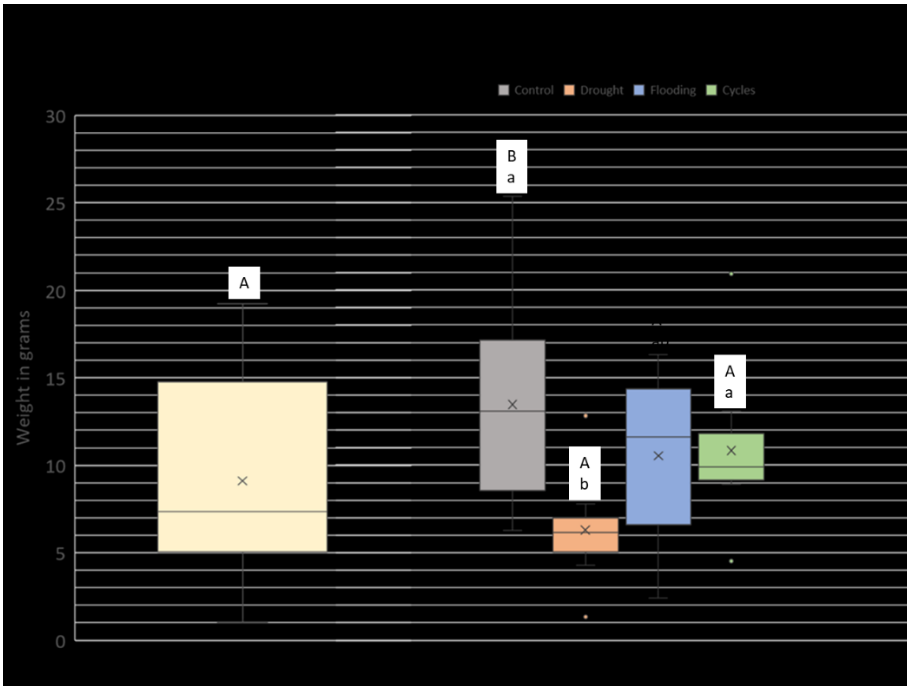


Figure 28 Boxplots of total dry biomass of Filipendula ulmaria after destructive harvest (One-way ANOVA df = 4, p < 0.030). Significant differences (at p < 0.05) exist between boxplots with different capital letters for 'Before' and 'End treatment' and with different lower letters for statistically significant difference within 'End treatments' . For example, "a" indicates significant difference relative to "b", but not to "ab".

For total dry biomass (TDB) in *C.* x *acutiflora* 'Karl Foerster' there were no statistically significant difference between start of destructive harvest TDB and end of treatment TDB determined by one-way ANOVA (F(4,59) = 2.448, p = 0.057). And no significant differences in TDB within the end treatments either, 'control' (9.88 ± 3.73 grams, 'drought' (9.41 ± 2.97 grams), 'flooding' (10.62 ± 3.39 grams) and 'cycles' (10.96 ± 3.67 grams). P-values not available as it did not pass the significance test from one-way ANOVA (Figure 29).

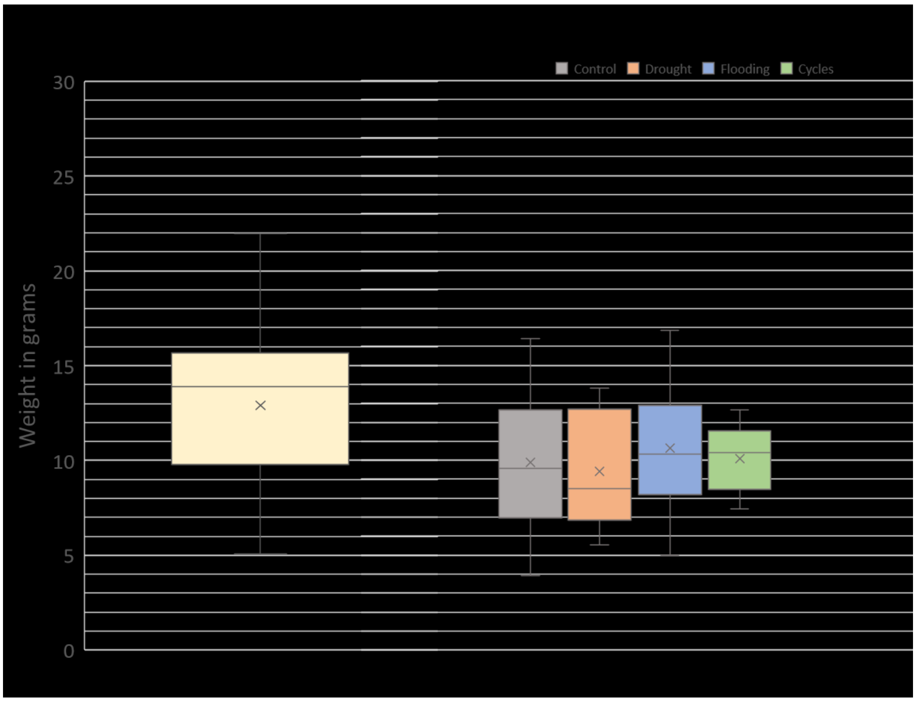


Figure 29 Boxplots of total dry biomass of Calamagrostis x acutiflora 'Karl Foerster' after destructive harvest (One-way ANOVA df = 4, p < 0.057). No significant difference between expected means were found.

For root dry weight (RDW) in *C.* x *acutiflora* 'Karl Foerster' there was a statistically significant difference between 'before treatment' RDW and 'end of treatments' RDW determined by one-way ANOVA (F(4,59) = 2.581, p = 0.047). The significant difference in RDW was between 'before treatment' (9.14 ± 3.80 grams) and 'end treatments': 'control' (6.79 ± 2.93 grams), 'drought' (6.22 ± 2.26) and 'cycles' (6.66 ± 1.37) , with p-values respectively of p=0.038, p=0.011 and p=0.029.
There was no significant difference between RDW in 'before treatment' (9.14 + 3.80) and RDW in 'flooding' (7.05 ± 2.00) with p=0.065. It can be remarked that mean 'before treatment' RDW are higher than all the means of RDW in 'end treatments', indicating poor root growth and root loss.

There were no significant differences in root dry weight within the 'end treatments', all p-values > 0.05. (Figure 30).

