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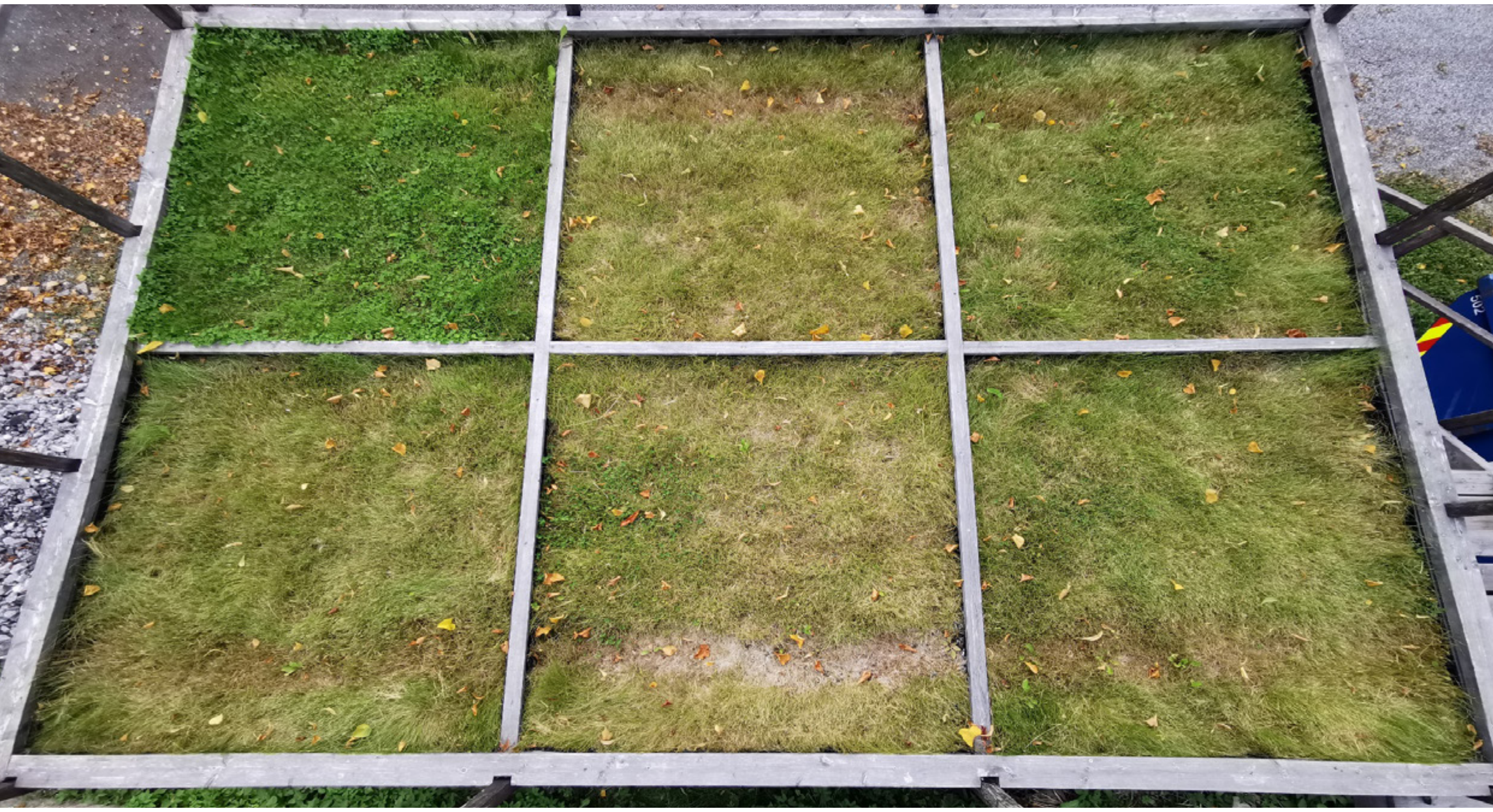

