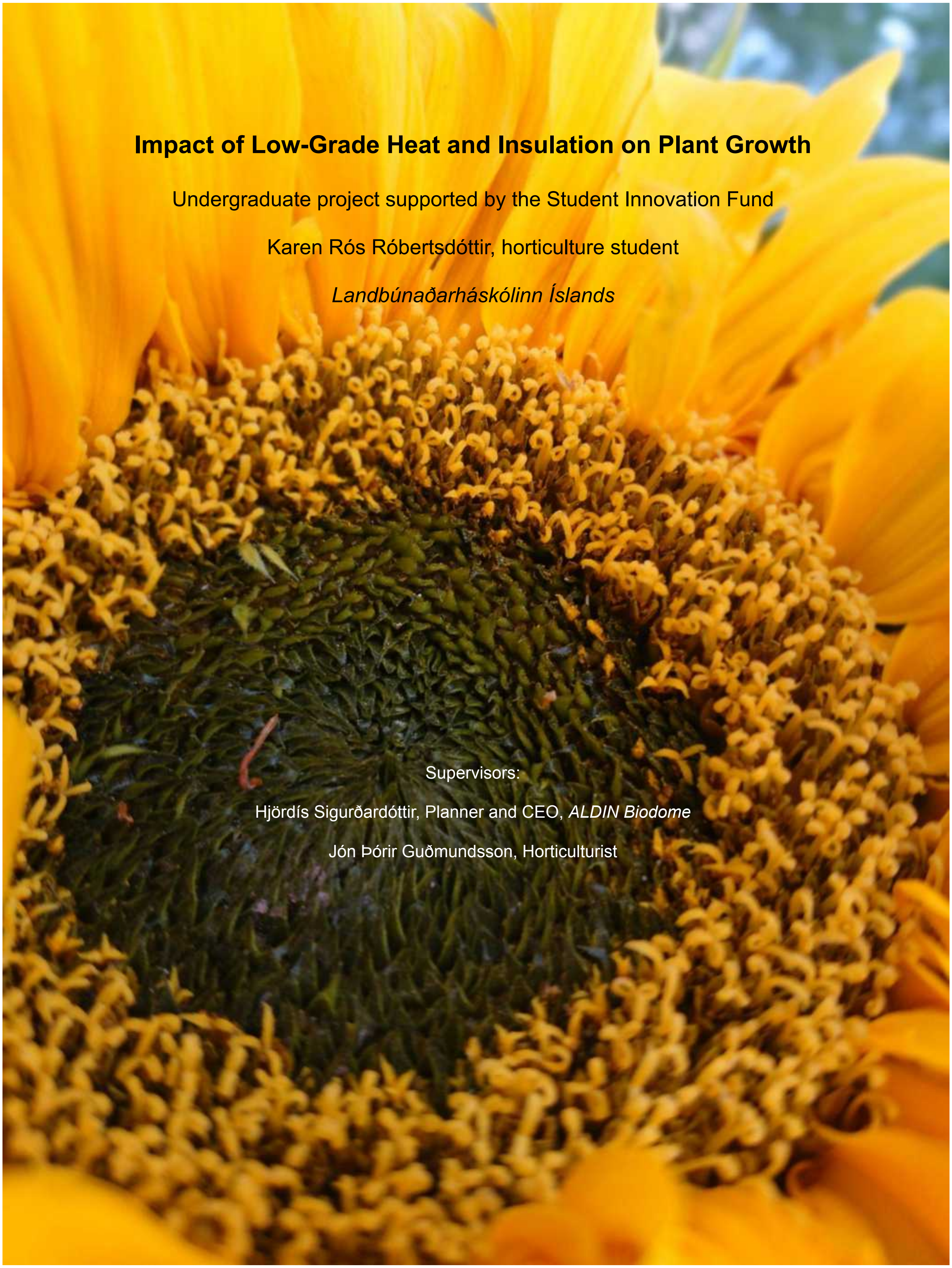


Impact of Low-Grade Heat and Insulation on Plant Growth

Undergraduate project supported by the Student Innovation Fund

Karen Rós Róbertsdóttir, horticulture student

Landbúnaðarháskólinn Íslands

Supervisors:

Hjördís Sigurðardóttir, Planner and CEO, *ALDIN Biodome*

Jón Þórir Guðmundsson, Horticulturist

Abstract

Large quantities of low-grade hot water are abundant in numerous locations, particularly as a byproduct of power generation. Disposal of such water is generally harmful to the environment (thermal pollution), and allowable discharge rates can become limited during periods of low river flow. Low-grade warm water is particularly abundant per-capita in Iceland, where geothermal wells and power plant outflows are used for a municipal heating system, being discharged at around 30°C. At the same time, while all temperate regions suffer from reduced cultivation potential in cold weather, high-latitude locations such as Iceland experience cool or cold weather during the entire year, significantly reducing cultivation options. Lower-grade heat, however, has reduced potential for maintaining soil temperature relative to higher-grade heat. Consequently, we established a programme to investigate the impacts of (and optimal configurations for) use of thermal wastewater in cultivation with insulated beds.

This year marks the first year that the garden has been available for full-year cultivation experiments and allows us to continue the experiments with perennials of last year. While last fall showed promise for the use of this abundant resource, this year should allow us to draw much stronger conclusions and test hypotheses that arose during the previous year.

Keywords: geothermal, thermal pollution, wastewater, heat, soil heat, root stimulation, growing season, cold-climate agriculture, Iceland

Ágrip

Víða í heiminum er til staðar mikið magn af volgu vatni (lághitavatni), sérstaklega sem affallsvatn frá orkuverum. Losun svona vatns er yfirleitt skaðleg fyrir umhverfið (hitamengun), og leyfilega magnið á losun ætti að vera takmarkandi þáttur þegar vatnshæð í ám er lág. Losun á volgu (og skaðlegu) affallsvatni er sérstaklega algeng miðað við höfðatölu á Íslandi, þar sem borholur og affallsvatn frá orkuverum eru notað til húshitunar, sem er svo hleypt út í fráveitu á rúmlega 30°C. Þó svo ræktungargeta á öllum tempruðum svæðum sé minni í köldu veðri, þá getur orðið svalt og kalt á norðlægum slóðum, eins og á Íslandi, allt árið í kring, sem dregur mjög úr ræktunarmöguleika utandyra. Hins vegar eru hlutfallslega ekki eins miklir möguleikar á að halda uppi hitastigi í jarðvegi með volgu vatni samanborið við heitt vatn. Þess vegna er markmið þessa rannsóknarverkefnis að skoða áhrif notkunar volgs affallsvatns í ræktun (og þá útfærslu) og þá í einangruðum beðum.

Þetta ár er hið fyrsta sem tilraunagarður ALDIN hefur verið til staðar fyrir heilsárs ræktunarrannsóknir og gefur okkur því tækifæri til að halda áfram að skoða framvindu fjölærra plantna sem gróðursettar voru í fyrra. Þó svo rannsóknarniðurstöður síðasta hausts lofuðu góðu er varðar nýtingu þessarar auðlindar eigum við að geta dregið mun sterkari ályktanir í ár þar sem verið er að prófa kenningar sem voru settar fram í fyrra.

Lykilorð (lauslega þýdd): Jarðvarmi, hitamengun, affallsvatn, hiti, jarðvegshiti, rótarvöxtur, ræktunartími, garðyrkja á köldum svæðum, Ísland.

Table of Contents

Introduction

Why This Research?

Last year, our research (funded by NSN) showed some tantalizing potential for the use of geothermal wastewater - available in abundance in Iceland, and normally discharged out to sea - for soil heating to lengthen the cultivation period and increase yields. The waste water, 27-30°, was routed through PEX tubing in the ground in different configurations in experimental beds, while control beds were left unheated (fig.1 and 2). While tantalizing results were observed, the research garden was established late in the year and hot water collected even later, limiting the amount of research that could be carried out and the quality of the conclusions. Additionally, many plants are perennials and may take one or several years to yield conclusive results.

Fig. 1: Valve cabinet for temperature control and monitoring

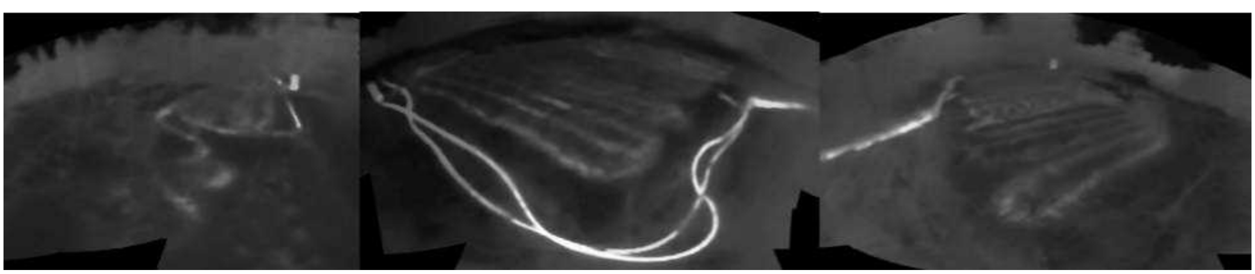


Fig. 2: Infrared imagery of the garden, showing heat reaching the surface from buried PEX tubing; the bright lines are non-buried outflow tubing. The images are taken from, from left to right: southwest; southeast, and northeast.

For vegetable growers who have access to geothermal wastewater or other low cost (but potentially low-grade or stranded) sources of heat, the project has potential economic implications, opening up the possibility of significantly increased yields at a much lower infrastructure cost compared to greenhouse construction. In an urban setting (such as in

Reykjavík), fruit tree and exotic plant cultivation is of particular interest where the weather creates shelter and sufficient light. Exotic fruits on trees in the city provide inspiration and joy, and can open doors for further experiments at a larger scale.

It is particularly interesting to try fruit growing in connection with the ALDIN Biodome which is an innovative project in and of itself. ALDIN has received international awards in the field of outstanding development project with a socio-positive impact (GWIIN, 2017); its goal is education, inspiration and the utilization of the energy resource in new ways to promote better health and awareness. Research on how to better utilize low-grade and stranded heat resources is a logical continuation of ALDIN's goals.

As was discussed last year:

> *A diverse diet with an increased emphasis on consumption of vegetables is an important part of a healthy lifestyle. Today there is an increased demand for plant-based diets, but Icelanders rely on imported vegetables and fruits to a great degree; indeed, 50% of the Icelandic diet is made of imported calories, including half of all vegetables, sugars, and oils and nearly all fruit, cereals, and beans (Halldórsdóttir & Nicholas, 2016). Today, especially in the wake of the COVID-19 pandemic, there have been increasing calls for a greater degree of self-sufficiency, both in Iceland (Ólafsdóttir 2020; Samband Íslenskra Sveitarfélaga 2020) and in Europe in general (Bruyninckx 2020).*

Based on the promise shown in the previous year's research, it is important to further quantify the potential.

2020 Growing Season: A Review

Fig. 3: The research garden in mid-September, 2020.

The research process got off to a late start due to regulatory and contracting delays, with permission to develop the garden granted on 16 Julys. Planting occurred between 25 and 29 July, and warm water was connected on 27 August (fig.3). Just days later we got our first cold storm on 30 August, and then another on 5 September with north winds below freezing that caused significant damage. Research continued up until December to see how plants would handle the arrival of winter, and were left - some with floating row covers, some uncovered - until the spring.

Fig. 4: Frost coats the garden in 2020

Due to the late arrival of heat and the early arrival of frost (fig. 4), data on sensitive plants like tomatoes, peppers, squash, and bananas was limited. Much more informative were cold-hardy plants like brassicas, lettuce and celery. Growth progressed faster in the control beds before heat was connected, particularly sunny uninsulated areas, while the situation reversed and growth was significantly faster in the experimental beds once heat was connected. Net benefits of 20-180% in growth were seen from heating, depending on the plants and beds.

Little difference was observed between plumbing patterns in terms of growth rates. Insulated heated beds performed worse than uninsulated heated beds, although suspicion focused on the use of insulation-filled trenches between rows rather than insulation on the surface, as well as the late start that insulated beds got (uninsulated beds were warmed by the sun).

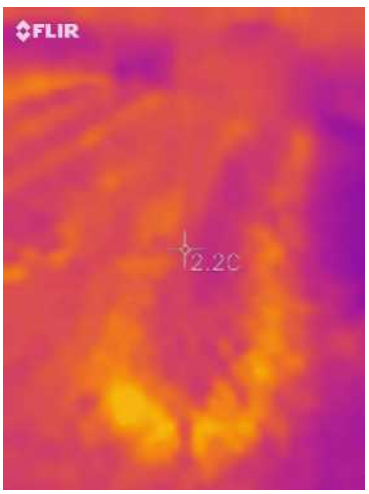


Fig. 5: Heat visible leaking through wood chips

Estimates of flow rates through the different beds were unexpected and contradicted by other measurements, and are assumed to be skewed by losses en route to the beds and flow disruption by air bubbles or debris. FLIR imaging (fig. 5) shows a clear order of insulation effectiveness, uninsulated < wood chips < pumice. Wood chips also proved snail prone, and less attractive than pumice. The one area where wood chips proved superior was durability under foot traffic.

Cucumbers succumbed to sunscald, fungus and cold. Tomatoes and squash were listless and showed little growth. Bananas and monstera suffered heavy cold damage. Bananas continued attempting regrowth until late fall / early winter, with more vigorous efforts in heated beds. Roses bloomed in both beds; aphids were a temporary problem, but were checked with neem and hand control. Blooming continued up through frost. Redwings predated cherries, honeyberry, strawberry, blackcurrant, and to a lesser extent tomato and plum fruits. Otherwise, no issues were observed with any berry plants or trees. The harvest of berry plants and trees was considered unimportant regardless, reflecting more how the plants were grown before being planted than their experience in the garden. Grape vines strangely bloomed after the first frost and only shortly before being defoliated by a hard frost.

Theft proved to be a frequent and problematic issue, with the largest and healthiest plants being targeted, skewing data via survivorship bias.

Between Seasons (Winter 2020-2021)

Fig. 6: Lettuce harvested on 21 Nov.

Progressively deeper frosts weighed down on the garden in October and November. Half of each of the mixed-crop beds (#1-5, 7, 8, and their respective controls) were covered in floating row covers. Regardless of row cover status, all celery died off after a frost of around -5°C. The brassicas and lettuce survived much longer (fig. 6 & 7). Lettuce was harvested as late as 21 November - still sizable heads. Most lettuce had taken significant damage from an unseasonal -15° freeze, but those under row covers were still salvageable (albeit with some frost discolouration). A final small harvest of some brassicas was done on 18 December; frost damage was relatively low, but effort needed to harvest, particularly underneath the floating row covers, became increasingly onerous and prevented further work. In particular, the row covers and the stones and

Fig. 7: Brassicas remaining in November

branches holding them down began freezing to the ground (fig. 8).