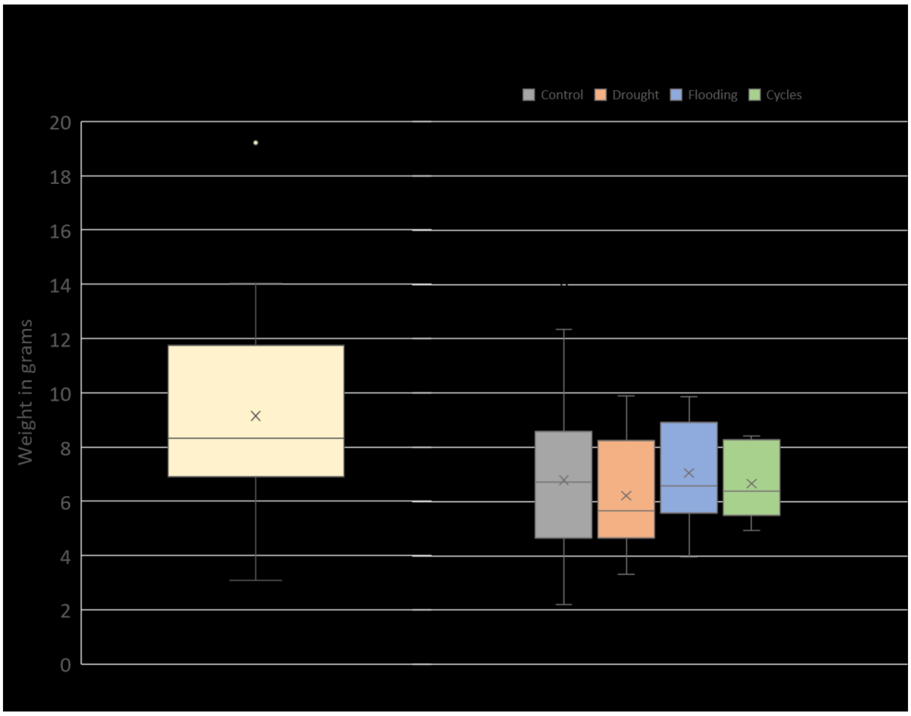


Figure 30 Boxplots of dry root weight of Calamagrostis x acutiflora 'Karl Foerster' after destructive harvest (One-way ANOVA df = 4, $p < 0.047$). Significant differences (at $p < 0.05$) exist between boxplots with different capital letters for 'Before' and 'End treatment' and with different lower letters for statistically significant difference within 'End treatments' . For example, "a" indicates significant difference relative to "b", but not to "ab".

For shoot dry weight (SDW) in *C.* x *acutiflora* 'Karl Foerster' there were no significant differences between 'before treatment' SDW and any of the 'end of treatment' SDW determined by one-way ANOVA (F(4,59) =0.677, p = 0.611). The 'before treatment' mean of SDW is higher than all 'end treatment' means, indicating poor shoot growth and decline.

There were also no significant differences between shoot dry weight within the 'end treatments'. 'Before treatment' the average SDW was 3.76 ± 1.37 grams, and for the 'end treatments' average SDW were: 'control' 3.10 ± 1.00 grams, 'drought' 3.19 ± 0.87 grams, 'flooding' 3.58 ± 1.56 grams and 'cycles' 3.41 ± 1.19 grams. (Figure 31).

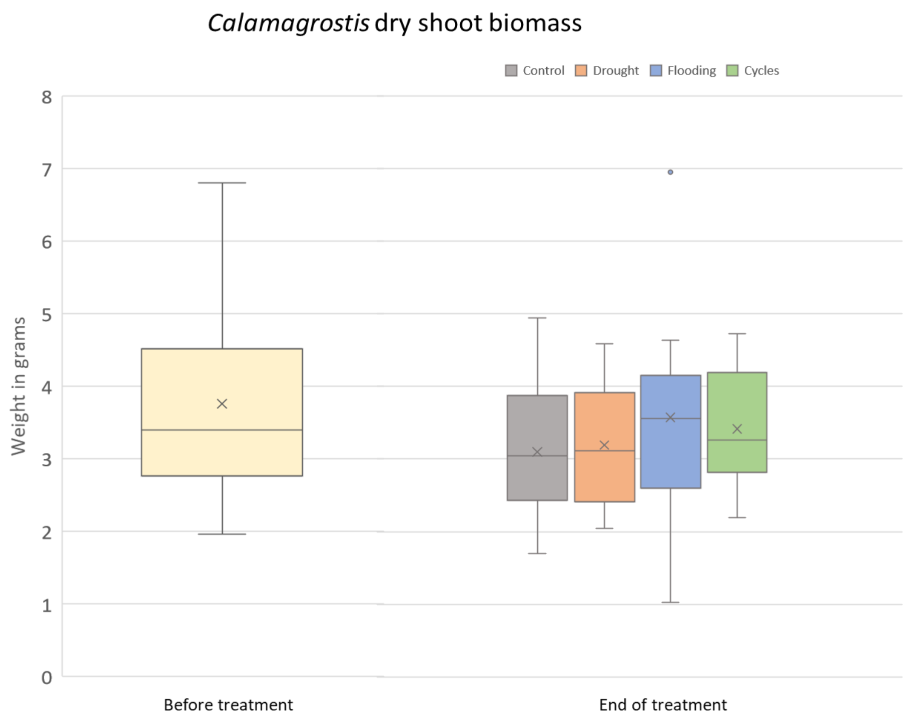


Figure 31 Boxplots of shoot dry weight (SDW) of Calamagrostis x acutiflora 'Karl Foerster' after destructive harvest (One-way ANOVA df = 4, p < 0.611). No significant difference between expected means were found.

For root dry weight (RDW) in *F. ulmaria* there were no significant differences between 'before treatment' RDW and any of the 'end treatment' RDW determined by one-way ANOVA gives F(4,59) = 1.936, p = 0.118.

Looking at the plot however, 'control' and 'drought' appear to be quite different in RDW and was revealed to be different when 'before treatments' was omitted and a new ANOVA test was run (F(3,39) = 3.553, p = 0.024). The significant difference in root dry weight was between 'control' (9.13 ± 4.56 grams) and 'drought' (4.14 ± 2.35 grams), with p=0.003. There were no significant differences between root dry weight in any other pairs, 'flooding' (6.97 ± 3.5 grams) and 'cycles' (7.26 ± 3.02 grams). (Figure 32)