Photo: Erik Joner

Use of biochar for green roofs

Green roofs are increasingly being used to meet the challenges of extreme rainfall and surface water management in cities and towns. Biochar is a locally sourced and carbon-negative material that can be used as a substrate component for green roofs. Here are some experiences NIBIO has gained in this area through research and testing of various concepts

GREEN ROOFS

On green roofs, substrate mixtures are usually composed of different components. The substrate should retain large amounts of rainwater for a relatively short time (15–30 min.) when there is a need to prevent overloading of storm water systems. This is called retention. The substrate should also be a habitat for vegetation that protects the substrate from wind and water erosion. Last but not least, the substrate should be as light and affordable as possible to support cost effective construction and establishment. Some emphasize that the substrates should be composed of locally sourced materials that are climate and environmentally friendly.

Green roofs are classified as extensive or intensive. Extensive roofs have a light and shallow substrate layer (5–15 cm) of coarse material that holds little water and is usually planted with drought-tolerant plants such as sedum. Intensive roofs have deeper, more nutrient-rich substrate layers that consist of more fine material. Intensive roofs are often planted with plants that do not tolerate drying out. The amount of fine textured material is one determinant for water retention capacity. In addition, green roofs often have a drainage and water reservoir solution composed of textile layers and cupped plastic mats under the substrate. For most green roof systems the substrate contains a large proportion of light-weight components such as volcanic material (pumice), expanded clay (Leca) and the like, which have varying contributions to the carbon inventory of the project.

BIOCHAR

Biochar has recently received attention as a component in substrate mixtures. Biochar of suitable quality can be made from forest waste and other wood by pyrolysis using a temperature greater than 400 ° C. It provides a nutrient-poor and stable coal resistant to microbial decay, and which has a number of favorable properties as a substrate component: high porosity, high ion exchange capacity, low volume weight, mechanical strength that resists compacting, moderate lime effect, etc. In addition, biochar can be made from local raw materials, often waste products which have low value and few alternative applications.

If biochar alone is to be used as a growth medium, it will place special demands on particle distribution, neutralization of alkalinity and adapted fertilization, which would likely be both demanding and expensive to achieve. The most relevant use of biochar on green roofs is therefore as one of several components in a mixed substrate. The production of biochar in Norway is currently at a small scale, but actors such as the waste treatment industry, bioenergy producers and substrate producers have recently established pyrolysis plants.

NIBIO’S EXPERTISE ON BIOCHAR AND GREEN ROOFS

For several years, NIBIO has worked both with biochar as a substrate component and with green roofs in various contexts. We summarize here some experiences with biochar as a component of substrate mixtures / growth media, especially with regard to use in green roofs.

INTENSIVE ROOF IN ÅS, NORWAY

In 2018, NIBIO built a demonstration roof in the municipality of Ås in the form of a tool shed with an accessible[1] roof (figure 1).

The roof was divided into six sections with different substrate mixtures. The aim was to test biochar as a component in substrate mixtures for green roofs, especially with regard to plant health, substrate compaction and change in the substrate’s properties over time