Fig. 8: Floating row covers over half of the garden

Fig. 9: Second-year cabbage (3,1kg)

Only a relatively small number of plants survived into the next year. These were not particularly studied, and most were allowed to flower to attract pollinators, and ultimately go to seed. That said, we did harvest and measure a massive 3,1kg head of cabbage from heated trial #5 (fig. 9).

Cold-weather crop seeds were ordered with the intent to do a late winter / early spring planting, and precultivation began indoors. This intended plan proved impossible; the control beds, and sometimes the upper layer of the experimental heated beds, were frozen solid. The plants could not be planted had to be delayed several months confined to their pots in subpar growing conditions and were in poor health by the time they could be planted (21 March 2021).

The Research Problem and Objective for 2021

To further our research, a new set of experiments were laid out starting in early spring of 2021, to examine:

- Extreme early-season cultivation
- Full-year cultivation
- Progress of the previous year's perennials
- Investigation of potential solutions for issues encountered in the past year
- New experimental species and cultivars

As with last year, experiments will be matched with controls - either heated experiments vs. unheated controls, or heated experiments matched with other heated experiments in other configurations. In each case, the objective will be to observe changes in yield and timing.

Research Questions

It is possible to extend the growing season in outdoor cultivation and affect the amount of harvest and species diversity with soil heating, and how does this impact economics?

1. What effect does soil heating have on the success of fruit trees and perennials?
2. How does heating impact early planting in the spring, e.g. in winter wheat, etc.
    a. Is it possible to extend the outdoor cultivation period and have an impact on the size of the harvest and the diversity of species which can be cultivated by means of heating the soil with geothermal wastewater? If so, how much, and how impactful can it be?
    b. What cultivation plan is optimal in terms of selected crop varieties and fruit trees?
        i. Soil and insulation

ii. Plumbing depth and flow patterns
iii. Growth progress and cultivation time periods
iv. Types of plants which can be cultivated (potentially including those not typically suitable to outdoor environments in Iceland)

3. What are the expected costs and operational expenses with such a system, and over what time period can it be repaid?
4. What are the potential benefits for farmers and gardeners in Iceland to implement such a system? What unexpected environmental impacts might there be from such a system?

Materials and Methods

Site Alterations

Two key alterations were required on-site compared to the previous year.

Security

As theft proved to be a problem the previous year, distorting research results, several measures needed to be taken.

- A very large sign describing the project and telling people to enjoy it from a distance but warning that the site was monitored was added over the winter (fig.10). It was anchored by a concrete block. No problems with the sign have been noted.

Fig. 10: The research garden sign, anchored by concrete blocks

- A security system was ordered but it required several iterations before a suitable one (Reolink, a GSM camera) was discovered. It arrived after extensive Singapore Post delays; it was not installed until 12 April (fig. 11), on a moderate-sized black cottonwood on the south side, approximately 4 meters up (fig. 12), with a south-facing solar panel. Nearly the entire garden except for the south corners is visible; however, only people walking relatively near the camera trigger the sensors. Alerts are automatically sent to a cell phone on motion events, and videos can be watched in real time or downloaded. On windy days, tree sway sometimes sets off false alarms, but this is not usually a problem.

Fig. 11: Camera installation

Tree trimming

To assist plants in continuing to grow late in the year, branches were removed from some of the trees to the south to open up a “window” for low-angle light to shine through in late fall / early winter. These were primary lower branches of black cottonwoods and middle branches of Sitka spruce (foreground and right-background of fig. 12).

Fig. 12: Camera and solar panel

Trench infill

Fig. 13: Pumice displaced from trenches and replaced with soil (first odd rows, then even). The resemblance to shallow graves is coincidental.

As one of the hypotheses to be tested this year was that insulation-filled trenching between rows is detrimental to plant growth, it was required that in some particular beds - the pumice beds #7 and #8 were chosen - half of the trenches on each row (the east side) would be filled in (fig. 13). This required removing large amounts of pumice, shoveling in (newly ordered) soil, and re-spreading the pumice; this took about 8 hours of work.

Pre-cultivation and Planting

Seeds of the following species / cultivars were purchased from Baker Creek Heirloom Seeds as an early order intended for a winter/early spring planting:

- Kale (*Brassica oleracea*): Dazzling Blue, Niro di Toscana
- Cauliflower (*Brassica oleracea*): Purple of Sicily
- Rutabaga / Swede (*Brassica napus*): Navone Yellow
- Tatsoi (*Brassica rapa*): Green
- Mizuna (*Brassica rapa var. niposinica*): Early
- Mustard (*Brassica juncea*): Green Wave
- Leek (*Allium ampeloprasum*): Giant Musselburgh
- Wheat (*Triticum aestivum*): Red Fife
- Lettuce (*Lactuca sativa*): Ice Queen
- Corn Salad / Mâche (*Valerianella locusta*): Verte a Coeur Plein 2
- Salad Burnet (*Sanguisorba minor*)

- Arugula (*Eruca vesicaria*): Wild Rocket

Later, the following warmer-weather varieties were purchased from Baker Creek Heirloom Seeds:

- Squash (*Cucurbita pepo*): Gelber Englischer Custard, Spaghetti
- Zucchini (*Cucurbita pepo*): Black Beauty
- Pumpkin (*Cucurbita pepo*): Jack Be Little, Winter Luxury Pie
- Cucumber (*Cucumis sativus*): Ancash Market, China Jade, Dragon's Egg, Early Fortune, Lemon

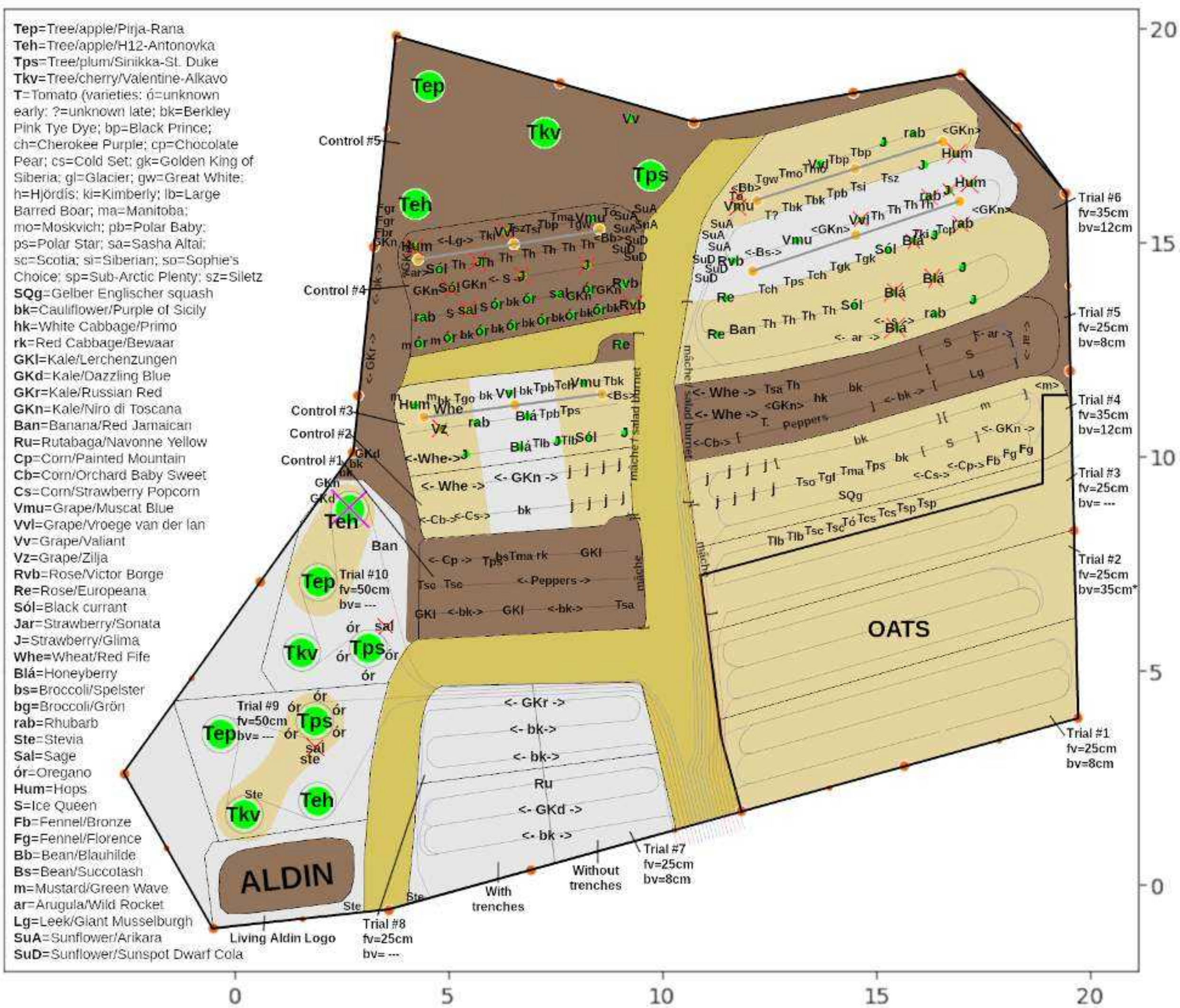


Fig. 14: The garden, as it stood in September 2021. Some earlier experiments, such as with mizuna and tatsoi, had been replaced by this point. Red Xs are marked over perennials which did not survive the winter. The purple X indicates "stolen".

- Squash (*Cucurbita maxima*): Buttercup
- Melon (*Cucumis melo*): Ha'ogen, Minnesota Midget, Petit Gris de Rennes Melon, Tommy Apple
- Watermelon (*Citrullus lanatus*): Blacktail Mountain, Silver Yamato
- Sunflower (*Helianthus annuus*): Arikara, Sun Spot Dwarf Cola
- Tomato (*Solanum lycopersicum*): Cherokee Purple, Chocolate Pear, Berkeley Pink Tie-Dye, Large Barred Boar, Great White, Golden King of Siberia
- Eggplant (*Solanum melongena*): Japanese White, Little Fingers
- Pepper (*Capsicum annuum*): King Of The North, Lipstick, Jimmy Nardello, Sweet Chocolate, Banana

Fig. 15: Measuring light levels during tomato precultivation

- Toothache Plant (*Acmella oleracea*): Bullseye
- Stevia (*Stevia rebaudiana*)
- Artichoke (*Cynara cardunculus var. scolymus*): Colorado Red Star
- Bean (*Phaseolus vulgaris*): Blauhilde, Succotash
- Corn (*Zea mays*): Orchard Baby Sweet Corn, Painted Mountain, Strawberry Popcorn
- Fennel (*Foeniculum vulgare*): Bronze, Florence

The following seeds were shortly thereafter purchased from Reimer Seeds:

- Tomato *(Solanum lycopersicum)*: Black Prince, Cold Set Tomato, Glacier Tomato, Moskvich, Oregon Spring, Polar Baby, Siberian, Siletz, Sub-Arctic Plenty, Sasha Altai, Scotia, Sophie's Choice, Polar Star, Manitoba, Kimberly

Fig. 16: Improvised seedling precultivation

Initially the plan was to do a winter planting to test the extremes of how early the season could be started with heat. In pursuit of this, seed trays were planted indoors in trays in an improvised setup on 5 November (fig. 16). Lighting was limited and uneven, but it was not anticipated that the plants would need to be in the setting for protracted periods of time. Around New Years the plants were ready to be planted, but this proved to be impossible, as the heated beds had an ice crust on the surface and the control beds were frozen solid; planting them would have required a jackhammer. The plants were kept indoors in these subpar conditions until outdoor planting on 21 March (fig. 17), alongside corn, bean and sunflower seeds that were directly sown. Wheat ‘Red Fife’ was planted earlier, around 1 March.

Fig. 17: Greatly-delayed seedlings planted in March

On 22 March a new batch of the same seeds were sown indoors. These were transferred to a cold frame on 3 April, and were planted on 12-13 May.

12 tiny strawberry ‘Glima’ plants were acquired from Jón Guðmundsson, a local fruit expert and project advisor. They were planted on 13 May.

The warm-weather seeds (excepting corn and beans, but inclusive of sunflowers) from Baker and Remier were sown indoors on 7 and 13 April, respectively; transferred to a cold frame on 14 May, and were planted from 27-30 May, alongside two banana plants.

Oat seed (variety “Perttu”) was purchased from Lífland, and was sown directly in the garden on 6 May. As the smallest available size was 40kg and only a tiny fraction was needed for sowing, the remainder was donated to a horse breeder.

Due to the failure of the outdoor-planted corn and beans (Fig 18), a second set was prepared on 28 May and planted on 8 July.

A second batch of seeds - corn Salad / mâche, cauliflower, lettuce, and kale ‘Niro di Toscana’ - was sown indoors on 6 June for a late planting on 29 July.

Fig. 18: The garden frozen after the spring planting. Paths of heating tubes are visible in the patterns of melt.

Weed and Pest Control

Weeds were controlled by a mixture of flame and hand weeding. An attempt was made to control dandelions not only in the garden, but additionally in the immediate area. Flame weeding was done with a propane torch.

No chemical pest control was utilized. An attempt was made to protect strawberries and tree fruit from birds by wrapping them in floating row cover after pollination.

Results

Site Evolution

No material change has been observed in the pumice, except for possibly some increased fragmentation at depth.

The wood mulch has been compacting somewhat on the pathways where it is relatively thin, allowing weeds to grow more easily. It remains however thick and lofted in the beds. While the mulch cannot be described as “decayed”, fungal mycelium is now common in it, and mushrooms randomly pop up in it.

Bare exposed beds experienced ice nails in general, but in particular the exposed heated beds, which became dramatically churned by frost nail action, leaving the surface loose and fluffy.

Apart from some increased bacterial growth, there are no meaningful visible changes in the warm water outflow.

Weeds and Pests

Weeds have been particularly abundant and aggressive in the uninsulated control bed and the uninsulated terrain around the control trees, especially grasses and creeping buttercup. With the exception of horsetails, weeds have been less common elsewhere, with the best control by far in the pumice. In mulched areas, particularly along the fences in the north, east, and south, dandelions were a common weed.

Horsetails were a common weed throughout the garden. Relatively little effort was put on its control, as it they tended to be low and ground-hugging, though were removed where they might interfere with roots. Their ability to grow even in pumice, sometimes even forming dense green mats on the surface, was particularly remarkable. Of particular interest, it was noticed that where horsetails grew in trial #5 (heated, uninsulated), the soil underneath the horsetail mat was warm to the touch; that is to say, horsetails can produce a sort of natural insulation.