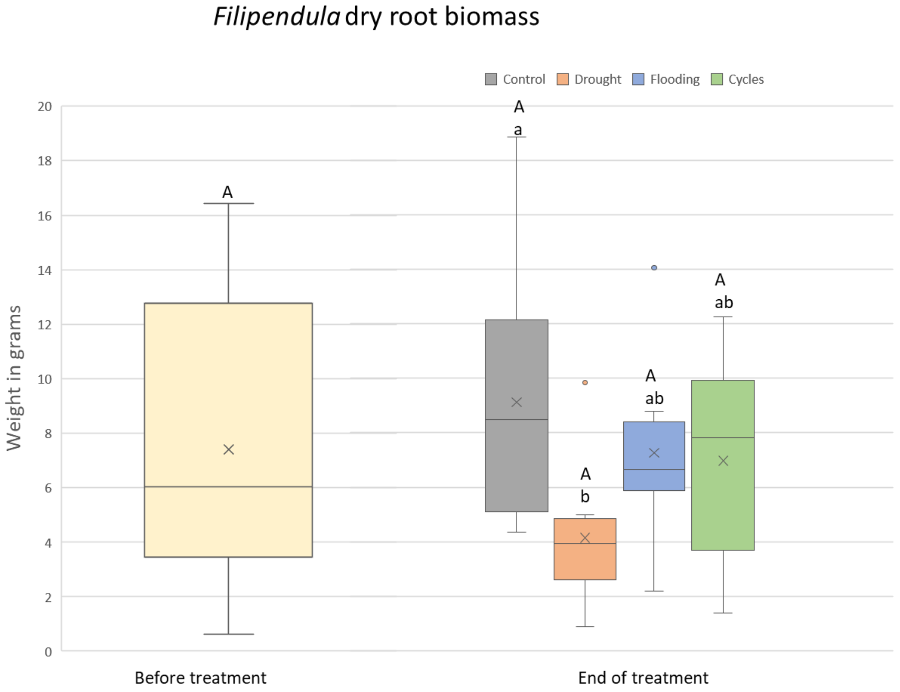


Figure 32 Boxplots of root dry weight (RDW) of Filipendula ulmaria after destructive harvest (One-way ANOVA df = 4, p < 0.024). Significant differences (at p < 0.05) exist between boxplots with different capital letters for 'Before' and 'End treatment' and with different lower letters for statistically significant difference within 'End treatments' . For example, "a" indicates significant difference relative to "b", but not to "ab".

For shoot dry weight (SDW) in *F. ulmaria* there were significant differences between 'before treatment' shoot dry weight and some of the 'end treatment' shoot dry weights (F(4,59) = 11.15, p = 0.000). The significant difference in SDW was between 'before treatment' (1.71 ± 0.83 grams) and end treatments SDW of 'control' (4.32 ± 1.52 grams), 'flooding' (3.55 ± 1.52) and 'cycles' (3.56 ± 1.29 grams) with all three p-values being p= 0.000. There was no significant difference in SDW in *F. ulmaria* between 'before treatment' (1.71 ± 0.83 grams) and end treatment 'drought' (2.51 ± 0.74 grams).

There were significant differences within 'end treatments' between the SDW of 'drought' and the three end treatments: 'control', 'flooding' and 'cycles', p-values respectively of p=0.000, p=0.009 and p=0.009. (Figure 33).

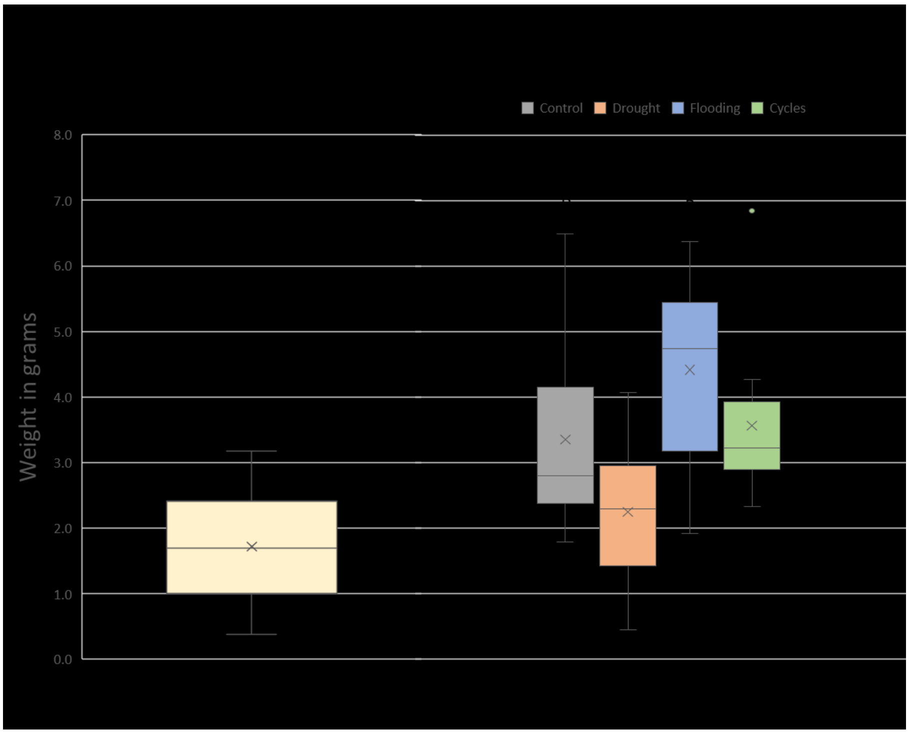


Figure 33 Boxplots of shoot dry weight (SDW) of Filipendula ulmaria after destructive harvest (One-way ANOVA df = 4, p < 0.000). Significant differences (at p < 0.05) exist between boxplots with different capital letters for 'Before' and 'End treatment' and with different lower letters for statistically significant difference within 'End treatments' . For example, "a" indicates significant difference relative to "b", but not to "ab".

3.3 Frost tolerance

In *F. ulmaria* all plants survived -5 °C , -10 °C and -15 °C, and all except for one plant from 'flooding' survived (9/10) in -20 °C. In -25 °C, there were no survivors from 'normal', 3/10 survived from 'drought', 4/10 survived from 'flooding' and 3/10 survived from 'cycles'. (Figure 34)

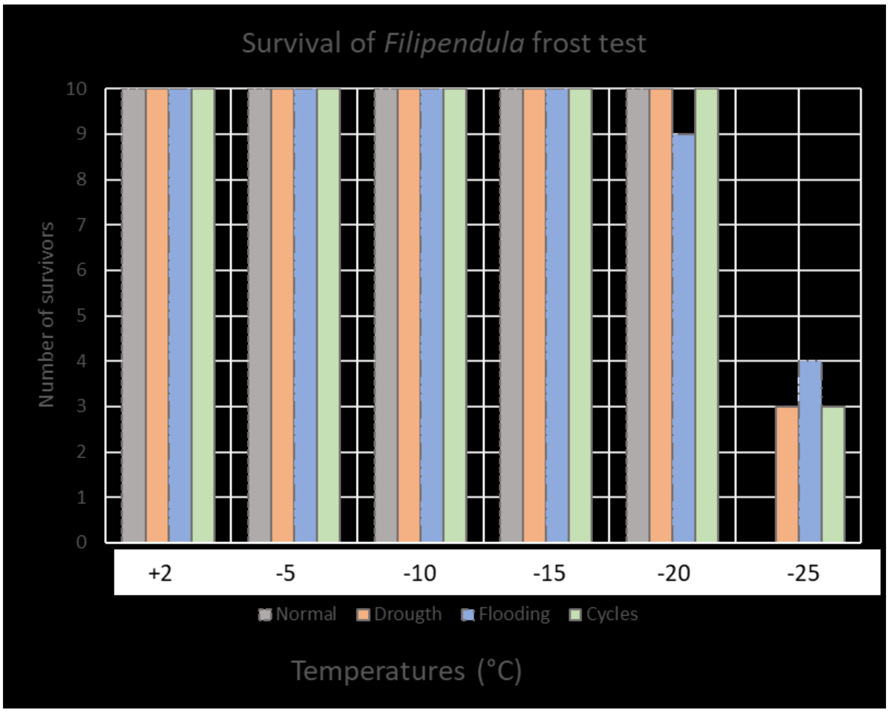


Figure 34 Survival of Filipendula ulmaria in frost test. 10 plants in each treatment for each temperature.