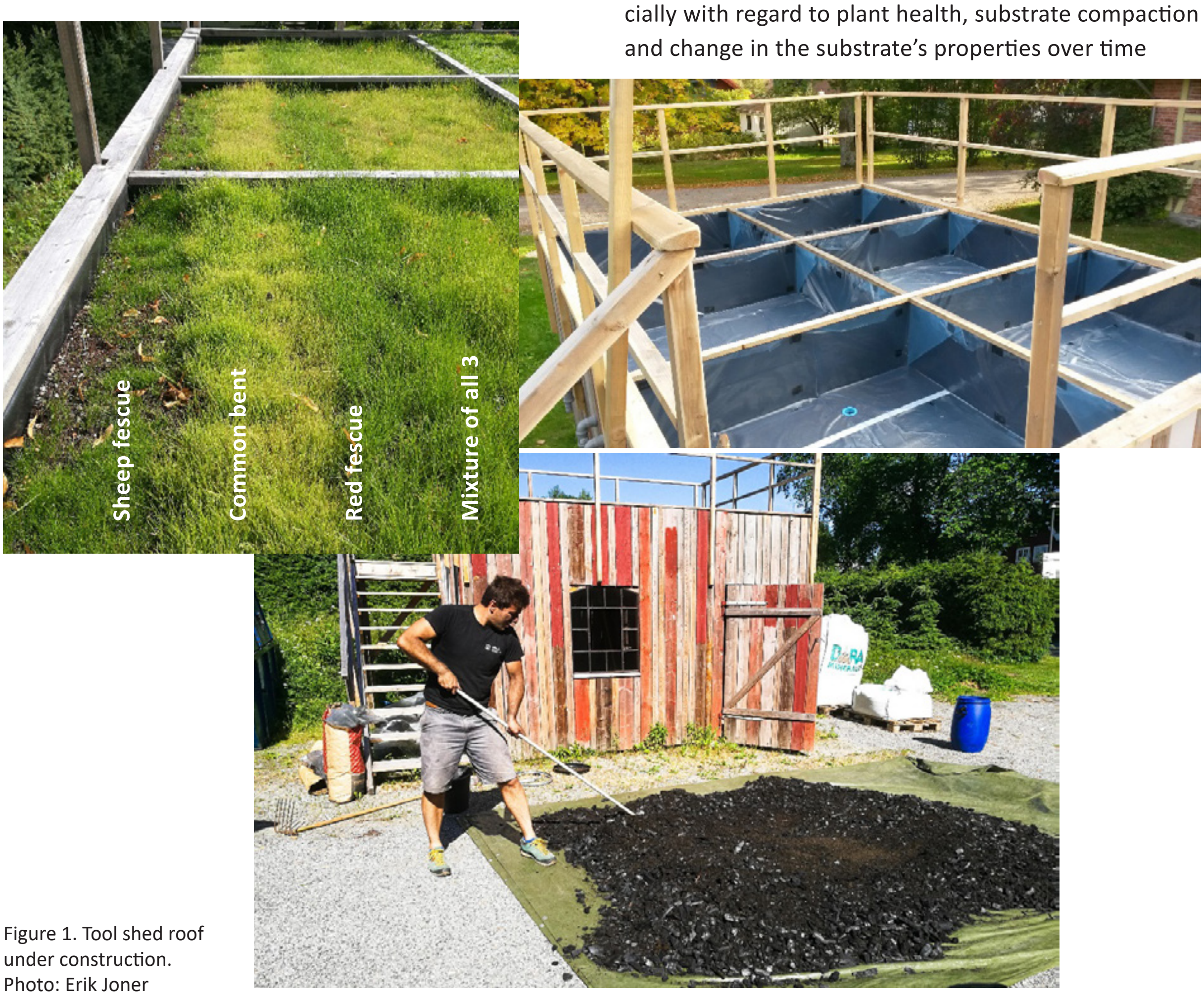

Figure 1. Tool shed roof under construction.
Photo: Erik Joner

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[1] A roof for user occupancy and with vegetation that can be walked on.

Table 1. Composition of substrate mixtures in different sections of the roof in Ås Municipality.

Field no	Composition of substrate (volume percentage)
1	98 % volcanic stone < 8 mm + 2 % compost (in the upper 25 cm), mineral wool (mats, in the lower 10 cm)
2	10 % compost 1 + 30 % Norwegian biochar 2 + 50 % volcanic stone + 10 % leca 3
3	20 % compost + 60 % Norwegian biochar + 20 % leca
4	20 % compost + 30 % Norwegian biochar + 30 % volcanic stone + 20 % leca
5	10 % compost + 30 % Norwegian biochar + 60 % volcanic stone
6	20 % compost + 30 % German biochar 4 + 30 % volcanic stone + 20 % leca

1 Garden / park compost sieved at <2 cm

2 Biochar produced from local hardwood, particle size 2–6 cm

3 Leca reused from a more than 20 year old infiltration plant for greywater (4 households) still intact and not crushed.

4 Biochar produced from forest waste, particle size 0–0.6 cm

(drainage capacity, pH and nutrient release.) The substrate depth was 35 cm. The various mixtures are presented in table 1. The sections were sown with three different grass species in segregated strips as well as with a mixture of all three species (see Figure 1.)