Aphids appeared on roses in late July / early August (fig. 19), and like last year, were problematic for approximately 1-2 weeks, were hand-controlled, and then ceased being a problem (assumedly due to the arrival of predators).

Fig. 19: Aphids on rose 'Europeana'

Due to planting oats in the most slug-prone part of the garden (the southeast) rather than brassicas and lettuce, slug damage was not as severe this year as last year. The heaviest damage was, again, on terrain insulated by wood chips. Control 'succotash' beans were heavily defoliated, as were some corn plants in both control and experimental beds, alongside random damage to brassicas; however, in general it was not a large problem

Cabbage fly was a major problem early in the season, observed the most directly in mizuna, but probably more widespread, and perhaps the cause of the loss of a number of cauliflower plants. No method of control was attempted.

Inchworms, most likely winter moth (*Operophtera brumata*), attacked all fruit trees, perhaps most noteworthy on cherry trees (fig. 20), in the summer. No control was utilized. Damage could be assessed as "mild to moderate".

Fig. 20: Inchworms on cherry 'Valentine'

Leaf flies (*Lyciella rorida*), harmless fungus eaters, were relatively frequently spotted resting on leaves - possibly attracted by the slowly-decaying mulch.

Redwings continued to target berries in the garden, although were not as visible this year.

Security

With the new security system, we were able to better monitor the comings and goings in the garden. Two incidents occurred.

Fig. 21: A man enters the garden and steals our hose nozzle

In July it was noticed that the spray nozzle for the garden hose was stolen. Review of past the footage showed a clear culprit: a balding man with a black t-shirt, blue jeans, and with a black-and-white dog, who could be seen entering the garden, picking up the hose, playing around with it, and bringing it out of the garden off-camera (Fig.21). The subject was later spotted at the garden in security footage, and was confronted. He initially denied the charges but after being shown the footage promised to not mess with the garden again.

Fig. 22: A tree disappears between two clips

In September - embarrassingly late into the season - measurements were being taken on the trees when it was noticed that one tree (Apple H12-Antonovka in trial #10) that was on the map did not exist at its location. Examining the security footage showed that it disappeared between 26 April and 2 May, but unfortunately it was far enough away from the security camera that its removal did not trigger filming (Fig. 22). A small pit was noticed where the tree used to be. That a thief would steal and walk off an entire rooted fruit tree is troubling.

Overwintering Brassicas

Fig. 23: Surviving kale 'Lerchenzungen'

Brassicas not harvested last year were left out in the field - half covered with floating row cover and half uncovered. A small number survived - primarily kale 'Lerchenzungen' (Fig 23), but also one red cabbage 'Bewaar' and one white cabbage 'Primo'. While floating row covers somewhat delayed and minimized frost damage, they did not seem correlated with winter survival rates. More unexpectedly, there was a zero percent survival rate in insulated beds; the survivors were all in uninsulated beds, both heated and unheated.

Survivors were allowed to flower (to attract pollinators), except for the white cabbage, which set a large 3,1kg head, which was harvested as soon as it showed signs of starting to flower in order to weigh it.

Fig. 24: 'Sinikka' plums set above a damaged branch

Fruit Trees

Flowering was observed on all trees in the spring. Fruit set was only observed on the cherry tree in heated experiment #9 (four fruits), and plum trees in both heated experiments (no fruit set was observed on any unheated trees). All cherries matured at a small size, inedible. Five plums set in experiment #10 (fig.24) (pruned to 3 on 27 August) and two set in experiment #9. These were wrapped in strips of row cover to hide and protect them from birds and are still maturing.

New growth was very heavy on the heated trees, frequently upwards of 70cm per branch (fig. 25), but minimal on the unheated trees, maximum of approximately 30cm per branch. However, both heated plum trees suffered having a branch break during wind storms; one managed to be successfully regrafted, but the other was lost.

Fig. 25: New growth on apple 'Pirja' / 'Rana'

Plant dimensional growth can be seen as below (measured 9-10 September); in parentheses for comparison is the change from the previous year. Trials 9 and 10 had full heat during the growing season, but while trial #9's winter heat was full, trial #10's winter heat was halved.

Trial	Tree	Height (cm)	Width (cm)	Length (cm)	H x W x L (m^3)	Girth (mm)
9	Apple Pirja/Rana	95 (+*29*)	65 (+*48*)	60 (+*48*)	0.37 (+*0.1*)	11.5 (+*4.5*)
9	Apple H12/Antonovka	170 (+*71*)	130 (+*79*)	105 (+*77*)	2.32 (+*2.2*)	17.5 (+*3*)
9	Cherry Valentine/Alkavo	115 (-*24*)	110 (+*54*)	55 (+*4*)	0.70 (+*0.3*)	19.5 (+*5*)
9	Plum Sinikka/St. Duke	185 (+*32*)	170 (+*128*)	160 (+*118*)	5.03 (+*4.8*)	26.5 (+*13*)
10	Apple Pirja/Rana	125 (+*37*)	95 (+*55*)	85 (+*64*)	1.01 (+*0.6*)	17.5 (+*7.5*)
10	Apple H12/Antonovka	*Stolen*	*Stolen*	*Stolen*	*Stolen*	*Stolen*
10	Cherry Valentine/Alkavo	150 (+*53*)	120 (+*63*)	90 (+*51*)	1.62 (+*1.4*)	15 (+*5*)
10	Plum Sinikka/St. Duke	150 (+*29*)	195 (+*116*)	160 (+*118*)	4.68 (+*4.3*)	24.5 (+*13*)
Control	Apple Pirja/Rana	65 (-*22*)	60 +(*38*)	30 (+*9*)	0.12 (+*0.1*)	12.5 (+*5*)
Control	Apple H12/Antonovka	125 (+*7*)	140 (+*61*)	55 (+*15*)	0.96 (+*0.6*)	19 (+*4*)
Control	Cherry Valentine/Alkavo	115 (+*18*)	45 (+*7*)	40 (+*9*)	0.21 (+*0.1*)	15 (0)
Control	Plum Sinikka/St. Duke	140 (+*21*)	95 (+*44*)	75 (+*43*)	1.00 (+*0.8*)	14.5 (+*1.5*)

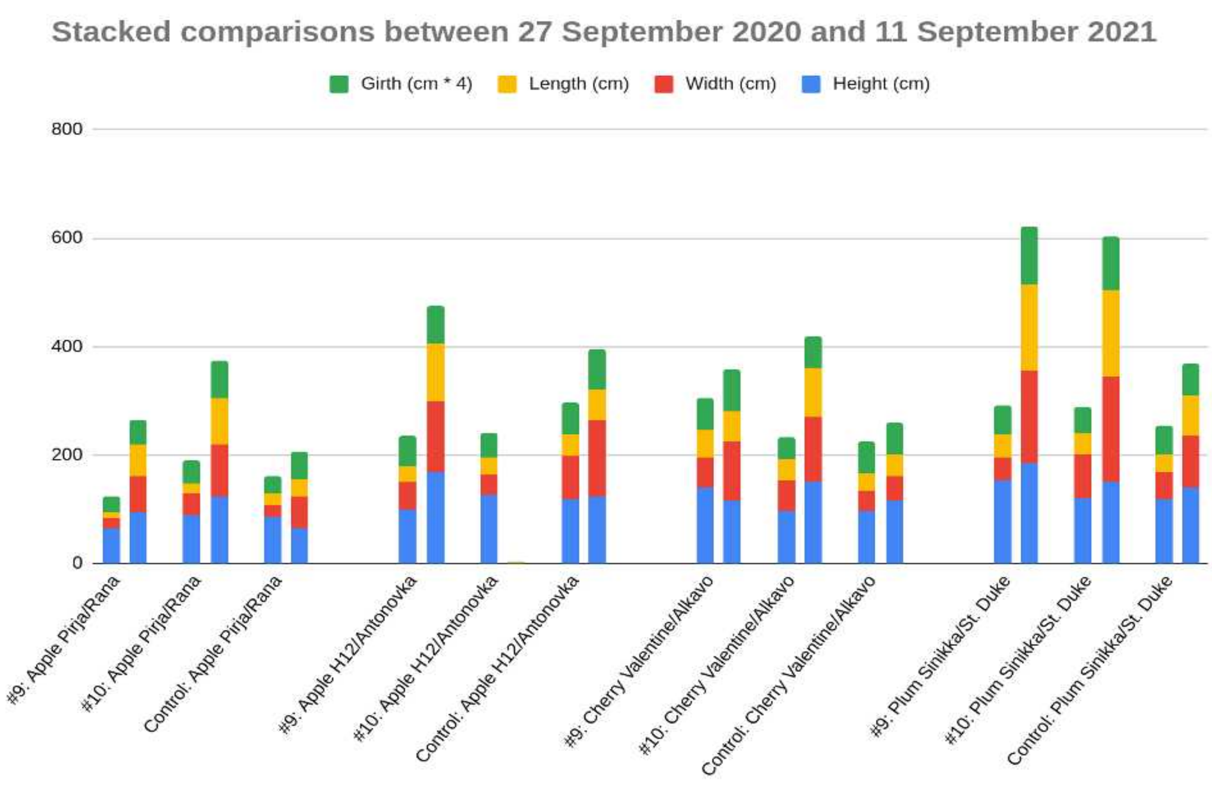


Fig. 26: Comparison between trees; all properties stacked atop each other to create a net score.

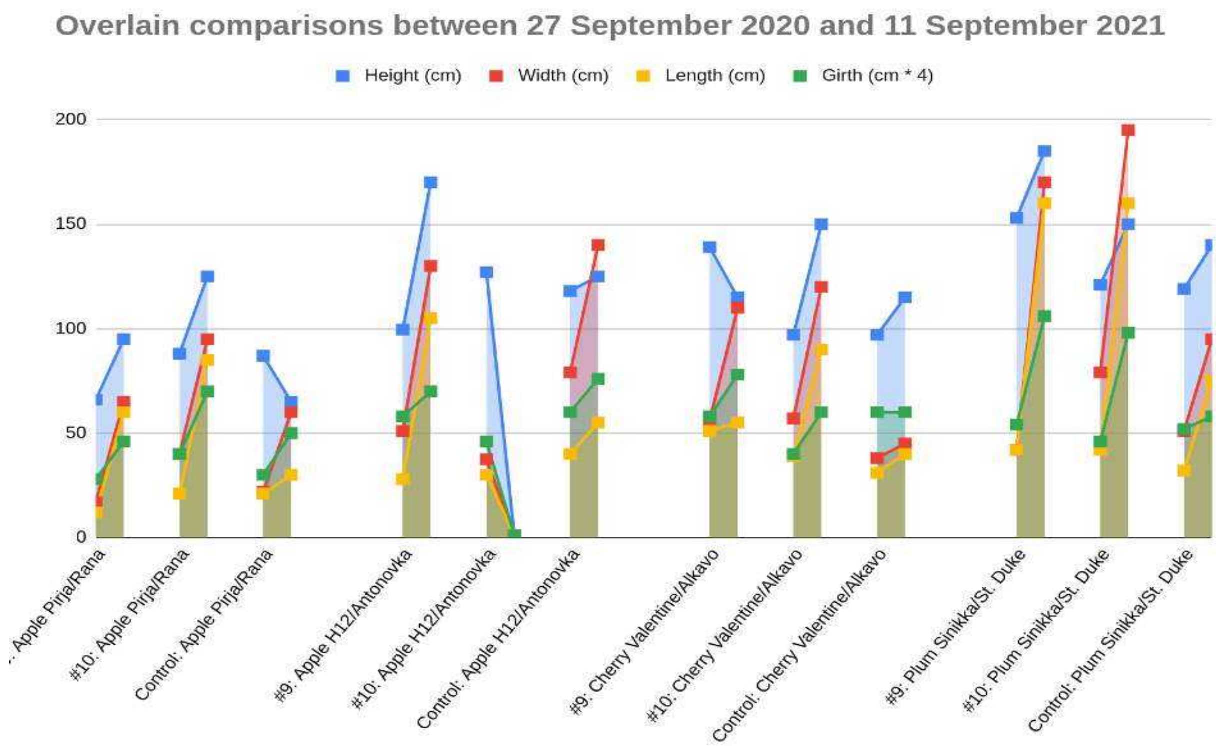


Fig. 27: Comparison between trees. Each property is plotted independently of the others for each tree.

While it's unclear whether full or halved winter heat (or moreover, any winter heat) was of benefit, it is clear that at the very least, heating in general seems to have provided a very significant advantage to growth rates (Fig 26 & 27). Hopefully in future years we will be able to draw better harvest conclusions.

Grapes

The initial impression was that there was a 0% survival rate from the grape vines; no growth was spotted until 8 July, when several buds were spotted bursting. Due to the mistaken impression that they had died, several plants were planted basically on top of them. In the case of 'Vroege van der Lan' on the north side of experiment #6, by the time it started growing, it was heavily in the shade of vigorous tomato plants, limiting its access to sunlight.

Without heat, grape ‘Zilja’ and one ‘Vroege van der Lan’ died, while the other ’Vroege van der Lan’, the ‘Valiant’, and both ‘Muscat Blue’ survived. In all, growth lacked vigour. Two of the grape vines with heat (the southern ‘Vroege van der Lan’ and the northern ‘Muscat Blue’) did not survive the winter, but one of each type survived. The heated ‘Muscat Blue’ that had access to sunlight grew vigorously (fig. 28), although it’s still unclear that such a late start will be sufficient to gather the energy needed to survive for another year.

Fig. 28: Grape ‘Muscat Blue’ with heat

Bed	Plant	Maximum length (cm)	New growth (cm)	Stem girth (mm)	Rootstock girth (mm)
Trial #6	M. Blue #1	X	X	X	X
Trial #6	M. Blue #2	122	47	7.5	15
Trial #6	Vroge #1 (shaded)	32	32	4.5	?
Trial #6	Vroge #2	X	X	X	X
Control	M. Blue #1	79	41	9	11
Control	M. Blue #2	74	17	5	11
Control	Vroge #1	X	X	X	X
Control	Vroge #2	80	77	3.5	10.5
Control	Zilja	X	X	X	X
Control	Valiant	48	48	3.5	5

In summary, winter survival rates were somewhat worse with heat (although this may disguise differences between causes of death), and further experimentation will be needed to determine whether their cultivation will prove long-term practical. During the growing season, 'Muscat Blue' grew better with heat, while 'Vroge van der Lan' grew worse (but was heavily shaded by tomatoes).

Hops

Like grapes, hops were extremely late to start the season. One of the unheated hops survived (fig. 29), while both of the heated hops died. Lacking a heated comparison and with only a single plant, it's hard to assess comparative vigour. Given the low survival rate, it would be premature to draw any conclusions as to the impact of heating over the winter.