In *C.* x *acutiflora* ‘Karl Foerster’ all plants survived -5 °C and -10 °C. In -15 °C, 6/10 survived from ‘normal’, 7/10 survived from ‘drought’, all 10/10 survived from ‘flooding’ and 8/10 survived from ‘cycles. No plants survived -20 °C or -25 °C. (Figure 35).

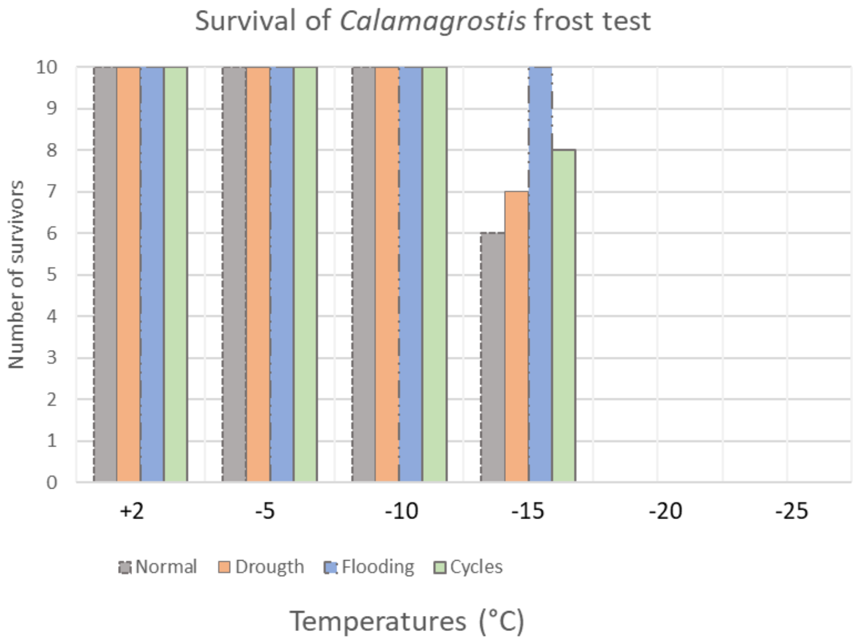


Figure 35 Survival of Calamagrostis x *acutiflora* ‘Karl Foerster’ in frost test. *10 plants in each treatment for each temperature.*

There is no trend between shoot dry weight and treatments at the different temperatures for *C.* x *acutiflora* ‘Karl Foerster’ . However, at colder temperatures the shoot dry weight is lower. There is little difference between dry weights of +2 °C and -5 °C with both average weights of around 0.5 grams, but at -10 °C it drops to almost 50% of the weight of -5 °C with around 0.3 grams. At -15 °C it is almost at zero with weight of less than 0.1 grams. (Figure 36).

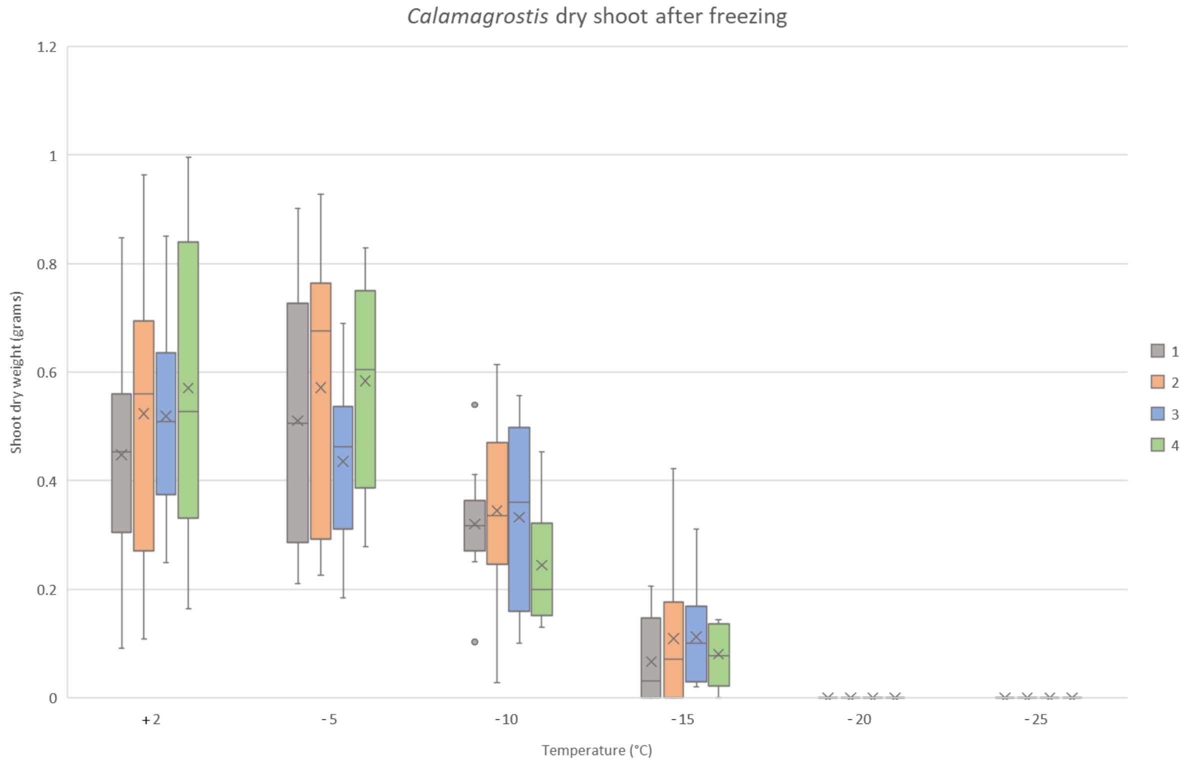


Figure 36 Boxplots of shoot dry weight for Calamagrostis x acutiflora 'Karl Foerster' after frost test.

There is no trend between shoot dry weight and treatment at the different temperatures for *F. ulmaria*. The shoot dry weight seems to go down gradually, until it reaches -25 °C where the average shoot dry weight drops from 0.8 grams to below 0.1 grams. (Figure 37).