A tool shed with a base area of 3x4 m was completed in June 2018 and was built with 6 separate equal draining chambers (131x146x39 cm). These were lined on the inside with plastic, equipped with corrugated plastic sheets to facilitate lateral drainage (egg carton design, approx. 3 cm high), and covered with geotextile. Then each chamber was filled with 700 L of 6 different substrate mixtures (approx. 35 cm substrate thickness). Each square was sown with strips of three different grass species individually (1/6 of the area per species) while the remaining area was sown with a mixture of the three the species.

The biochar used on the test roof in Ås

We used two types of biochar: A Norwegian biochar produced by slow batch pyrolysis of hardwood (Helge Haugen, Hurum), and a German biochar produced by Pyreg based on mixed coniferous forest waste.

The Norwegian biochar consisted of relatively solid and large particles (2–6 cm) with a density of 0.25 kg / L and a pH of 8.2 while the German biochar consisted of easily crushable, finely particulate material (0–0.6 cm) with a density of 0.26 kg / L and a pH of 9.4.

Effects on retention

The ridge roof was used to compare substrate mixtures in terms of dispersion measured as breakthrough time and discharge rate in a subsequent measurement period. In general, increasing amounts and more fine-grained biochar gave slower discharge,

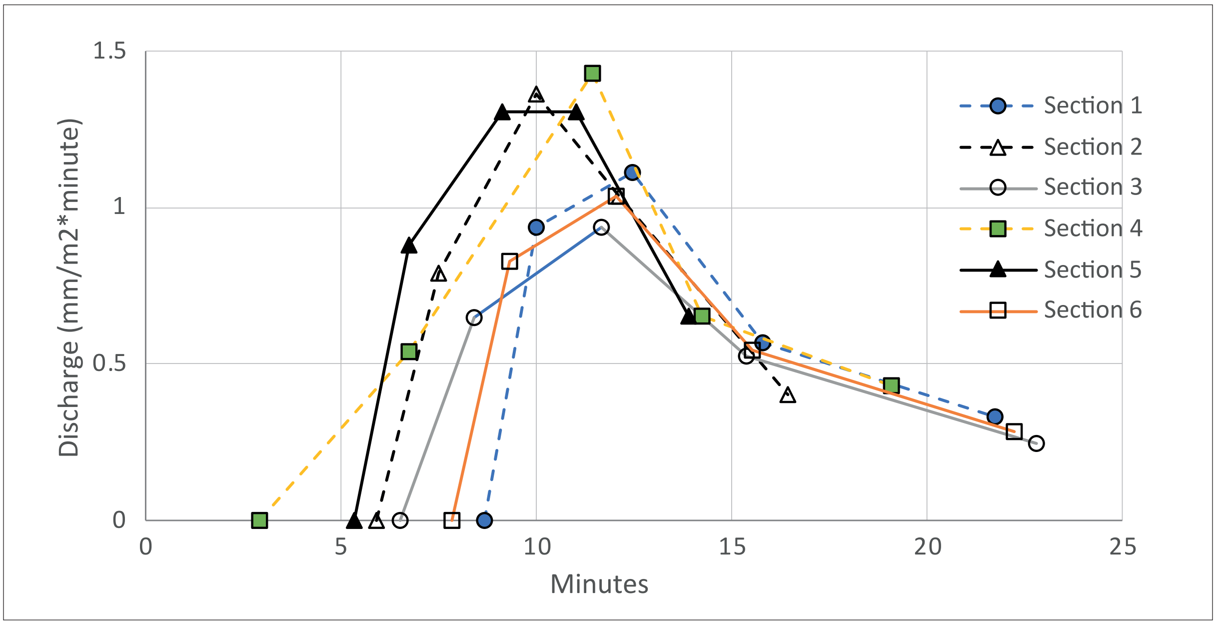


Figure 2. Discharge from the test roof. All fields were exposed to 30 mm rain within a 10 minute period. The discharge rate was measured until 40 % of the precipitation volume had run out. The substrate contained about 50 % of its maximum water storage capacity at the start of the experiment.

Table 2. Substrate pH and discharged water, as well as dissolved matter in runoff measured as optical density (OD).

Field	pH substrate, with ≈ 50 % water	pH substrate 2 d after saturation	pH runoff	Dissolved matter (OD at 634 nm)
1	7.10	7.13	7.4	0.013
2	7.16	7.20	7.5	0.004
3	7.34	7.23	7.6	0.004
4	7.23	7.25	7.6	0.005
5	7.17	7.19	7.7	0.012
6	7.30	7.20	7.7	0.003

while increasing amounts of compost or leca gave faster discharge. Slower discharge corresponded with later breakthroughs, reduced maximum discharge volume and longer retention time. An example of such a simulated precipitation and discharge episode can be seen in Figure 2.