Hops can be cultivated in Iceland, but tend to do poorly and decline over time. It is possible that the plants planted last year were too immature and/or planted too late in the season.

Fig. 29: Hops on 7 July, having sprouted at some point in June

Strawberry 'Sonata'

All three strawberries that lacked heat and soil insulation perished in the winter. All but one that had insulation survived (#JH3), a heated / insulated plant that had been in ill health since its transplanting the previous fall. That is to say, survival rates were 3/3 without heat and 5/6 with heat. The heated strawberry #JH6, in experiment 6 (technically in an insulated bed) had little to no insulation in practice, but was among the survivors, possibly because of its soil heating.

Fig. 30: Strawberry (no row cover) emerging from heated bed #6 on 2 March

Two strawberry plants without heat had floating row covers, while none that had heat had row covers to compare with. Both plants with row covers had vegetation remain green throughout the winter; all lacking row covers - heated or not - saw their vegetation die back. Those with dead vegetation and no heat perished (fig. 31).

Strawberry plants with heat began very rapid and aggressive growth early in March (fig. 30). Plants without heat, however, grew lethargically. The heated plants thus caught up to the unheated plants that retained their vegetation, and ultimately set more fruit which began maturing much sooner.

Fig. 31: Unheated strawberry without row cover

Harvest and measurements were greatly frustrated by external factors. Initial fruit set was higher with the eastern, heated plants (fig. 32), but no effort was made to count or measure them, with the intent being to measure at harvest. All clusters of berries were wrapped in strips of floating row cover to protect them from birds. However, botrytis began claiming the berries, particularly on the plants with heat. To minimize this, strips were unwrapped from the berries and simply placed over them with bits of mulch or pumice weighing them down. However, the strips - particularly on the eastern (heated) side -

kept being found away from their berries. It is unclear whether this was due to the action of wind or birds - and berries kept disappearing. In short, only a small fraction of the set berries were recovered, with a particularly low recovery rate on the heated / eastern side.


Fig. 32: Heated strawberry (6 June)

Of recovered berries, with plants listed of the form J[H=heat, C=cold]#, where # is the order of the plants from west to east in the control bed and north to south in the heated bed:

- 19 July:
    - JH1 = 29g
- 2 August:
    - JH1 = 21g + 1g (rotten) + 4g (rotten) + 1g (rotten)
    - JH2 = 12g (rotten) + 3g (rotten) + 4g (rotten) + 4g (rotten)
    - JH6 = 5g (rotten) + 5g (rotten) + 1g (rotten) + 3g (immature)
- 4 August:
    - JH1 = 32g + 12g + 15g + 5g (immature) + 5g (immature) + 10g (rotten) + 8g (rotten) + 2g (rotten) + 2g (rotten)
    - JH2 = 12g (rotten) + 6g (rotten) + 1g (rotten)
    - JH6 = 16g
- 10 August:
    - JH1 = 4g (rotten) + 2g (rotten)
    - JH5 = 1g (immature)
- 4 September:
    - JC2 = 32g

    - JC3 = 30g + 23g
- 11 September:
    - JC1 = 27g (rotten) + 28g (rotten) + 29g (rotten) + 10g (rotten) + 5g (rotten) + 16g (rotten) + 5g (rotten)
    - JC2 = 8g (rotten)
    - JH6 = 5g (half eaten)

A small number of additional berries remain to be harvested. It should be noted that while berries were not recovered from some surviving plants, all did set fruit. No taste difference was noted between the heated and unheated berries; both were of excellent quality.

Due to the unexpectedly vigorous growth of tomatoes and rhubarb, some strawberry plants, particularly JH1, began being overgrown later in the season.

Followup next year will utilize netting rather than floating row cover to try to simultaneously exclude animals without rotting the fruit, in order to get accurate measurements.

Fig. 33: Heated strawberry (15 July)

Strawberry 'Glima'

Fig 34: Eight tiny strawberry 'Glima' plants were planted in two identical beds on 13 May: left (with heat) and right (without heat)

Based on the great promise shown by the strawberries from last year and needing to confirm the observed impacts of insulation and heating, it was decided to expand our strawberry experiment. Twelve tiny plants of cultivar 'Glima', a common outdoor-cultivated strawberry, were donated by Jón Guðmundsson and planted in wood chips on opposite sides of the central walkway (eastern experiment 4 / western control 2). Only a small number of small berries were recovered this year.

- 19 July: 4g
- 2 August: 1g + 2g

It is not the first-year yield, however, but the first year growth that was staggering (fig. 34). Without heat, growth was lethargic, but with heat the strawberries rapidly formed a thick, dense carpet of runners spreading across the experimental bed and out into the walkway, covering approximately three square meters. The difference could not be more visually stark, and it's exciting to look forward to next year to find out how this translates into harvest. The plan will be to cover half of each strawberry bed with floating row cover to compare the difference.

Rhubarb

Fig. 35: **Top:** rhubarb plants (left: heated; right: unheaded) on 14 June. **Bottom:** the same plants on 21 September (bag for scale)

Last year, 6 rhubarb plants were planted. Two of four that were planted with heat did not regrow this year (one in pumice, one between pumice and mulch); both that returned were in mulch. Both of the plants lacking heat by contrast survived (one in soil, one between pumice and mulch). While this sample size is too small to draw statistical conclusions, the inference of poorer survival with winter heating was also emphasized in early spring, when the rhubarb without heat started (unexpectedly) growing earlier and faster than the rhubarb with heat. It gives the appearance that either the prevention of hibernation or the drying out of soil has a negative impact on rhubarb.

During the growing season, however, this relationship was reversed. Heated rhubarb grew much more vigorously, forming larger plants with longer, thicker stems (fig. 35). Indeed, the unexpectedly expansive growth of the heated rhubarb proved problematic, overgrowing adjacent plants which had been assumed to be safe from it. No rhubarb was harvested, however, in keeping with standard guidance for allowing plants to establish themselves in their first two years.

Plant	Width (cm)	Length (cm)	Area (m^2)	Longest stem (cm)	Greatest girth (mm)	Largest stem volume (cm^3)
Trial #6-1	180	175	2.47	46	31.5	358
Trial #6-2	210	195	3.22	51	29	337
Control #1	127	110	1.10	31	17	70
Control #2	140	140	1.54	27	19	77

In short, the experience thus far suggests that wintertime heating is *probably harmful* to rhubarb (at least in the absence of irrigation at the start of the growing season), but *extremely beneficial* during the growing season, with a 2.2x increase in plant area and a 4.7x increase in maximum stem volume. Indeed, the heated plants are so vigorous that they could readily have been harvested this year (planted late last summer), while the control plants should not be harvested until next year at the earliest; a whole year can be subtracted from planting to harvest.

Blackcurrants

All blackcurrant plants survived their first winter (fig 36). Initial growth was similar to slightly stronger in plants that had received heat over the winter. Growth however was dramatically accelerated

Fig. 36: Blackcurrant with heat (grocery bag for scale)

during the growing season in plants that received heat (fig. 36), although no plants flowered or set fruit this year.

Plant	Length (cm)	Width (cm)	Height (cm)	Volume (m^3)	Girth - largest stem (mm)
Trial #6-1	118	73	85	0.38	12
Trial #6-2	133	107	80	0.60	15
Control #1	43	38	45	0.039	14.5
Control #2	53	42	56	0.065	11

Experience thus far is interpreted as an unclear or limited advantage to winter heating, but a tremendous benefit - at least to vegetative growth - during the growing season. The visible difference between heated and unheated bushes is staggering - on average 2.6x larger on the long axis, 2.2x larger on the narrow axis, 1.6x taller, and 9.4x greater volume (approximated as an ellipsoid).

Further growing seasons will be required to assess fruiting potential.

Honeyberries

A strong adverse relationship was observed between heating and honeyberry survival rates; zero of four heated plants survived, while both unheated plants survived. While initially unclear what the cause was, a review of earlier footage shows honeyberry buds breaking in March in the heated beds (fig. 37), before a series of deep freezes; this (dormancy breaking due to heat) is undoubtedly what killed them.

Fig. 37: Honeyberry buds breaking in mid-March

The surviving two unheated plants grew at a sluggish pace typical to Iceland. Neither flowered nor set fruit. Both however remain healthy.

Plant	Length (cm)	Width (cm)	Height (cm)	Volume (m^3)	Girth - largest stem (mm)
Trial #6-1	X	X	X	X	X
Trial #6-2	X	X	X	X	X
Trial #6-3	X	X	X	X	X
Trial #6-4	X	X	X	X	X
Control #1	34	31	41	0.023	9
Control #2	46	38	49	0.045	10.5

Oregano

All oregano plants - heated and unheated survived, and multiple harvests were made.

Date	Bed	Average (g/plant)
5 July	Mulch / #9 (full winter heat)	74 (46-96)
	Pumice / #10 (half winter heat)	140 (120-174)
	Bare / Control	33 (1-73)
20 August	Mulch / #9 (full winter heat)	150 (85-210)
	Pumice / #10 (half winter heat)	176 (180-195)
	Bare / Control	103 (10-182)
Total	Mulch / #9 (full winter heat)	116 (46-210)
	Pumice / #10 (half winter heat)	160 (120-195)
	Bare / Control	68 (1-182)

In short, heat roughly doubled oregano yields and improved growth consistency. The most dramatic improvements were in early summer yields (fig. 38), whereas the unheated oregano struggled until the soil warmed up. A caveat should be noted that there are different insulative materials between beds and the bare-ground control is the bed that suffered the most from weeds.

Fig. 38: Early-season oregano harvest

Sage

Only four sage plants were present previously. Both that were with heat died over the winter, and one of the two without heat died. Too few plants were present to draw meaningful conclusions on heating's impact on survival rates. Yields from the single remaining plant (fig. 39) were 42g and 46g on 10 July and 4 September, respectively, but have no comparison figures.

Fig. 39: Single surviving sage plant (6 March)

Roses

Six rose bushes were planted last year - small-flowered 'Europeana' roses (fig. 41) and large-flowered 'Victor Borge' roses (fig. 40), three plants in each of the heated and unheated beds. Of these, all

Fig. 40: Rose 'Victor Borge' (11 September)

Fig. 41: Rose 'Europeana' (20 August)

died back to the base during the winter. One of the unheated 'Victor Borge' roses did not regrow, while the others began regrowing. The heated roses began regrowing sooner and more vigorously, and a profound difference was visible through the whole summer between heated and unheated roses. Heated roses began blooming in the middle of August and were heavily blooming by the end of August, while unheated roses began blooming near the end of August.

As of 14 September, 'Europeana' with heat averaged 5 times as many blooming flowers and 8 times as many buds as the unheated one (fig. 42). 'Victor Borge' with heat had 3 times as many blooming flowers and 5 times as many buds as the unheated survivor - double that if the non-surviving 'Victor Borge' is counted into the control bed's average.

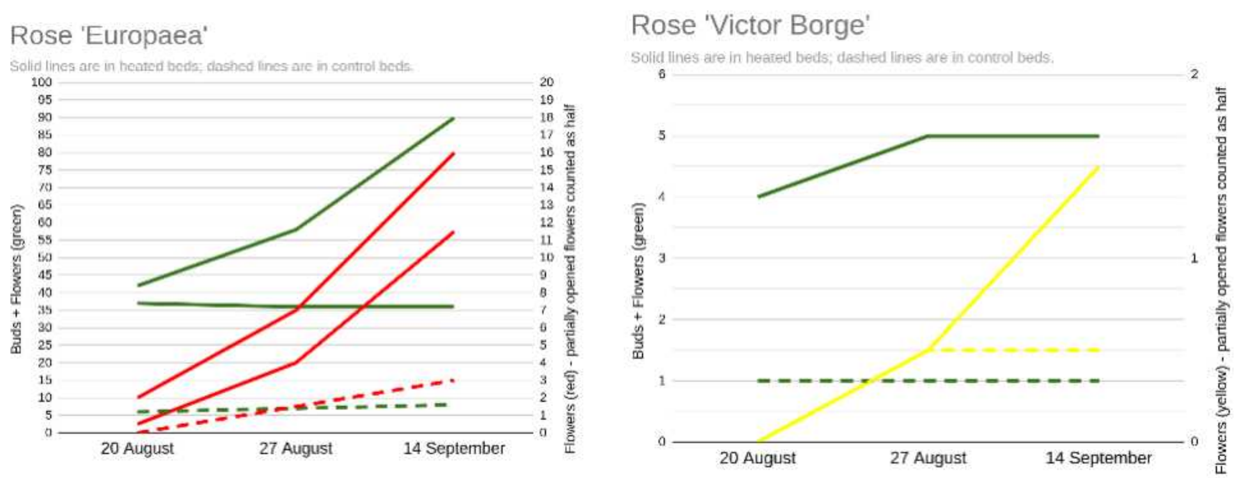


Fig. 42: Abundance of buds (green) and roses (red, yellow) over time - heated (solid) and unheated (dashed).

With heat, it should be possible to cultivate rose gardens of the style normally associated with more temperate climates. Due to the lack of vigour in the unheated roses, however, time will tell whether the remaining two even manage to survive from year to year.

Sunflower 'Arikara'

Despite a later start than would be desirable (sown indoors in late April, planted outdoors at the end of May), the 'Arikara' sunflowers grew to an impressive height in both beds, though taller in the heated bed, and with much greater girth (fig. 43). Of the four unheated Arikara sunflowers, two of them suffered snapped stems in windstorms - one perished while the other grew along the ground with low vigour. Of the three girthy heated Arikara sunflowers, no wind damage was suffered.

Fig. 43: Measuring maximum stem girth on 'Arikara'

Plant	Height (cm)	Girth (mm)
Trial #6-1	180	59
Trial #6-2	195	34.5
Trial #6-3	188	34
Control #1	167	26
Control #2	174	22.5
Control #3	X	X
Control #4	Prostrate	20.5

Fig. 44: Sunflower 'Arikara' beginning to bloom

As at the time of writing Arikara is only beginning to go into bloom (fig. 44), no measures can be provided as to the flowers' sizes and abundance.

Sunflower 'Sun Spot Dwarf Cola'

Fig. 45: Dwarf sunflowers without (left) and with (right) heat. All were planted at the same time and spacing.

A more remarkable contrast was observed in the 'Sun Spot Dwarf Cola' sunflowers. The heated sunflowers grew rapidly and into each other (suggesting that the recommended spacing for this cultivar was insufficient), while the unheated plants remained as small isolated individuals with narrower canopies (fig. 45). Some leaf damage was suffered during late summer fertilizer application, but this did not appear to hinder growth or flowering.