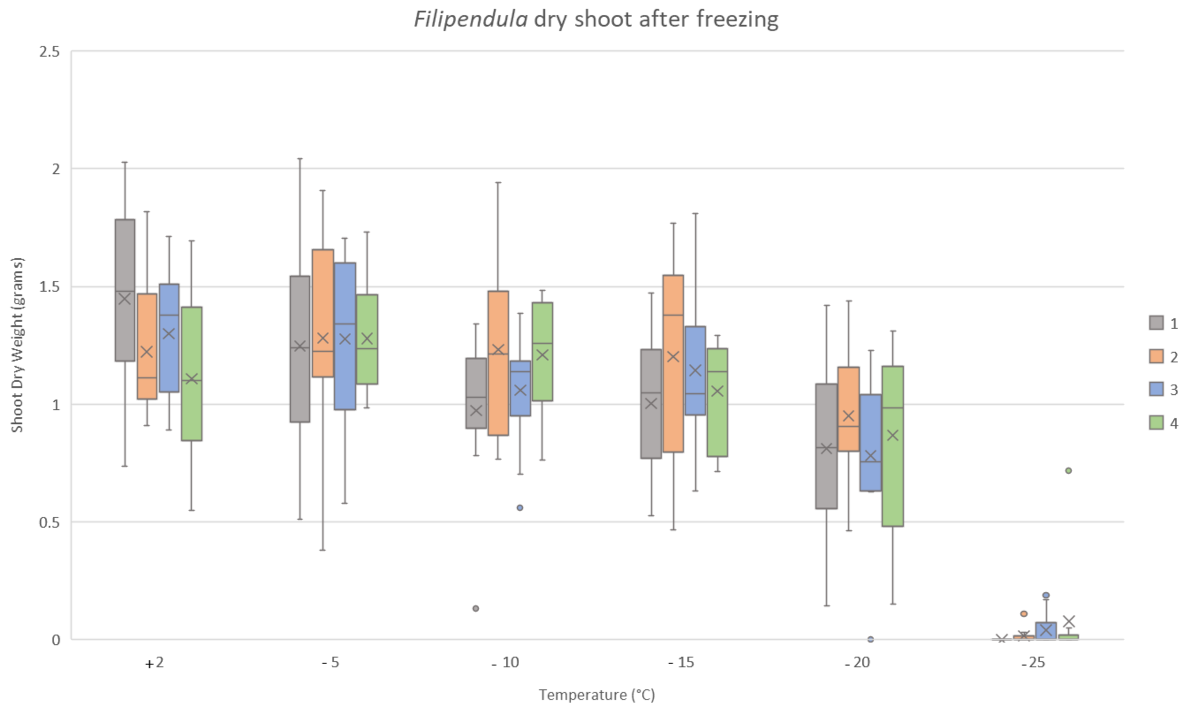


Figure 37 Boxplots of Filipendula ulmaria shoot dry weights after frost test.

Comparing the two species *F. ulmaria* is much more frost tolerant than *C.* x *acutiflora* 'Karl Foerster', both from the survival count and from the boxplots of shoot dry weights. In the shoot dry weights of *C.* x *acutiflora* 'Karl Foerster' is around 0.5g on average for +2 °C and -5 °C, around 0.3g for -10 °C, and 0.1g for -15 °C. While *F. ulmaria* is between 1.5g and 1 gram for all temperatures between +2 °C and -15 °C, and around 0.8g for -20 °C, before almost being at zero with less than 0.1 g for -25 °C. Although it needs to be considered that for *C.* x *acutiflora* 'Karl Foerster' only 5 growing points were used as 1 plant for the freezing, whereas *F. ulmaria* kept all the growing points for 1 plant.

3.4 Summary score table

In the summary score table (Table 3) we see that for both species 'flooding' scores the highest and is 1st ranking treatment in overall performance of the different measuring categories: root dry weight (RDW), shoot dry weight (SDW), total dry biomass (TDB), height, number of leaves/tillers and frost test.

‘Flooding’ scored 18 and 18.5 (out of 24) for *F. ulmaria* and *C.* x *acutiflora* ‘Karl Foerster’ respectively. ‘Cycles’ got a score of 16 and 16.5 in *F. ulmaria* and *C.* x *acutiflora* ‘Karl Foerster’ respectively, proving both species do well in 1 day of flooding and 6 days of drought. ‘Control’ got a score of 17 and 14 respectively for *F. ulmaria* and *C.* x *acutiflora* ‘Karl Foerster’. For this treatment the roots were large for both species (rank 4/4), but the shoots were among the smallest (rank 1/4 and 2/2). ‘Drought’ was the lowest scoring treatment with a score of 9 and 12 for *F. ulmaria* and *C.* x *acutiflora* ‘Karl Foerster’ respectively. It was especially bad for *F. ulmaria* scoring only 1’s for all measuring categories except for in the frost test.

Table 3 Summary scores of cyclic flooding performances for each treatment in Calamagrostis x acutiflora ‘Karl Foerster’ and Filipendula ulmaria. The measuring categories are root dry weight (RDW), shoot dry weight (SDW) total dry biomass (TDB), height (in cm), number of leaves/tillers and frost tolerance. In each category, 4 is the best and 1 is the worst. Higher score in sum shows better performance. In ranking, 1 is best.

		RDW	SDW	TDB	Survival	Height	Tillers/leaves	Frost	Sum	RANK
Filipendula	Control	4	2	4	100%	4	2	1	17.0	2
	Drought	1	1	1	100%	1	1	3	9.0	4
	Flooding	2	4	3	100%	2	4	4	18.0	1
	Cycles	3	3	2	100%	3	3	2	16.0	3
Calamagrostis	Control	4	1	2	100%	2	4	1	14.0	3
	Drought	1	2	1	100%	3	1	4	12.0	4
	Flooding	3	4	3.5	100%	1	3	2	18.5	1
	Cycles	2	3	3.5	100%	4	2	3	16.5	2

4 Discussion

Although there was 100% survival for both species during the cyclic flooding treatments the growth and physiological response varied. Most raingardens are constructed in such a way that the water is drained within 24-72 hours (Uncapher & Woelfle-Erskine, 2012). Both species showed suitability to this rain garden moisture dynamics because neither species showed to have significantly lower growth in the ‘flooding’ treatment which had the longest period of flooding of the four treatments, 72 hours. In fact, in the summary score table (Table 3), ‘flooding’ scores highest overall for both species. This can be explained by the fact that they are both found in moist environments naturally (Johansson & Nilsson, 2002; MacCaskey, 2001). The fact that both species are water loving plants can also explain why it seems that both ‘flooding’ and ‘cycles’ got better overall growth in both species than the ‘normal/control’ group. One explanation for this can be that the watering was too short in ‘normal’, although it was more frequent. In ‘normal’ water was filled up to the tops of the pots and then directly drained out which took around 30 minutes. Yuan & Dunnett also found that their ‘control’ did not do as well as the 1-day flooding in terms of growth, for species preferring more moisture (Yuan & Dunnett, 2018).

It was assumed that root growth would be the most sensitive to periodic flooding, due to possible damages on root metabolism and nutrient acquisition because of periodic hypoxia and anoxia, and thus plants in ‘flooding’ would have the least root growth (Voesenek et al., 2016; Yuan et al., 2017). This did not seem to be the case in this experiment, root growth was not lower in ‘flooding’ than in any of the other treatments (Figure 30 and Figure 32). Yuan & Dunnett (2018) found in their study that in the four day flooding treatment, there was a significant decrease in root growth for only 4/15 species they tested. There were no significant differences between any treatments in root growth for *C.* x *acutiflora* ‘Karl Foerster’ but in *F. ulmaria* there was a difference between ‘normal’ and ‘drought’. With ‘drought’ having very little root biomass in comparison to ‘normal’. This could mean that *F. ulmaria* is more sensitive to drying out than *C.* x *acutiflora* ‘Karl Foerster’ (Figure 32).