Effects on pH

Biochar, compost and a number of other materials used in substrate mixtures usually have a high pH.

To counteract the adverse effects of increased pH on the vegetation, the biochar pH was modified by the addition of acid when the roof was established. The effect of this over time was uncertain, and therefore the pH of the substrate was measured on all sections and also of the discharged water from these at different times. As Table 2 shows, the pH varied only slightly between the different substrate mixtures. The addition of acid to the biochar thus allowed a high proportion of biochar to be used in the substrate mixtures without a significant increase in pH, and the pH in the substrate remained largely below 7.5 (pH varied from 0 to 0.3 units during the year). The pH of the run-off water was at times 0.5–1 units higher than the pH of the substrate, but usually only 0.2–0.5 units higher. This suggests that the alkalinity may be leached out over time. Dissolved matter in runoff measured after 2 years showed still a slight leaching of organic material after almost 3 years. Such leaching did not increase with an increasing proportion of compost or biochar in the substrate mixtures (table 2).

Other observations

The thickness of the substrate of the roof was originally 35 cm. Total compaction over 3 years was only about 2 cm despite the fact that the roof was exposed to foot traffic. Collapse occurred mainly during the construction year, and may be partly due to compression of the drainage layer.

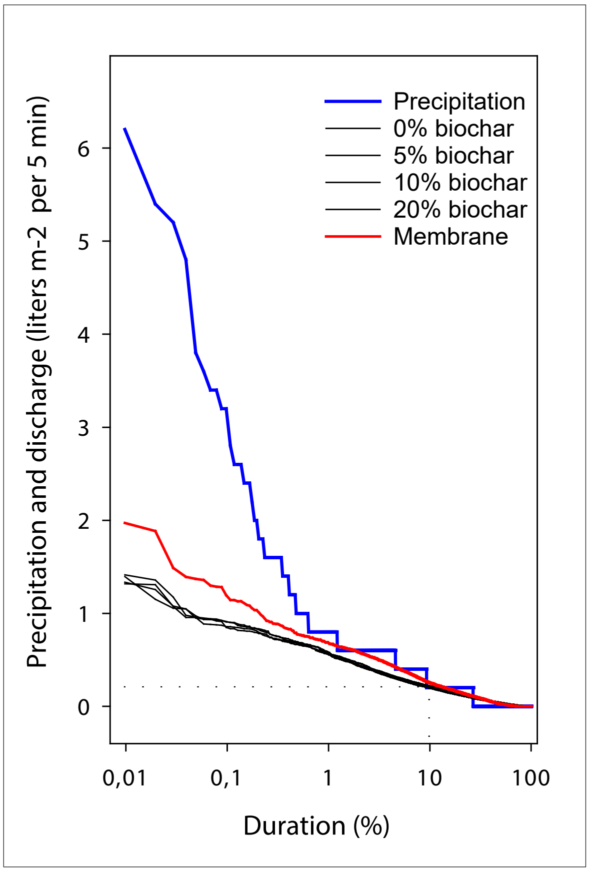
Plant growth was very strong on Section 1 (the reference section, this was cut regularly and grass was removed), and low to moderate on other sections (these were fertilized with a low dose of urea in the second growing season and cut 1-2 times a year). After 2 years several white clover plants appeared, especially in Sections 1 and 3. Of the three grass species used, growth and survival was best for red fescue. Common bent died out during the winter of the 3rd year. Sheep fescue functioned much like red fescue, but established itself more slowly.