Plant	Height (cm)	Girth (mm)	Primary flower (mm)
Trial #6-1	52	27	129
Trial #6-2	34	30.5	124.5
Trial #6-3	58	34	120.5
Control #1	29	13.5	2x 40 x 70
Control #2	35	11.5	78
Control #3	24	11.5	76

Height measurements alone do not do justice to how much “fuller” the heated plants were. At the time of writing, the primary flowers are finishing up their blooming but are not ready for seed harvesting, while numerous secondary flowers are preparing to bloom.

Wheat

Fig. 46: Germinating wheat (14 March)

Seeds of ‘Red Fife’ were planted as soon as the soil in control beds was thawed enough to be penetrated (around the start of March); even this was a chore, as some places were thawed better than others. Due to a limited seed supply, a sparse planting was utilized. By 14 March, germinating wheat plants were visible forming neat rows in the heated beds (fig. 46), but took so long to germinate in unheated beds that it was initially assumed that they had perished and the control beds ceased being monitored. Eventually (~May-June) however it was noticed that wheat had grown there, albeit smaller, later, and sparser than in the heated bed.

Fig. 47: Maturing heated wheat (17 September)

As of the time of writing, the wheat plants are still green and are thus not ready for harvesting (fig. 47); visually, one could estimate that the yield with heat will probably be about four to five times higher than the yield without heat, due to the higher density of germinated plants and larger heads - but actual measurements are needed to assess this. Wheat plants with heat are about 110cm with heads a mean 12cm-long and 13mm diameter. Wheat plants without heat are about 100cm tall with heads a mean 9cm long and 9.5mm diameter.

Additional wheat seeds have been ordered for a fall planting to see how well wheat survives the winter and thrives in the spring the subsequent year.

Oats

Fig. 48: Oat 'Perttu'

A large oat 'Perttu' (fig. 48 &49) experiment was conducted this year in experiments #1-#3, with control beds around the trial's edges (away from the heating pipes / near the fence) and with isolated patches elsewhere in the garden. Planting was significantly later than wheat (6 May) and denser, due to an ample supply of oat seed. It may well have been possible to plant them weeks earlier, but the seed was not immediately available until May.

Fig. 49: Insulation moved, oats sown, soil added on top.

Like wheat, there are similar visual differences between experimental and control plants, but the grain is not yet ready for harvest. One problem that was significantly greater with oats was wind damage (fig. 50): despite the research garden being relatively sheltered, much of the oat bed was knocked over by winds, which also led to complications with it resting

Fig. 50: Wind damage in the oats was significant

atop tomato plants just to their north and shading them. It is unclear whether soil heating increased the risk of wind damage or not; due to how much oat plants impact their neighbors, much larger experiments would be required to determine this.

Mean heights of heated oat plants are about 130cm (although this is difficult to assess due to wind damage). Mean heights of control plants to the south are about 85cm; control plants to the east about 120cm; and control plants far to the west about 105cm tall. Due to the loose head structure of oats, its volume cannot be as readily estimated as with wheat.

Corn

Corn (alongside beans) was planted twice. The first attempt was direct-planted on 21 March to see whether soil heating could allow for such early timing. Seeds never germinated in the control beds, but germinated in early April in the heated beds. While they struggled with the cold weather, it initially looked like they were going to survive, but slowly withered back and died somewhere around the April-May timeframe.In response to this, a new batch was planted indoors much 28 May, very late in the season. These were planted outdoors on 7 July.

Fig. 51: Purpling in unheated corn leaves, indicative of poor root function.

Similar to tomato plants, there was some yellowing associated with new growth in corn plants in the heated beds, which mostly disappeared over the subsequent weeks - while in the control beds, plants not only yellowed somewhat, but also suffered a strong purple-tinge (reminiscent of phosphorus deficiency and indicative of poor root function) (fig. 51). This discolouration remained throughout the summer in the control beds, and the growth rate was reduced.

Some corn plants seemed to be attacked heavily by pests (never seen but presumed to be slugs) while young; however, once they reached sufficient size, the attack rate seemed to drop significantly.

Due to the very late planting, no yield was expected; however, ‘Orchard Baby’ sweet corn has actually flowered in the heated bed (fig. 52), and it is possible - although probably more unlikely than likely - that we may yet see a harvest. ‘Painted Mountain’ and ‘Strawberry Popcorn’ were more heavily attacked by pests and not in as optimal of locations, and are yet to flower as of the time of writing. Also at the time of writing, no corn plants in the control bed have flowered.

Fig. 52: Heated ‘Orchard Baby’ corn flowering

As of 17 September, plants were the following heights (low heights = pest damaged). ‘Mean’ is the mean height of all plants that are at least 2/3rds the height of the largest plant (to exclude pest-damaged plants):

Bed	Variety	Flowering?	Heights (cm)	Mean (cm)
Heat, #5, west	‘Orchard Baby’	Yes	16, 40, 50, 28	45
Heat, #4, east	‘Strawberry Popcorn’	No	46, 3	46
Heat, #4, east	‘Painted Mountain’	No	47, 48, 20	47.5
Control, #2, west	‘Orchard Baby’	No	23, 25, 12	24
Control, #2, west	‘Strawberry Popcorn’	No	25, 44	44
Control, #1, west	‘Painted Mountain’	No	30, 33, 24	29

Beans

The situation with beans was similar to that of corn - first planted too early (0% germination in either bed), and then too late. Like corn, some plants were attacked, particularly ‘Succotash’ in the control bed (on mulch). Apart from attack, the plants look healthy. Flowering was observed for the first time on 17 September in heated ‘Succotash’ beans (fig. 53). A harvest is still questionable. Heated vines are significantly longer than unheated vines.


Fig. 53: Flowering bean ‘Succotash’

As of 17 September, plants were the following heights (low heights = pest damaged). ‘Mean’ is the mean height of all plants that are at least 2/3rds the height of the largest plant (to exclude pest-damaged plants):

Bed	Variety	Flowering?	Heights (cm)	Mean (cm)
Heat, #6, northwest	‘Blauhilde’	No	45, 110, 150	130
Heat, #6, southwest	‘Succotash’	Yes	100, 60, 70, 60	85

Control, #4, east	'Blauhilde'	No	45, 40, 40	42
Control, #3, east	'Succotash'	No	20, 10	20

Like corn, we will want to repeat this experiment next year with better timing,

Bananas

Fig. 54: Wrinkling on new banana leaves

This is our second year attempting to grow 'Jamaican Red' bananas as exotic decorative plants, and while there was hope that with a full year and soil heating we might see "happy plants" during the warmer months, plants in both beds grew sluggishly and with deformed new leaves (wrinkling / stuck inside previous leaves, in a manner reminiscent of calcium deficiency) (fig. 54). As the soil is calcium-rich (a mixture of compost and shell-sand), this appears to be more an indicator of poor root or transport function.

Plant	Height to last mature leaf (cm)	Girth (mm)
Trial #6	34	44
Control	24	35

We can fairly conclusively say that soil heating is insufficient to grow decorative 'Jamaican Red' banana plants (it is a heat-loving cultivar). Next year we will consider planting M. basjoo and M. sikkimensis; while neither yield a decent fruit, fruit was never in the realm of possibility for outdoor cultivation regardless, and these are among the cold-hardiest banana species.

Squash, Melons, and Cucumbers


Fig. 55: Squash 'Gelber Englisher' with buds on 27 August

While a wide range of squash, melon and cucumber plants were planted (sown in mid-April, planted outdoors at the end of May), the early results were poor. Every single plant died in the control beds within 1-2 weeks, with cucumbers being the fastest to die. In the heated beds, it took 2-3 weeks for most to die (again, cucumbers first), with one survivor: a 'Gelber Englisher' squash (fig. 55). Its leaves suffered from cold stress-induced yellowing that a number of other plants suffered, but subsequent leaves came in green and the plant grew fine after that point. As of writing (mid-September), it is 68 x 55 x 35cm and has five unopened flowers. However, it is doubtful whether we will see any yield off of it before it is killed by frosts.

While a search for hardier cultivars could be of use, the two primary lessons thus far to utilize next year are to grow the plants to a greater size indoors and to transplant them outdoors later, say mid-June.

Peppers and Eggplants


Fig. 56: Heated peppers on 8 July. All survived but grew little.

Like squash, melons and cucumbers, a wide variety of pepper cultivars were planted but performance was lacklustre. Every single unheated pepper plant died within 1-2 weeks of planting, while every heated pepper plant survived (fig.

56) - but growth was sluggish to nonexistent, and to date none have flowered or even show signs of preparing to flower. While a better search may yield some cold-hardier pepper cultivars, our results - while showing the benefit of heating - are still not promising for making this a practical outdoor plant.

Eggplants, planted along with peppers, died in both heated and unheated beds. Again, while better cultivars may exist, they appear even less promising than peppers.

Tomatoes

Fig. 57: Cool-weather yellowing

While generally (and rightly) seen as warm-weather plants like peppers, eggplants, and cucurbits, our tomato plants - perhaps aided by our efforts to find cold-hardy cultivars - seem to have performed better than their warm-weather brethren. Likewise planted with less-than-ideal timing at smaller-than-ideal sizes, they started off by showing stress-yellowing in the heated beds (fig 57), and both yellowing and poor root-function-indicative purple leaf tones in the control beds. However, for the most part they did not die in either bed.

Control plants put on little to no growth, and instead went straight to flowering. In contrast with most plants where heat implies earlier yields, unheated tomatoes yielded fruit long before heated plants (August 24th vs. - as of September 17th - all heated bed fruits are still green) - but only relatively small numbers of small fruits per plant. Heated plants by contrast became large, lush green bushes before even starting to flower (fig. 58). Greatly exceeding our growth expectations, most plants collapsed or broke their simple stakes, adopted a sprawling growth habit along the ground, and merged into each other (knowing now how aggressively they can grow with soil heating, in the future we will need to prepare for this).

Fig. 58: **Left**: Unheated ‘Polar Baby’ went straight to flowering. **Right:** Heated tomatoes on 14 August.

While the goal was to have roughly even lighting conditions for all plants, various circumstances frustrated this. One is the aforementioned habit of the tomatoes growing into each other, leaving some tomatoes more space-constrained / shaded than others. An unexpected factor was for the tomatoes planted on the north end of trial #3 (tall varieties were planted there). Not only did the oats grow higher than expected (while the tomatoes largely broke their supports and sprawled), but the wind damage in the oats left oat plants growing into and over the tomatoes (fig.59). With a relatively small number of plants per cultivar due to the large number of cultivars, this lighting unevenness was an unwelcome complicating factor.

Fig. 59: Top to bottom: 1) Tomato and oats on 14 June; 2) on 2 August; and 3) on 29 August

In the table below, plants will be listed in the form “[H (heated) or C (control)][B (bare), P (pumice), or M (mulch)][cultivar code][ID]” ((see the garden map for a mapping between cultivar codes and cultivar names; the leading T is omitted). *Light* is on a scale of 1 (shaded) to 10 (bright). Stages are one of V (vegetative), b (early blooming), B (late blooming) or F (fruiting). "*Orig. height*" is the height of the plant at planting. "*Fruit volume*" is the net volume of all fruits combined. *'Det/Ind'* is D for Determine, I for Indeterminate, or S for Semi-Determinate; a lower-case 'd' is a determinate that grows like an indeterminate (e.g. sprawling), while lower-case 'i' is an indeterminate that grows like a determinate (e.g. bushy). Cells are colour coded by relative value, where a high value is white and a low value is dark grey; a rough estimate of how well a plant performed given the conditions can be gotten by looking at how much lighter or darker a row is vs. its *Light* column (brighter than *Light* = performed well, darker than *Light* = performed poorly). Measurements were taken between 15 and 17 September.

Plant	Light	Length (cm)	Width (cm)	Height (cm)	Volume (m³)	Girth (mm)	Stage	Fruits	Fruit volume (cm³)	Orig. height (cm)	Det/ Ind
HMlb1	3	102	74	71	0.28	21	b			12	i
HMlb2	2	80	51	43	0.09	15.5	b			10	i
HMsc	2	69	59	60	0.13	15	b			19	d
HMsc	2	60	60	70	0.13	12	b			?	d
HMó	2	63	41	71	0.10	16	b			12	?
HMcs1	2	59	53	50	0.08	10.5	b			25	d
HMcs2	2	75	63	67	0.17	10.5	b			27	d
HMsp1	3	81	74	59	0.19	21	B			19	d
HMsp2	4	92	63	67	0.20	17	F	2	8.4	16	d
HMso	8	100	67	45	0.16	21.5	b			20	D
HMgl	6	120	89	52	0.29	15	B			?	d
HMma	6	101	76	49	0.20	21	F	5	240.5	17	d
HMps	7	83	74	47	0.15	18	F	5	78.6	15	d
HBsa1	6	83	75	50	0.19	21	B			19	d
HBsa2	8	92	63	67	0.20	17	F	2	8.4	16	d
HMh1	10	61	57	41	0.07	11.5	V			?	?
HMh2	9	80	53	68	0.15	10.5	V			?	?
HMh3	9	55	52	62	0.09	13	V			?	?
HMh4	8	84	49	48	0.1	12.5	V			?	?