In raingardens strong root growth is important for persistence and survival, and to keep the raingarden functioning (Uncapher & Woelfle-Erskine, 2012). Roots make the soil more permeable, keeps it from clogging and there are more flow pathways for water to drain near roots (Virahsawmy et al., 2014). As both species had lowest root growth in the ‘drought’ treatment (11 days drought, 24 hours flooding), it is not recommended to use these species for a site which is mostly dry, or at the margins of a raingarden that get less water than the bottom. Although it would be possible to supplement with artificial watering when needed.

In the shoot biomass from harvested plants there was no significant differences between any of the treatments for *C.* x *acutiflora* ‘Karl Foerster’, but there were in *F. ulmaria,* between ‘drought’ and the three other treatments ‘normal’, ‘flooding’ and ‘cycles’. With ‘drought’ having lower shoot dry weight than the other treatments, proving again that *F. ulmaria* doesn’t grow well in long periods of no water.

Height and number of leaves are a quantitative traits widely used in comparative plant ecology, they are essential to a species’ carbon gain strategy and can be used as indicators for a plants growth and health (Westoby et al., 2002). For height and number of leaves in *C.* x *acutiflora* ‘Karl Foerster’, ‘drought’ and ‘cycles’ had a relatively high average number of leaves while those treatments had the fewest in average number of leaves (Figure 25 and Figure 26). This could mean that there is a strategy to grow higher over producing more leaves. *C.* x *acutiflora* ‘Karl Foerster’ had a slightly higher average height at the end of the treatments (61 cm) than before (59 cm), but not nearly as much as one would expect (Figure 25). One Norwegian experiment found the plumes of the plant to grow up to 166cm tall, and the tillers up to 97 cm (Heimdal, 2013). For number of leaves in *C.* x *acutiflora* ‘Karl Foerster’ it is also slightly higher average number at the end, than before treatments started. ‘Drought’ had the fewest number of leaves, and significantly different from ‘normal’. Suggesting that the species grows less dense when it gets too dry.

Filipendula ulmaria grew longer leaves in the end treatments (41 cm) than it was before treatments started (32 cm), but there were fewer leaves after treatments than before in both ‘normal’ and ‘drought’, while ‘flooding’ and ‘cycles’ had approximately the same amount of leaves before and after treatments (Figure 24 and Figure 27). *Filipendula ulmaria* plants from ‘flooding’ were on average shorter than the other ‘end treatments’ but had more leaves, while plants from ‘drought’ were both shorter and had fewer leaves on average. *Filipendula ulmaria* plants were also far from what could be expected of it in terms of height, its species description says it grows to up to 150 cm in the wild (Lid & Lid, 2005) .

Explanations for why both species were growing less than would be expected, even for the control groups can be that neither treatment provided the ideal moisture condition. As mentioned, lighting conditions of the greenhouse were confined to deep shade. The pH of the soil type from Lindum used was 7.7, which is a bit high as the ideal soil pH for best nutrient availability is between 5.5 and 7 (Brady & Weil, 2008). For both species, yellow leaves were present especially towards the end of the experiment, and more prominent in ‘drought’ and ‘flooding’ than in ‘normal’ and ‘cycles’ (appendix I). This could suggest lack of nitrogen (or other nutrient), drying out too much, lack of oxygen due to flooding or just simply that they were old leaves or that the autumn was here. Chlorosis in older leaves can suggest lack of nitrogen (Aasen, 1997). Because no tests were taken for nutrient deficiency, it is only possible to make guesses for what the cause of is the yellow and brown of leaves. The roots of the plants all looked healthy and there was no sign of any plants being rootbound or in any way limited by the pot size.

As for the weekly height and number of leaves measurements they revealed no real trend and the spread and averages remained almost constant throughout the weeks for both measures in both species, except for weekly number of leaves in *F. ulmaria* (Figures 18-21). In weekly number of leaves for *F. ulmaria* all treatments had a trendline of slope steeper than -0.5x, indicating no apparent differences between the treatments with regards to the number of leaves (Figure 19). Plotting the averages of each week allowed to see more clearly how it went for the average for each species in each treatment (Figure 22 and Figure 23). Here the differences were clearer between the treatments, but because it does not include the spread it can give the impression that the differences were bigger than they were.

In the frost tolerance test, *F. ulmaria* proved to be much more frost tolerant than *C.* x *acutiflora* ‘Karl Foerster’. This can also be explained by the fact that *F. ulmaria* is native to Norway and is also found in even colder regions such as Siberia (Vysochina et al., 2013). In the frost test the growing points were just covered with a 3 cm thick layer of sand, which does not isolate that much, and the growing points reached the same temperature as the frost chambers. This would not happen so often in true outdoors conditions. Outside vegetation cover, snow, and soil, isolate the growing points and the soil even 20cm down is rarely the same temperature as above the ground. Still the test revealed *F. ulmaria* can stand temperatures down to - 20 °C and 25% of the plants survived - 25 °C (Figure 37). For *C.* x *acutiflora* ‘Karl Foerster’ it revealed that it can stand temperatures down to - 15 °C, but the regrowth was only 1/6 of the weight of - 5 °C, and no survivors from - 20 °C (Figure 36). The differences in growth from each temperature might have evened themselves out if we had left the plants to grow for more than 4 weeks, or they could have been even bigger revealing frost damage to the plants from the coldest temperatures. Chang et al. (2014) found in their study of recovery of frost damage in potato plants that even though there were difference in growth and spread of plants that had significant frost damage 28 days after freezing, the plant had recovered and growth matched that of the plants without frost damage after 35 days.

There was a lot of fungi on the *F. ulmaria* plants, a few had it in the start of the experiment and by the end almost all of them had some fungi. This is probably because of dense placement of plants which lead to higher humidity, and are ideal for the spreading of fungus (Agrios, 1988). Gamborg also found higher presence of fungi with dense spacing of plants in her experiment, and that fungi decreased if plants were separated (Gamborg, 2018). The lack of light and natural breeze also most likely contributed to the spread of fungi, being under the roof having wind barriers on 2/4 sides. In nature *F. ulmaria* plants grow in the open allowing moisture to evaporate much faster. None of the *C.* x *acutiflora* ‘Karl Foerster’ plants had any fungi. Even if the presence of fungi on *F. ulmaria* might have had possible limitation on growth, the effect would be cancelled out since it was present on all of the individuals, and the differences in growth between the treatments were still present.