EXTENSIVE ROOFS AT SÆRHEIM

In 2014, NIBIO built ten stations to measure run-off continuously from test roofs at Særheim in Rogaland, Norway. The test roofs that are connected are 2 x 3 m with an adjustable roof slope.

We measured runoff from experimental green roofs with different structures and included biochar in many of the experiments (Figure 3). It is not always so easy to isolate the effect of biochar. So far, we only have long-term series of runoff from extensive roofs with a thin, coarse substrate layer of 5 cm and where the biochar content has been from 0 to 20 % by volume. Runoff measurements over a year are shown in Figure 4. There is a minimal effect of biochar on runoff from such thin roofs. We expect greater effect

Figure 3. Experimental roof on NIBIO Særheim where different compositions of substrate and vegetation are examined.
Photo: Arne Sæbø



Character 4. Duration curve for rain and runoff from trial roof with an extensive structure with 5 cm growth masses under sedum mats. In the substrate, fine biochar (BK) is mixed in from 0 to 20% by volume. The measurements have been carried out over a year at Jæren. The curves show the proportion of time (in %) the runoff has been greater than or equal to one given value, f.ex. exceeds the precipitation 0.2 liters per m 2 and 5 minutes, only 10% of the time (illustrated with those dotted lines). The curves for the different blends of biochar were almost identical and are shown with the same color..

for thicker layers and for growth masses with less coarse material. Fine biochar in coarse growth masses also yields some runoff of biochar particles.

EFFECTS OF BIOCHAR ON GROWTH AND DROUGHT RESPONSES OF ROOF VEGETATION

We have also investigated how the incorporation of biochar into substrates affects the vegetation. Mixing of from 0 to 60 volume percent biochar in thin layers of substrates of 5 and 10 cm showed positive effects of quantity - where biochar of up to 10 % by volume on growth and survival during drought for species such as sea campion, common bird's-foot, sea plantain and sheeps fescue. Larger quantities had no further effect. For the sedum species we tested, increasing amounts of biochar had a negative effect on growth. We followed up this experiment with a more detailed study of these effects. Three different pumice-based base mixtures with substrate (one standard mixture for sedum roofs, one added with more organic material, and one adjusted to a slightly higher pH) were diluted with 0–30 % volume percent biochar. Growth and drought experiments were conducted at a depth of 10 cm for three species. This experiment showed that the effect of biochar varied with the properties of the substrate it was mixed into, and between the species that were tested (Figure 5). Here too, the response flattened out or decreased with admixtures above 10 % by volume. It was not clarified in which substrate one can expect the most positive effect of biochar. Plants that thrive in substrates with high pH do not seem to benefit from biochar.