HPch1	10	119	68	44	0.19	17	V			9	I
HPps	9	116	73	40	0.18	14.5	F	4	140.0	19	d
HPch2	9	104	100	58	0.32	15	B			28	I
HPgk	8	90	83	45	0.18	16	B			7	I
HPgk	6	156	82	42	0.28	13	b			22	I
HPki	6	87	83	67	0.25	15	F	2	6.5	18	S
HPcp	5	146	134	74	0.76	15.5	b			29	I
HPh1	5	62	42	52	0.07	9	V			?	?
HPh2	5	78	57	51	0.12	10.5	b			?	?
HPh3	5	75	56	57	0.13	9.5	B			?	?
HPh4	4	61	37	55	0.06	9.5	B			?	?
HP?	8	101	87	77	0.35	20	B			?	?
HPbk	6	114	88	47	0.25	19.5	b			24	i
HPpb1	6	94	64	38	0.12	9	F	5	13.9	29	d
HPpb2	6	94	59	39	0.11	9	F	2	13.6	28	d
HPsi	5	97	77	60	0.23	19	b			19	d
HPsz	2	79	55	42	0.10	13.5	b			22	D
HMgw	7	53	45	42	0.05	13.5	b			28	I
HMmo1	6	115	66	60	0.24	16.5	b			25	I
HMmo2	5	136	61	68	0.3	20	B			23	I
HMbp1	5	127	100	79	0.53	26.5	F	1	8.3	24	I
HMbp2	4	87	78	78	0.28	24.5	B			25	I
CBsa	10	67	50	39	0.07	15.5	b			?	d
CBsc1	7	59	53	39	0.06	14.5	B			23	D
CBsc2	6	33	27	32	0.01	9.5	B			17	D
CBps	9	35	23	36	0.01	9.5	F	2	38.0	9	d
CBma1	9	81	56	36	0.09	12.5	B			17	d
CPlb	9	44	42	32	0.03	11	b			9	i
CMlb	9	61	40	50	0.06	13	B			22	i
CPpb1	8	61	60	17	0.03	7.5	F	10	86.5	31	d
CPps	8	X	X	X	X	X	X	X	X	24	d
CMgk	7	39	20	38	0.02	7.5	F	1	12.0	25	I
CPpb2	8	45	36	25	0.02	8	F	3	21.2	21	d
CMch	8	54	36	21	0.02	15.5	b			28	I
CMbk	8	70	67	30	0.07	19.5	b			26	i

CBh1	9	20	23	66	0.02	5.5	B			?	?
CBh2	9	38	28	90	0.05	7	B			?	?
CBh3	9	39	31	37	0.04	6	B			?	?
CBh4	9	35	25	79	0.04	6	B			?	?
CBh5	9	41	38	70	0.06	7.5	B			?	?
CBh6	9	44	43	70	0.06	8	V			?	?
CBh7	9	40	38	66	0.05	6.5	V			?	?
CBki	8	41	29	34	0.02	11.5	F	2	17.1	13	S
CBsz	8	54	45	45	0.06	14	F	1	19.7	19	D
CBsi	8	45	38	39	0.03	11.5	b			20	d
CBbp	8	66	64	46	0.10	17.5	b			26	I
CBma2	8	71	46	40	0.07	11.5	b			21	d
CBgw	8	X	X	X	X	X	X	X	X	34	I
CBó	8	56	53	47	0.07	11.5	F	1	2.7	55	?


Fig. 60: Heated tomatoes (9 September)

It is possible (and in fact likely) that other tomatoes were planted in the control beds (a few heated cultivars seem to be matching unheated controls), but the plants died and no remnants of the plants nor their labels could be located.

The mean volume of heated tomato plants was 0.20m³; the mean volume of unheated tomato plants was 0.05m³ (1/4th). The mean stem diameter of heated tomato plants was 15.5mm; the mean stem diameter of unheated tomato plants was 10.7mm (2/3rds). This is despite the fact that the mean lighting level (arbitrary scale) for heated tomato plants was only 5.6, vs. 8.3 for controls.

Fruit cannot be evaluated easily at this point in time. While the mean fruit mass in heated beds is 12.6g, vs. 7.9g (3/5ths) in control beds; however, this is misleading, as many plants in the control beds immediately started allocating resources towards fruit production, while the heated beds focused on vegetative growth and now have much greater *capability* for fruit production (fig. 61). But it is unclear whether, due to seasonal timing, whether that capability will translate to actual fruit production. An earlier start next year with larger plants should increase the odds that it will.

Fig. 61: A large amount of growth was put on during August; June/July growth could have been accelerated with larger plants.

By and large, the tomato plants themselves remained pest-free. However, some ripening tomatoes disappeared or had bites in them; birds are suspected, and nets will be required in the future.

In terms of standout cultivars:

- Every single 'Polar Star' fruited (in both beds), and were two of our top three producers thus far (offsetting this: the plants were usually reasonably well lit).
- Our single heated 'Manitoba' currently holds the most fruit, nearly a quarter kilogram (at 1g/cc), grown at only a moderate light level. The two unheated 'Manitoba's' put on an unimpressive performance.
- For cold beds, our two 'Polar Baby's did reasonably well, but the two cold bed 'Polar Babys' were 2 of the top 3 producers, including the #1 slot. It also produced quite early.

- Of heated plants in shaded spots, ‘Sub-Arctic Plenty’ did the best in their adverse conditions, and would be interesting to try again under better conditions.
- In terms of growth potential, ‘Chocolate Pear’ became a massive plant, under only moderate lighting conditions. It is only in the early stages of flowering, however. That said, being a small-fruited variety, it might mature them quickly.
- ‘Black Prince’ also put on a reasonably strong general performance in the heated beds (size, some fruit, moderately adverse conditions).

On the other end of the spectrum, the store-tomato seedlings provided by Hjördís late in the season, while planted large, were unsurprisingly underperformers, being seeds of cultivars likely adapted to greenhouse conditions.

Fig. 62: Unheated tomatoes (7 September)

Mizuna

A Japanese leaf brassica, Mizuna was planted in trial #7 (pumice-insulated) as a comparison between bed design with (19 plants) and without (17 plants) insulating trenches between rows, in the frontmost (southernmost) row (which is at present occupied by a late planting of cauliflower). A control bed was planted in Control #4 (bare

Fig. 63: Mizuna ready to be harvested (control bad)

ground, fig. 63) and along the western fence with 16 plants. This was done on 12-13 May (in pumich fig 64).


Fig. 64: Heated mizuna (4 June)

In the first harvest (22 June, fig. 65), 1877 grams were harvested from plants without trenches (99g/plant), 659g from plants with trenches (39g/plant), and 433g from unheated plants (30g/plant). However, there was visual damage from cabbage fly in a number of the plants in the heated beds (surprisingly, no visible damage in the unheated beds), and 4 of 19 plants in the no-trenches test, and 4 of 15 plants in the with-trenches tests had outright died. Excluding those plants (but still including those which took minor damage), per-plant harvests were 125g/plant with heat/no trenches; 51g/plant with heat/with trenches; and again 30g/plant without heat.

Mizuna had already been trying to bloom on 22 June, and by 4 July it seemed to want to do little but bloom; a final harvest was made, with the plants uprooted. 405g was recovered from plants without trenches; 478g from plants with trenches; and 137g from control plants. Excluding further cabbage fly-killed or nearly-killed plants (which in the heat/without-trenches section were numerous), yields averaged 37g/plant; with heat/trenches yields were 39g/plant; and without heat they were 8.6g/plant.


Fig. 65: After the first harvest

Total yields were 2282g with heat/without trenches; 1137g without heat/with trenches; and 580g without heat. Per-surviving-plant yields (using the survivor count of 22 June) were 152g/plant with heat/without trenches; 87g/plant with heat/with trenches; and 36g/plant without heat. Plants with heat/without trenches produced 74% more than plants with trenches and 322% more than plants without heat. Plants with heat/with trenches produced 142% more than plants without heat. Plants with heat (regardless of trench configuration) produced 240% more than plants without heat.

Heat provided for a strong production increase, particularly in the absence of trenches between rows, yet it could have been significantly more had it not been for cabbage fly attack - again, particularly on the side lacking trenches. It is possible that the heated soil or the pumice covering proved a more fertile breeding ground or attractant for cabbage fly - or simply that the position on the south side of the garden did. While due to our low inflow temperature we cannot test this, cabbage fly cannot tolerate high temperatures (~35°C), so a plumbing configuration that would allow for elevating soil temperatures to these temperatures for a few days could in theory eliminate this threat entirely. This would likely require inflow of water of at least 40-45°C.

This study also showed, as noted, a significant benefit for the removal of insulating trenches. This is all the more impressive as the east side, in which the trenches were removed, is slightly shadier than the west side. As pumice insulates so well on its own, this is not a large sacrifice in terms of added heat loss. As laying the trenches was an added complication in garden setup, this is good news. As with last year, the working hypothesis is that the presence of trenches reduces available root space and makes the soil easier to dry out.

Given mizuna’s proclivity to flower, replacement plants should be prepared for planting at harvest; cut-and-come-again harvesting becomes increasingly difficult with time.

Tatsoi

Tatsoi (“Chop-Suey Greens” / “Vitamin Greens”) is another Asian brassica grown for its dark-green leaves, reminiscent of a sort of ‘cruciferous spinach’. Tatsoi was planted in trial #5 on the east side (currently occupied by lettuce) on 12-13 May, as well as in Control #4 (similarly, bare ground), with slightly more ligh (fig. 66)t. A small number were also planted to the east of Trial #5, with slightly less light.

Fig. 66: First harvest of tatsoi (control)

Tatsoi was our first plant to be harvested when a couple plants showed signs of flowering, on 15 June - just a month from planting to harvest. The 16 plants with heat yielded 1045g (65g/plant), while the 18 control plants (fig. 66) yielded 336g (19g/plant) - a 3.5x difference per-plant (fig. 67).

As with mizuna, tatsoi was an aggressive flowerer; as a consequence, it was removed during the second harvest on 5 July. Only 11 plants were found at harvest time (cabbage fly damage?) for a total harvest of 226g - 21g/plant from a basis of 11 plants, or 14g/plant from the original basis of 16 plants. By contrast, the control bed yielded only 53g - a mere 4,1g per plant on the basis of the 13 remaining plants, or an even lower 2,9g on the basis of the original 18 plants.

Fig. 67: **Left**: harvest from the heated bed. **Right**: control harvest

A “cut and come again” for a second harvest is clearly not justified for tatsoi; it should be harvested and then replanted at monthly intervals.

Cauliflower


Fig. 68: Cauliflower 'Purple of Sicily', nearing harvest

The 'Purple of Sicily' cauliflower - in practice yielding a product with properties somewhere between cauliflower and broccoli, although with a frequently attractive (though unpredictable) purple tinge on the heads (fig. 68) - was planted on 12-13 May in trial #8 (heat, pumice) to compare with and without insulative trenches. Three were also planted as controls elsewhere, one of which died.

For unknown reasons, nearly half of the plants planted with insulating trenches died at a young age, while none of those with heat but without trenches did. Six plants were left with trenches and eleven without trenches.

This cultivar proved surprisingly slow to mature. Primary heads began being harvested on 20 August, where three heads with trenches were harvested - 510g, 137g, and 210g, for a total of 878g. With trenches, four heads were ready - 217g, 172g, 238g, and 124g, for a total of 751g. No control-bed cauliflower was ready.

On 27 August, another head (288g) was harvested from a heat + trenches plant, while three heads - 178g, 496g, and a massive 816g - were harvested from plants with heat / without trenches. Again, no control-bed heads were ready. This brought the total up to 1166g from the beds with trenches and 2241g from beds without trenches.

The two heads without heat were harvested on 4 September with disappointing yields - 45g and 7g, respectively, bringing the total to 53g. An additional 306g primary head and three secondary heads (45g, 52g, and 41g) were harvested from the bed with heat / without trenches, bringing the total to 2685g. A 288g primary head was harvested from the bed with heat / with trenches, bringing that bed's total to 1454g.

Another 269g head was harvested on 11 September from the heat / no trenches bed, bringing its total up to 2954g. On 17 September, another 203g head was harvested from the heat / no trenches bed (total 3157g), and a 48g secondary head from the heat / with trenches bed (total 1502g).

Using the number of surviving plants in each bed after early mortality, per-plant yields were 287g/plant with heat / without trenches; 250g/plant with heat / with trenches; and a mere 26.5g/plant without heat.

The long time to maturity, the high mortality rate for some young plants, and the low yields from control beds suggest that this cultivar may be a poor fit for Icelandic conditions; yet with heat, yields were still good. It should be noted in the above comparison that while yields without trenches were only slightly (15%) greater than with trenches, the plants with trenches were not only in a slightly sunnier location, but due to the much greater spacing caused by the loss of so many plants after planting, the lighting difference was amplified (fig. 69). Again, this argues against trenches in bed design.

Fig. 69: Plants without trenches had more room to spread their leaves

An additional planting was conducted on 29 July. These plants are still far from being read to harvest.

Rutabaga

Fig. 70: Rutabaga after harvest

Rutabaga / swedes of variety 'Navone Yellow' were planted out 12-13 May. They flourished and were allowed to continue growing until the first plants showed signs of flowering, on 10 August - although could have very easily been harvested much sooner, certainly late July and potentially even early July. Planting was on the north side of trial 7. Three extra plants were planted as controls. Additionally, two plant from the super-early March planting that had to endure severe ice and windstorms survived and made it to maturity in trial bed #5 as well, although were not registered in the experiment due to different planting times.

Fig. 71: 1.6kg rutaba harvested from a heated bed

From the bed with heat / no trenches, 13 plants yielded 7988g, or 614g/plant. Three of these plants yielded over 1kg (1074g, 1189g, and 1594g (fig. 71)). From the bed with heat / with trenches, 13 plants yielded 7870g, or 605g/plant. Two of these were over 1kg (1254g and 1491g). From the control bed without heat, three plants yielded 356g, or 119g/plant (57g, 107g, and 192g, respectively). That is to say, rutabaga with heat/ without trenches yielded 5.2x more than controls; rutabaga with heat / with trenches yielded 5.1x more than controls; and rutabaga with trenches yielded 1,5% more than those without trenches. While this is within the margin of error, it should be noted that those with trenches received slightly more light as well. Regardless, both configurations yielded much more than controls (fig. 72).

Fig. 72: Left: with trenches; Right: without trenches; Top: controls

Kale - 'Russian Red'

Planted (like most plants) on 12-13 May, this cultivar was again used to test cultivation with-or-without trenches (this location was on the north end of trial #8).

The first harvest was on 5 July when there were signs that it was preparing to bolt. Of 13 plants with heat / without trenches, two perished (probably due to cabbage fly). 3242g were harvested, or 295g per living plant. Of 15 plants with heat/trenches, all survived, and the harvest was 3330g, or 222g per plant. Without heat (control bed, west side of Control #4), 8 plants yielded 120g, or 15g per plant. This is a massive 17x more per plant with heat than without.

The next harvest was on 20 August. Of the heated bed without trenches, only 10 plants remained of the previous 11, but yielded a

Fig. 73: Two harvests yielded around eight overflowing bags like this

massive 10700g, or 1070g per plant. The 15 plants with trenches yielded a nearly as impressive 9523g, or 635g per plant. The eight control plants yielded 760g, or 95g per plant.


Fig. 74: 'Russian Red' on 23 June

The kale plants in general have not been as aggressive about flowering as the mizuna and tatsoi were, which has allowed for a continuous "cut and come again" harvesting strategy. The huge yields (fig. 73) have actually proven problematic, it's been challenging to locate people to donate to when you have 20 kilograms of kale at a single harvest without an organized distribution network. All together, heated 'Russian Red' kale (fig. 74) with trenches yielded 13942g, which using the initial 11 plants as a baseline averaged 1267g/plant. Heated 'Russian Red' kale without trenches yielded 12853g, averaging 857g/plant. Unheated control 'Russian Red' kale yielded 880g, or 110g/plant. This equates to 11.5x more per plant with heat/no trenches vs. controls, and 7.8x more per plant with heat/trenches vs. controls. The net benefit of heat per plant is 9.4x vs. controls.