‘Flooding’ was the highest-ranking treatment for both species, indicating that both *F. ulmaria and C.* x *acutiflora* ‘Karl Foerster’ would do well in wetter types of raingardens and that 3 days of completely saturated soil is not a problem for either species (score 18 and 18.5 out of 24), with 4 days of drying out in-between (Table 3). 1-day flooding and six days of no water was the ‘cycles’ treatment, scoring 16 and 16.5, proving both plants to tolerate this kind of dynamic in a raingarden. ‘Drought’ with its 3 days of flooding followed by 11 days of no water was tough for both species scoring only 9 and 12. It was warm during the days of the experiment mostly between 18-25 °C, but some days as high as 30 °C, leading to even dryer conditions even though they were sheltered from the sun by the roof (Figure 8). Some plants nearly died in the ‘drought’ treatment but came back to life after watering again. This shows that neither plant species is suitable for use in rain gardens with longer periods of drought (11 days), while 6 days of no watering is fine. ‘Control’ is not very realistic as a raingarden dynamic, with watering twice a week and only for 30 minutes and thus the growth results was intended to be used as comparison for the other treatments.

With climate change it is expected that the summers get hotter and drier, and there will be fewer and more intense precipitation events for Oslo (City of Oslo Agency for Climate, 2020). Oslo city in July 2019 had a period with 7 days of no rain and a period with 5 days of no rain, August 2019 also had a period of 7 days of no rain and 5 days without rain (not counting 0.1 mm as a stop of days with no rain, appendix II)(met.no). This shows that selecting species that can stand relatively long periods of drying will be important when selecting plants for raingardens.

Assumptions on moisture sensitivity of plants are often derived from their tolerance to fluctuations in flooding and drying out and can be found in a variety of botanic guides for gardeners (Dunnett & Clayden, 2007; Steiner & Domm, 2012), and can often be predicted from their habitats. Yuan & Dunnett (2018) describes four levels of moisture sensitivities, (1) continuous inundation (i.e. wetland species), (2) periodic or seasonal inundation (i.e. wet meadow species), (3) infrequent inundation (i.e. species near rivers that flood infrequently) and (4) intolerant of inundation (i.e. species from dry arid regions). Both species tested in this experiment are found in wet meadows and places of infrequent inundation and were proven to tolerate periodic flooding well. Yuan & Dunnett (2018) also suggested that these four levels of moisture sensitivities can be used to see where in the raingarden the species should be placed. For example species intolerant of inundation can go to the margins, and wetland species tolerant of continuous inundation can go in the bottom (Figure 5). Perennials planted in environments according to their ecological needs result in greater longevity and lower maintenance demands (Hansen & Stahl, 1993).

5 Conclusion

The experiment has shown that both *Filipendula ulmaria* and *Calamagrostis* x *acutifoila* ‘Karl Foerster’ are suitable raingarden candidates for use in Nordic climates although *C*. x *acutifoila* ‘Karl Foerster’ should not be used in places were winter temperatures reach below -15 °C. They are both species which are found in frequently flooded environments and thus well adapted to a typical raingarden moisture dynamic. *C.* x *acutifoila* ‘Karl Foerster’ is more drought tolerant than *F. ulmaria,* and *F. ulmaria* is more tolerant to longer periods of inundation than *C*. x *acutifoila* ‘Karl Foerster’.

Based on this, results and that raingardens should drain within 72 hours, *F. ulmaria* as a wet meadow species is suitable for the bottom and slopes but should not be used in the margins. *C. x acutiflora ‘Karl Foerster’* as a species found in wet areas and areas of infrequent inundation, is suitable for all three areas of raingardens, bottom, slope and margins.

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Appendix

Appendix I. Selection of pictures of leaves from each treatment in each species

Figure 1 Leaves from 8 randomly selected plants in 'normal' of F. ulmaria in from destructive harvest (of 20).

Figure 2 Leaves from 8 randomly selected plants in 'drought' of F. ulmaria in from destructive harvest (of 20).

Figure 3 Leaves from 8 randomly selected plants in 'floodingl' of F. ulmaria in from destructive harvest (of 20).

Figure 4 Leaves from 8 randomly selected plants in 'normal' of F. ulmaria in from destructive harvest (of 20).

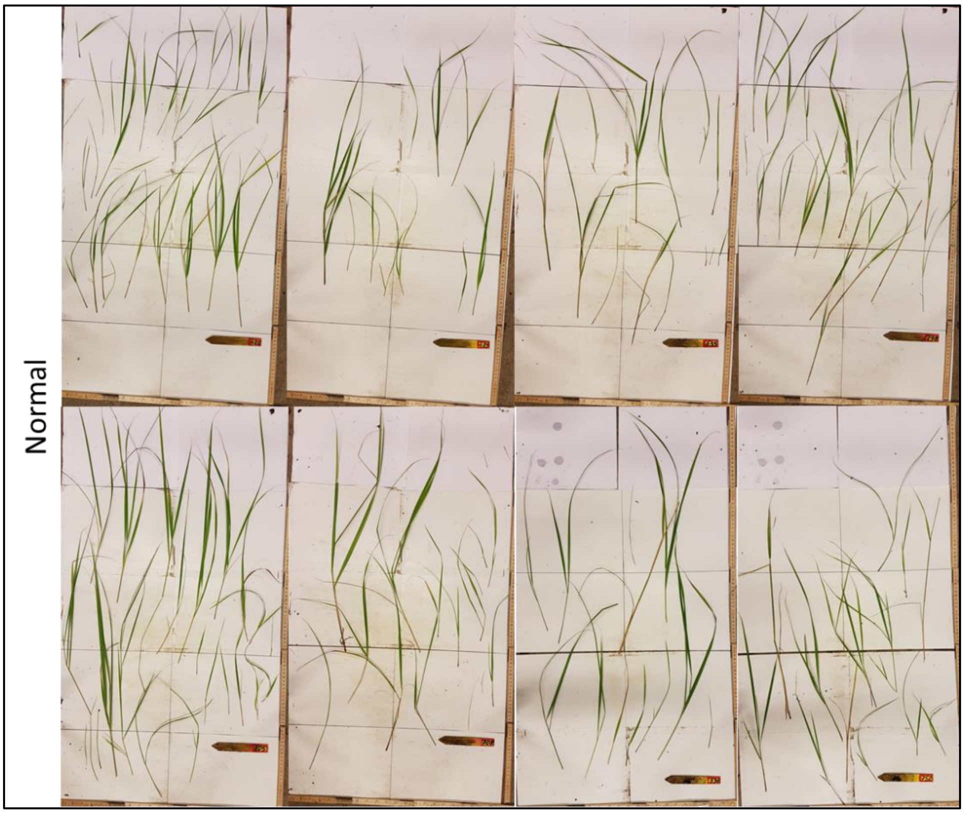

Figure 5 Tillers from 8 randomly selected plants in 'normal' of C. x acutiflora 'Karl Foerster' in from destructive harvest (of 20).

Figure 6 Tillers from 8 randomly selected plants in 'drought' of C. x acutiflora 'Karl Foerster' in from destructive harvest (of 20).