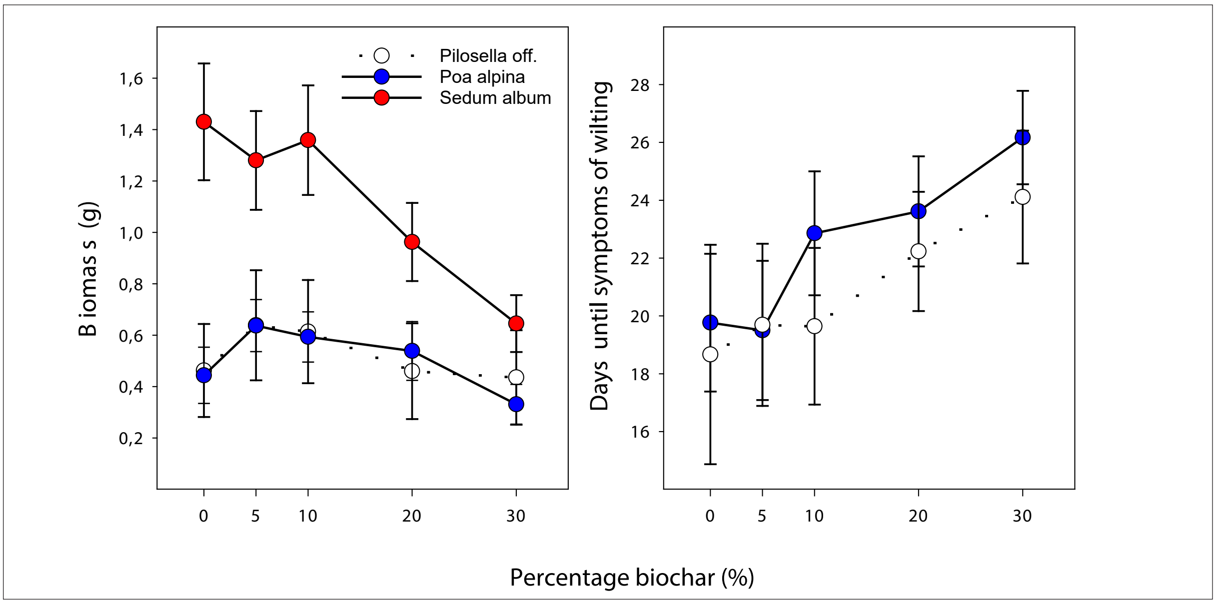


Figure 5. The effect of biochar in the substrates on plant biomass (left) and the time it takes for the plants to begin to wilt during longer drought periods (to right) is shown with 95 % confidence interval. The effect on the drought response must be considered in context with plant size. Bigger plants user more water.

Biochar. Photo: Erik Joner

OPPORTUNITIES AND LIMITATIONS

se of biochar in substrates on green roofs requires that a number of factors be taken into account that will affect the costs and function of such roofs. Factors that may limit biochar use are availability, price and quality as well as lack of experience and knowledge of use on specific types of roofs.

Biochar in substrates for green roofs must meet the requirements of national fertilizer regulations regarding heavy metals. For biochar made from forest waste etc. this is not a problem, especially if the ash content is low. High ash content may require pre -treatment to avoid the negative effects of high pH, or necessitate a reduction in the amount of biochar used. Fire safety considerations may also lead to limits on the amount of biochar that can be used.

Substrates with > 30 % (volume) of biochar are considered combustible if they are exposed to drought

The advantages of using biochar lie in particular in the material's favorable properties in terms of weight, porosity, bearing strength and nutrient absorption.

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In addition, the use of biochar can score high regarding aspects related to climate, environment and sustainability. Biochar is a carbon-negative material that can be sourced locally, and can be used in marketing construction projects and companies that want an improved environmental profile, or in voluntary compensation schemes for carbon emissions. At present, biochar is not recognized as a measure for carbon capture and storage in Norway, but in 2019 the international climate panel IPCC opened for inclusion in national climate accounts under certain conditions. In 2022, the inclusion will not be applied in Norway.

More information about biochar:
Norwegian Biochar Network: www.biokull.info,
NIBIO's website about biochar.

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