Fig. 75: A 2kg harvest from a single (moderately slug-attacked) plant

Plants without trenches yielded 1.5x more than plants with trenches. While the plants with trenches were in a slightly brighter location, the death of several no-trench plants led to a sparser spacing on the no-trench side. These two factors probably partially cancel each other out, but may be overall somewhat to the no-trench plants' benefit. Still, there is a clear benefit to a no-trench design.

Kale - 'Dazzling Blue'

'Dazzling Blue' kale (fig. 76) was planted in Trial #7 between mizuna and rutabaga on 12-13 May (a somewhat shadier spot than the 'Russian Red' kale), along with controls in / west of Control #4. Whether due to the shade or the cultivar, the first harvest was somewhat later, 19 July - however, it was slightly greater as well.

Fig. 76: Kale 'Dazzling Blue'

Plants with heat / without trenches (13 plants) yielded 4030g and 310g/plant (3.4x controls). With heat / with trenches (15 plants) the yield was 3572g and 238g/plant (2.6x controls). Among controls (4 plants), the total yield was 380g and 95g/plant.

A second harvest of 'Dazzling Blue' kale was conducted on 4 September once the plants showed signs of flowering again. Of the 13 plants with heat / without trenches, the yield was 3749g and 288g/plant. With one fewer plant in the non-trench cohort, the yield was 5340g and 381g/plant. Only 3 control plants were large enough for harvest; the yield was 496g with 165g/plant.

Net yields were thus 7509g (578g/plant) for heat / without trenches (3.9x more than controls); 8912g (594g/plant) with heat / with trenches (4x more than controls); and 591g (148g/plant). The plants with trenches had 2.9% higher yield than plants without trenches, but were also in a slightly brighter position.

Kale - 'Niro di Toscana'

A later-acquired set of seeds, 'Niro di Toscana' kale (fig. 77) was not planted out until 27-30 May. Seven plants were planted on the east side of trial #4, while 6 controls were planted scattered around controls #3, #4 and along the western fence.

The first harvest was conducted on 10 August. 2640g were harvested from the heated bed (377g/plant). Only 85g was harvested from 5 of the control plants (17g/plant). Heated plants thus yielded 22 times that of controls.

Fig. 77: 'Niro di Toscana' (4 August)

Later in the season, however, the eastern part of trial #4 became overgrown - by mustard from the north and by blown-over oats from the south. Only two plants were visible needing harvest (preparing to bolt) - 54g and 64g, respectively, for an average of 59g. Only one plant was noticed needing harvest in the control bed, which had been missed in the previous harvest - a much larger 202g. Given the irregularities of the second harvest, it should probably be excluded from analysis.

A number of additional plantings were done on 29 July at a variety of locations around the garden, but these are not ready for harvest at present.

Mustard

Mustard 'Green Wave', a cultivar grown primarily for its leaves, was planted in the northeastern portion of trial #4 (13 plants) on 12-13 May. Controls (12 plants) were planted on the western edge of control beds #3 and #4.

The first harvest (fig. 78) was only a month later on 15 June - a total of 901g in the heated bed (69g/plant) and 216g in the control bed (18g/plant) - a 3.8x difference.

The second harvest was done on 4 July. 1700g was harvested from heated beds (131g/plant), while only 8 plants were found in the control bed with harvestable amounts - a yield of 280g and 35g/plant.

A third harvest was done on 19 July. 1469g was harvested from the heated bed at 113g/plant. Yet another plant disappeared or was unharvestable from the control bed; the yield was 58g at 8g/plant. Mustard by this point had become insistent on flowering, and it was decided to allow it to do so in order to measure the seed yield (which will not be available until later in the year).

Fig. 78: **Top**: heated mustard harvest. **Bottom**: control harvest

The total heated yield was 4070g of leaves from the heated bed (313g/plant), vs. a control yield of 554g - on the basis of the original 12 plants, that equates to only 46g/plant (a 6.8x difference). A mitigating factor, however, in the unheated control beds' favour was the steady encroachment by rhubarb over the growing season, which slowly increased the shade levels.

Arugula


Fig. 79: March-survivor arugula (4 August)

12 plants of arugula ‘Wild Rocket’ were planted on 12-13 May in trial #5. Four survivors from the March test planting also survived in the heated bed (fig. 79). Seven control plants were planted east of trial #5 and another three in control #4.

The first harvest was on 4 July. Heated plants yielded 831g (69g/plant). Six of seven control plants were ready for harvest and yielded 194g (22g/plant) - a difference of 3.2x. The old plants of course yielded even more 1199g (300g/plant).

The second harvest was on 4 August (two heated plants delayed to 10 August). Of the four old heated plants, one was for unknown reasons in poor health. The other three yielded 1125g (fig. 80), or 281g/plant. Of the main heated experiment, two were in poor health and not harvested; of the remaining 10 plants, the yield was 1246g (125g/plant). Of the control beds, one plant was in poor health; of the remaining 9, 774g was harvested, or 86g/plant (1.5x more in unheated vs. heated beds). The cause of some plants' poor health never became clear; rather than regrowing from their previous harvest, they remained stunted and discoloured.

On 20 August, a survivor in a control bed was discovered from the March planting. It was harvested for the first time, yielding 135g.

On 4 September, a new harvest was conducted, but many plants had either been overgrown by the (unexpectedly-large) rhubarb plant or were in poor health. Only one old plant remained (160g). Six plants from the main experiment remained, yielding 657g (109.5g/plant) (fig. 80) - probably significantly lowered by the encroaching rhubarb plant. Seven control plants remained, yielding 728g (104g/plant) - 11% more in controls than heated plants.

Fig. 80: 672 grams from a single plant.

Overall, 2734g was recovered from the main heated experiment (initially 12 plants, declining to 6 shaded plants by September); 2484g was recovered from the March-planted heated plants (initially 4, declining to 1 by September), plus 135g from a March-planted control; and 1696g from the main control plants (initially 10 plants, declining to 6 by September). The net benefit from heating was thus 1.34x, though heavily caveated by them being overgrown to near-nonexistence late in the season.

Mâche

Mâche / Corn Salad 'Verte a Coeur Plein 2', as it is quite a small plant, was planted along the sides of the central walkway on the southern end (along the east side of Control #1 and the west side of parts of trials #3 and #4. As mâche is famous for its origins as a weed in grain fields, a

Fig. 81: Mâche (4 June)

portion of the heated plants were planted to overlap with oats to see how they would yield (fig. 81).

The first harvest was on 4 July. 11 plants co-planted with oats (fig. 82) were deeply overgrown and fully shaded, and these were harvested in their entirety, yielding 292g (26g/plant). 16 other heated plants were cut down to their basal rosette, yielding 529g (33g/plant) - a surprisingly small difference. 27 control plants were harvested similarly, yielding 460g (17g/plant). Heat thus approximately doubled yields.

Fig. 82: Mâche overgrown by oats

At the next harvest, there were only 6 plants with heat to be harvested (others lost in the oats?), and all being shaded by the oats to their south. They yielded 41g (6.8g/plant). 23 plants were harvested on the unheated control side, yielding 290g (12.6g/plant) - 85% more. The difference is presumed to be primarily due to shade.

By this point, the plants were all too focused on flowering to maintain reasonable harvests; they were allowed to flower as a (minor) decoration to the path, and a new batch of mâche was planted in place of the salad burnet to the north, on 29 July. As of writing (19 September), the plants are large enough that they could be harvested at any point.

Salad Burnet

Salad Burnet was planted on 12-13 May just north of the mâche on both sides of the path. Having proven itself a surprisingly hardy plant, all the march plantings with heat survived the deep freezes and windstorms that killed many

Fig. 83: Heated salad Burnet surviving hard frosts

other plants, such as a variety of brassicas (fig. 83).

The first harvest was on 4 July. March survivors yielded 262 grams (29.1g/plant). 22 newly planted heated plants yielded 136g, or 6.2g/plant. 26 unheated plants yielded a mere 26 grams (1.1g/plant); a single average March plant yielded more than the entire unheaded May bed. For an apples to apples comparison, May heated plants yielded 5.6x as much as May unheated plants.

The second harvest was only two weeks later, on 19 July. 28 plants (a decrease of two) with heat yielded 306g (10.9g/plant). 22 unheated plants (a decrease of 4) yielded 32g (1.5g/plant) - a 7.5x benefit for heat.

Fig. 84: Uprooted salad burnet. All harvests were far more than could be used.

Salad burnet was ready for harvest yet again on 2 August (fig. 84), but a problem arose: we were harvesting large amounts, but nobody knew how to use it. In retrospect, while we were trying to use it as a lettuce-type plant it would have been better thought of as an herb, with its delayed-cucumber flavour. The decision was made to uproot it and replace it with mâche / corn salad. 31 plants with heat (the reason for the increase is unclear) were harvested, yielding 775g, an average of 25g/plant. 23 unheated plants were harvested, yielding 133g (5.8g/plant) - 4.3x more with heat than without. It was also noted that the four March salad burnet controls had survived, and they were harvested for the first time - however, they only yielded 27g (6.75g/plant) - essentially the same total as the later-planted unheated plants.

Overall, in the same amount of area, heated salad burnet yielded 1479g, while unheated salad burnet yielded 218g - a net difference of 6.8x. While the yield could have been increased in the unheated bed by denser planting (since they simply did not grow nearly as large, as quickly), the impact was quite dramatic.

Fennel


Fig. 85: 'Florence' (4 August)

A small number of fennel plants - two 'Florence' (fig. 85) and one 'Bronze' - were planted in in each of heated (trial #4, east side) and unheated (along the western fence, just north of control #4) beds. The initial plants were rather uneven in size, some only a several centimeters tall, while others were dozens of centimeters tall; however, the mix was averaged out in size between the two beds. While quite large, no plants have been harvested yet, as we're waiting for seed development.

As of 17 September, fennel development was as follows:

Bed	Plant	Height (cm)	Girth (mm)	Umbels
Heated	Florence	119	19.5	1
Heated	Florence*	155	31	16
Heated	Bronze	125	18	1
Control	Florence	119	17	0
Control	Florence	93	13	1
Control	Bronze	25	3	0

** - Windthrown / knocked over by oats and partially shaded as a consequence*

The benefit of heating can be clearly seen, with mean heights of 133cm vs. 79cm; a mean girth of 23cm vs. 11cm; and a total of 18 umbels vs. just one. Perhaps noteworthy, the worst performing heated fennel plant was still a better performer than the best-performing unheated fennel plant. The best-performing fennel plant was a standout - the height of an adult with a stem like a tree branch - and hopefully with a larger experiment in better conditions that level of performance could be achieved repeatedly..

Lettuce

Fig. 86: 'Ice Queen' (second planting)

Lettuce 'Ice Queen' - planted on 12-13 May (east side of trial #4 and along the western fence as a control) proved a confounding experience. Plants with heat appeared to initially be growing faster, but then slowly seemed to die back one by one. Plants were also harvested later than they should have been, giving them a chance to start to bolt. During the harvest on 10 August, it was discovered that the stems of the heated lettuce plants (grown in mulch) were all rotting (potentially *Fusarium* wilt - fig. 87), but the stems of the control plants (grown in soil) were not. It is unclear whether the rot problem was the heat, the mulch, or a combination of the two. A new experiment was planted on 29 July and will probably be ready for harvest within a couple weeks (fig. 86).

Fig. 87: Rot on heated / mulched plants

Bed	Non-rotten weight (g)	Percentage rotten
Trial #4	133	75%
Trial #4	73	75%
Trial #4	355	30%
Trial #4	95	0%
Trial #4	390	5%
Trial #4	416	40%
Control (western fence)	1063	0%
Control (western fence)	210	0%
Control (western fence)	199	0%

** - Non-rotten weight uses a generous definition of "non-rotten"; significant amounts were still discarded due to being unappealing.*

Leeks

Leeks ('Giant Musselburgh') were planted out on 12-13 May on the east end of trial #5 (fig. 88), along with a control planting in the northwest corner of Control #4. None have been harvested at this point, although those in the heated bed are large enough at present that they could be harvested as proper leeks (up to 3cm in diameter). Those in control beds still more closely resemble spring onions, with ~1cm stems.

Fig. 88: Heated leeks (17 September)

Acmella and Stevia

Four acmella ("Buzz Button" / "Toothache Plant") plants and four stevia plants were planted on 12-13 May - two with heat and two without for each of the two species. All controls perished relatively quickly. The two heated acmella one of the heated Stevia plants eventually died, but one stevia plant survived and grew all summer - albeit at a relatively unimpressive rate (as of 18 September it was approximately 30cm tall). No harvest has been taken at this point, and the primary goal is to see if the heating allows it to survive the winter.

More experimentation with these plants - planted out at a later date - will be needed next year.