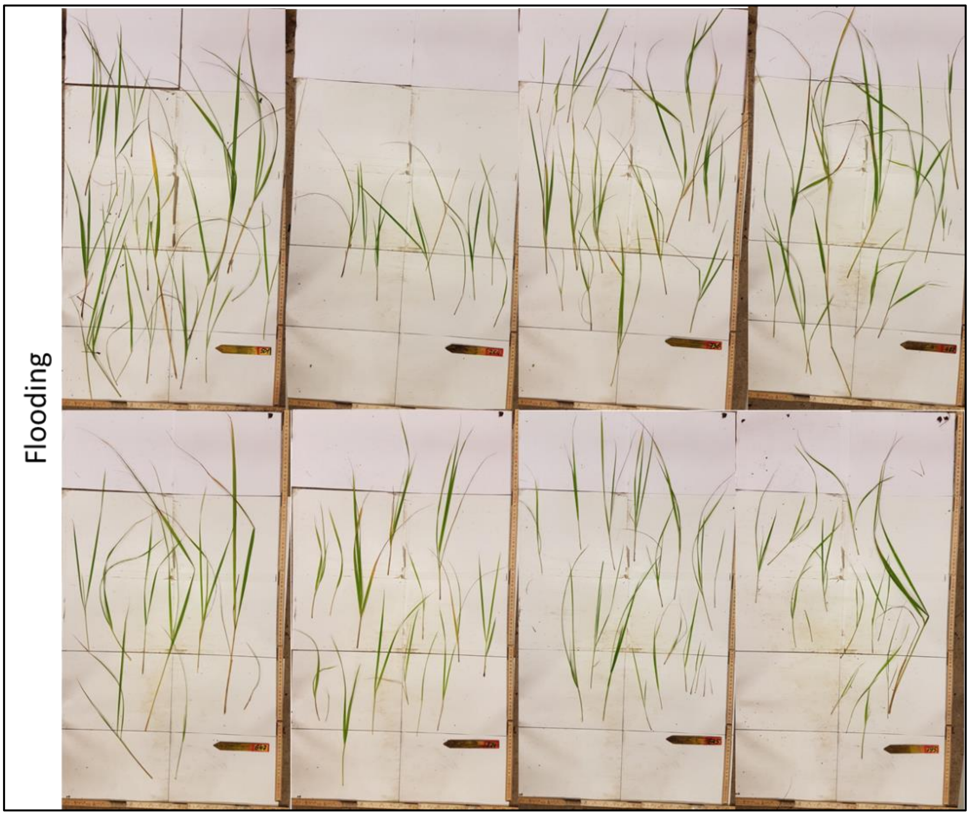

Figure 7 Tillers from 8 randomly selected plants in 'flooding' of C. x acutiflora 'Karl Foerster' in from destructive harvest (of 20).

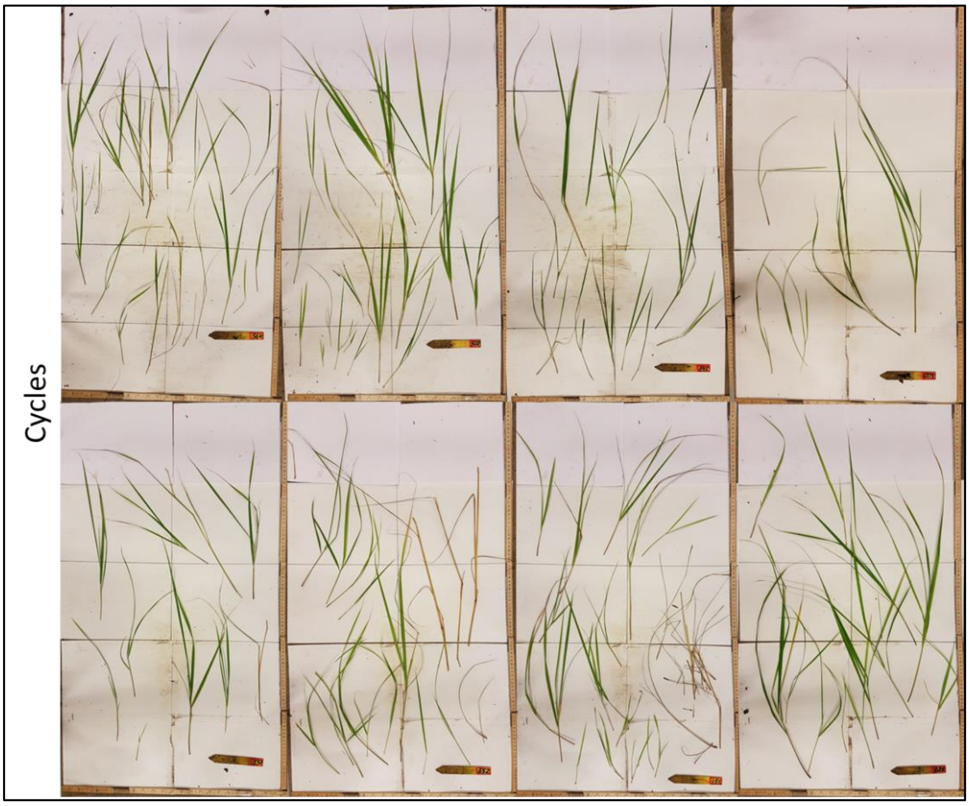

Figure 8 Tillers from 8 randomly selected plants in 'flooding' of C. x acutiflora 'Karl Foerster' in from destructive harvest (of 20).

Appendix II. Precipitation in Oslo the summer of 2019

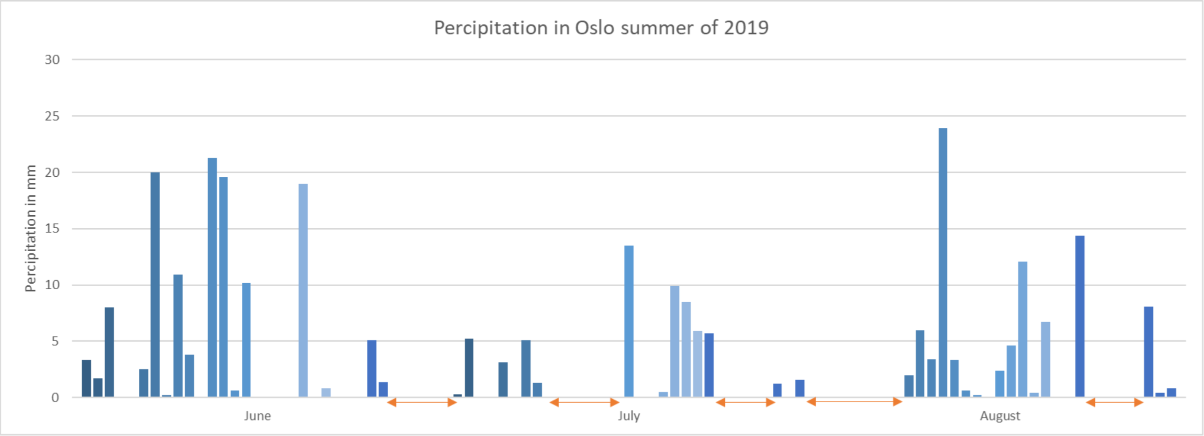

Table 1 Precipitation in Oslo the summer of 2019. Orange arrows show periods longer periods with no rain. Data from (met.no)

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