Conclusions

Summary of Experiments

Key:

Harmful in the winter / early spring; unknown in summer	Unclear; needs more study	Negative in winter, but positive in summer	Unclear in winter; positive in summer	Positive in winter and summer	Impractical outdoors in Iceland even with heat

Plant	Results
Fruit Trees	Heat dramatically increased vegetative growth (often ~70cm vs. max ~30cm). Developing fruit on heated plum trees, none on unheated. No visible difference between different overwintering temperatures.
Grapes	Moderate winter mortality rate, somewhat higher with heat. Unclear whether heat is benefiting during the growing season; needs more study.
Hops	Only one plant (of four) survived the winter (unheated control); no comparison.
Strawberry ‘Sonata’	Started growing much sooner and more vigorously with heat, with a higher winter survival rate. Set fruit 1 ½ months earlier. Visually more fruit set, but measurements were complicated by birds, fungus and rhubarb overgrowth.
Strawberry ‘Glima’	Heat yielded approximately an order of magnitude more vegetative growth in a newly planted bed - formed a dense ~3m² carpet from 8 tiny plants.
Rhubarb	Summer heat provided a 2.2x increase in plant area and a 4.7x increase in maximum stem volume; could reduce the time between planting and harvest by a year. Overwinter heat probably not useful, potentially harmful.
Blackcurrants	Heated pllants grew on average 2.6x larger on the long axis, 2.2x larger on the narrow axis, 1.6x taller, and 9.4x greater volume. No fruit yet.
Honeyberries	100% winter mortality in heated beds, 0% in unheated beds - broke dormancy too soon.
Oregano	Heat doubled yields, with a 3.2x increase per plant in the first harvest.
Sage	Only one plant (of four) survived the winter (unheated control); no comparison.
Roses	Regrew from the base. No mortality with heat (vs. 1 in 3 among controls). 3-5x more blooms and 5-8x more buds among heated plants vs. remaining controls. Questionable whether unheated plants will survive another winter.
Sunflower ‘Arikara’	Heat led to 10% taller plants with vastly thicker stems, and 0% wind damage (vs. 50%). Too soon to assess flower and seed production.
Sunflower Sun Spot	Vastly larger plants with heat. Primary flowers about 2.5x the surface area. Too

Dwarf Cola'	soon to assess secondary flowers or seed production.
Wheat	Much earlier germination with heat, yielding denser and slightly taller plants, and seed heads about twice the volume. Too early to assess yields.
Oats	Somewhat taller plants. Difficult to assess other properties at this stage. Suffered significant wind damage.
Corn	Seeding in mid-March was too early. Direct planting in mid-July was too late. Heat nonetheless led to larger plants and the blooming of 'Orchard Baby' by September.
Beans	Also planted both too early and too late. Heated vines 3-4x longer than unheated. Heated 'Succotash' are flowering.
Bananas	'Jamaican Red' banana can *survive* with or without heat, but while heat helps, it is not enough to *thrive*. Experiment should be repeated with hardier species, such as M. sikkimensis and M. basjoo.
Squash, Melons, and Cucumbers	Controls quickly died; heated plants survived longer, but all but one ('Gelber Englisher') died. Need to repeat with a later planting of larger plants.
Peppers and Eggplants	While all unheated peppers and eggplants quickly died and all heated peppers survived, no variety thrived or flowered. Better cultivars would be needed.
Tomatoes	Unheated plants stayed small, discoloured, and many went straight to flower. Heated plants became massive, albeit with later fruiting. Unclear ultimate yield. Future experiments should plant larger plants.
Mizuna	Bolt-prone. Cabbage fly-prone. Quick early crop. Heat increased yields 240%. No-trench configurations increased yields by 74%, in slightly lower lighting.
Tatsoi	Bolt-prone. Quick early crop. Heat increased yields 3.5x.
Cauliflower	'Purple of Sicily' very slow to develop, probably poorly adapted to Iceland. 10x greater yield per plant with heat. Removal of trenches increased yields 15%, despite much less light per plant.
Rutabaga	Heat increased yields over 5x, with 1/5th of harvested rutabagas being over 1kg each, and the largest 1.6kg. Yields were roughly equal between trenched and non-trenched plants, though the trenched plants were slightly better lit.
Kale - 'Russian Red'	25kg harvested from ~6m² semishaded heated area just by 20 August (40t/ha), with still more potential. Heat increased yields 9.4x. Removal of trenches increased yields 1.5x, though non-trenched plants were slightly better lit.
Kale - 'Dazzling Blue'	Heat increased yields ~4x vs. controls, though experimental plants were worse lit. No meaningful difference with or without trenches, though trenched plants were slightly better lit.
Kale - 'Niro di Toscana'	Small experiment. Heated plants yielded ~22x vs. controls in the first harvest. Second harvest complicated by confounding factors.
Mustard	First of three leaf harvests: 3.8x more yield with heat than controls. Overall yield 6.8x greater, but the controls suffered from increased shading later in the year.
Arugula	3.2x more yield with heat than controls initially (May-plantings), overall only 1.34x, due to overgrowth by an unexpectedly-large rhubarb plant. Also several plants became dwarfed by an unknown pathogen or pest. March-planted arugula yielded 2.7x vs. May-planted; 4 March plants survived with heat vs. only 1 without.

Mâche	2x more yield with heat at the primary harvest. Only half as much with heat in the small second harvest, due to overgrowth. Initial plants coplanted with oats (w/heat) yielded 79% as much as ones planted away from oats.
Salad Burnet	6.8x more with heat vs. controls. Super-hardy, esp. with heat, but little culinary experience with the plant limited its utility.
Fennel	68% taller with heat, over double the mean girth, and 17 umbels (at time of writing) vs. 1. Smallest heated plant larger than the largest unheated plant.
Lettuce	Grew faster with heat initially but suffered badly from fusarium rot. Unclear whether heat or mulch was to blame. Needs more study.
Leeks	Diameters at present roughly 3x higher in heated beds. Could be harvested now in heated beds; unheated beds need at least another month, if not more.
Acmella and Stevia	4 of 4 acmella plants and 3 of 4 stevia died. Controls suffered more. A later planting should be tested.

Discoveries

While the previous season had been suggestive that heating might yield significant growth impacts, the late start left this answer unclear. While heat assisted growth (albeit at a slowing rate) into the winter, once freezes became deep and consistent, the heat lowered the survival rates of the remaining brassicas, raising concerns about adverse consequences from winter heating on breaking dormancy.

This year, questions about whether heat increases yield were unambiguously answered: dramatically in most circumstances. Indeed, growth rates of some plants were so unexpectedly large that they caused neighboring experiments to be overgrown, hindering research quality. In the case of tomatoes, heated plants grew so large as to overwhelm their insufficient stakes, leaving them to sprawl. Seeing non-traditional plants not simply surviving, but thriving in an Icelandic garden has been quite the sight.

The impact of winter heating still remains unclear on most plants, with the exception of strawberries, which seemed to unambiguously benefit from it. Rhubarb may have been adversely affected, and honeyberries (fatally) broke dormancy too soon. More testing will be needed on this front among other perennials.

A stark visualization of the power of ice nails could be seen between insulated and uninsulated beds (fig 89) - massive ice nails from the heated soil being visible in uninsulated beds but not insulated beds. The ice nails left the soil in the uninsulated beds churned and fluffy in the spring.

Fig. 89: Frost nails dramatic without insulation, absent with insulation

In terms of timing, for most plants where harvest is conducted just before or after flowering - for example, many brassicas - heating made no impact on timing, only yield. Sunflower and rose blooming times were not very different, and trees bloomed at the same time. Strawberries fruited far earlier with heat than without it.

Fig. 90: Prostrate horsetails formed a natural insulation in patches

While we initially set up our beds to test the impacts of different plumbing configurations - which seem not to make a big impact - and three different insulation possibilities (pumice, mulch, or bare), a new possibility - low insulative living groundcovers like horsetails - presented itself (fig. 90). This should be researched further, as - so long as they don't hinder crop growth - such groundcovers are free and self-renewing.

Our hypothesis that trenches between heated rows - designed to increase insulation - might be harmful appears to be upheld. Given that a trenched design takes extra work to set up, they should be avoided.

As feared, cabbage fly proved a problem in our research garden, where we try to avoid the use of pesticides. It is a shame that, lacking a higher-temperature water feed, we cannot test heating the soil to 35°C for 3 days as a control mechanism.

Attempts to use strips of floating row covers as bird control proved inadequate, due to poor protection and the encouragement of rot. Nets should be utilized next year.

Primary Conclusions

- Heating with wastewater is a powerful way to extend the cultivation period of crops, increase harvests, and grow plants which otherwise would be difficult or impossible here outdoors.
- Heating of the soil over the winter proved helpful for some plants (such as strawberries) but harmful for others (such as honeyberry)
- Heating of the soil helped some plants to survive cold snaps in the spring (e.x. salad burnet) but the impact was not universal, that is, did not apply to all plants.
- Heating of the soil over the summer had a dramatic impact on growth, particularly vegetative growth. The volume of plants with heat was up to ten times greater.
- With soil heating it is possible to shorten the time considerably between planting an harvest (for example, from 2 years to 1 with rhubarb)
- With soil heating it is possible to harvest earlier (for example, strawberries 1.5 months earlier than controls)
- The harvest from heated beds was usually 2-5 times greater vs. controls.
- It is best to design heated beds without insulative trenches.
- The types of insulative materials each have pros and cons, but in general, pumice was a better choice than wood chips.

Discussion

- ***It is possible to extend the growing season in outdoor cultivation and affect the amount of harvest and species diversity with soil heating…***

Fig. 91: Winter harvest

The winter of 2020-2021 showed that brassicas could be kept growing - albeit at a significantly reduced pace - all the way up to December (fig. 91). In the spring, strawberries began growing much earlier (March) and faster, as did March-planted whea. Survival rates of some crops against hard freezes and windstorms were significantly enhanced (such as arugula, mâche and salad burnet), in some cases increasing total harvests dramatically due to the extra two months. Some plants - at least planted small and weak as our March seedlings were, and lacking time to establish themselves - were unable to survive the hard freezes and windstorms (e.g. brassicas, lettuce, leeks). April plantings next year - e.g. between this year's March and May plantings - should be quite illustrative.

- ***...and how does this impact economics? What are the expected costs and operational expense with such a system, and over what timeperiod can it be repaid?***

As per the previous section, heating over the growing season proved to be of dramatic, sometimes mind-boggling benefit. Despite the relatively small garden plot and the fact that many parts of it were unplanted, we were frequently left struggling to find people to donate our harvests to. Particularly with respect to...

- ***Plumbing depth and flow patterns***

... little if any difference was noted between heated beds of different plumbing designs, and trenches were determined to adversely affect most plants. This would argue for simplicity in design. As per our calculations in our previous year's report (*"Pricing at Scale"*), most of the cost of heating a garden is hot water, not setup. With design simplifications, this further biases the equation as being primarily one of hot water costs and not of setup costs. Where even mildly warm water (as we use) can be acquired at little cost, geothermal heating of the soil should be strongly considered.

At 60-80cm between PEX tubes, e.g. 1.5 tubes per linear metre, and a cost of €1 / 150 ISK per metre, the tubing cost is approximately €22500 / 3.4M ISK per hectare, which amortized over three decades equates to a paltry €750 / 112500 ISK per hectare per year. While earthmoving costs, plumbing costs, etc have to be added to this total, the primary driving cost remains local warm water prices, which vary dramatically.

At our location, our contract with Veitur provides for a rate of 93.9901kr (€0.623) per day (meter size 25-50mm) with a unit cost on the water of 4.8862kr (€0.0324) per cubic metre - a rate cheap compared to hot water, but expensive compared to the fact that this water would otherwise be discharged and earn Veitur nothing. At our average consumption of around 12 litres per minute, this works out to around 34328 ISK (€228) per year for the meter and 30838 ISK (€204) for the water. As we only use a small fraction of our meter's capacity, on a larger scale this equates to an annual cost of approximately 2000kr (€13) per heated square metre, or

20M kr (€130k) per hectare. However, eliminating winter heating for crops that do not benefit from it, optimized insulation configurations, more thorough usage of water heat (such as not wasting it on paths), and indeed potentially lower peak heating temperatures, could dramatically reduce this figure. Ultimately, however, the cost effectiveness depends on each particular location's water cost.

- ***What effect does soil heating have on the success of fruit trees and perennials?***

A combination of young trees and a cold, dry late spring / early summer led to limiting fruiting potential this year - although our heated plums did set fruit and our unheated plums did not. However, in terms of vegetative growth, heating provided a *dramatic* beneficial impact, with plants putting on what would otherwise be multiple years' worth of growth in a single growing season.

While growing-season heating proved to be a strong universal positive for fruit trees and perennials, wintertime heating was not as clearcut. A stark warning could be seen in honeyberries, which had a 100% fatality rate with heating and a 0% fatality rating without heating, due to heat causing dormancy breaking before a series of hard freezes. Some possible other harmful winter-heating impacts could be seen in grapes, hops, sage and rhubarb, although it is not as clear cut and will require further study. The two fruit tree beds were heated at different temperatures over the winter and there was no notable difference in growth potential.

- ***How does heating impact early planting in the spring, e.g. in winter wheat, etc.***

Our experience is that early-planted plants in heated beds will germinate immediately while unheated beds will have delayed germination or no germination at all. However, it is critical that the plants be of a variety whose leaves can survive whatever late deep frosts or windstorms may arrive, due to Iceland's unpredictable weather. In the specific example of winter wheat, of course, its vegetation had no problem with surviving these conditions, and thus got a head-start on its later-planted control bed.

- ***Is it possible to extend the outdoor cultivation period and have an impact on the size of the harvest and the diversity of species which can be cultivated by means of heating the soil with geothermal wastewater? If so, how much, and how impactful can it be? / Types of plants which can be cultivated (potentially including those not typically suitable to outdoor environments in Iceland)***

In addition to the aforementioned dramatic harvest increases, we have tested the bounds of increasing species diversity. While preventing root freezing and ensuring root function is part of the picture, it is not the whole picture - leaf resistance to frost, plant cues from atmospheric temperature or timing based on sunlight that aren't appropriate to Icelandic conditions, etc - also have a strong impact. And indeed, even heating soil to ~20°C may still be well below the desired temperatures of highly tropical plants (such as bananas).

Fig. 92: Mâche with (left) and without (right) heat in March

That said, we've seen promising results thus far (fig. 92) as described in previous sections, and intend to continue pushing the envelope.

- ***Growth progress and cultivation time periods - what cultivation plan is optimal in terms of selected crop varieties and fruit trees?***

All plants tested thusfar appear to benefit from growing season heat, although winter heat is not as clear. Farmers and gardeners can thus choose whatever plants they wish. How much earlier crops can be planted (if at all) however, and how much later into the season, appears to vary greatly depending on the plant and no single rule can be established.

Growers should fully account for increased mature plant sizes in terms of their spacing versus what they're accustomed to at present to avoid plants shading each other or other neighboring plants.

- ***Soil and insulation***

The different types of insulation (only one soil type has been tested) impact rate of heat loss (pumice being superior to mulch, which is superior to bare ground); pests (pumice is superior to bare ground which is superior to mulch, at least as far as slugs are concerned); appearance (pumice is generally the most aesthetically pleasing option); tolerance of foot traffic (mulch is superior to pumice); weeds (pumice is superior to mulch, which is superior to bare ground); decay (mulch breaks down faster than pumice wears down); price (pumice is more expensive than mulch); and carbon supply (mulch continuously adds carbon to the underlying soil). It is possible - although unclear - whether mulch was related to our levels of fusarium rot in lettuce plants, or whether the elevated risk was from soil heating; this is currently being tested.

- ***What are the potential benefits for farmers and gardeners in Iceland to implement such a system? What unexpected environmental impacts might there be from such a system?***

The benefits are quite clear: if one wishes to see dramatically increased growth, and even mildly warm water (such as geothermal wastewater) is available at low cost, this can be readily achieved with soil heating. Depending on the plant species and cultivar, it might also be possible to plant earlier, harvest later, shift harvest timings, or grow plants that otherwise will not grow in Iceland; each type of plant must be tested in its own right. But in terms of increasing growth potential and yield, soil heating appears to provide a near-universal benefit (apart from potential crop-specific pest or disease impacts which may prefer the warmer temperatures).

Followup

As with before, the research garden now provides us with a baseline to continue experiments.

The results from a number of species or plants grown in certain conditions remain unclear. In particular there's a lot of uncertainty over the benefits or harms of winter heating. Some perennials - planted last year late in the year, which then died - quite likely simply did not have enough time to establish themselves, and should be replanted next year.

While the vegetative growth of many perennials has been dramatic, the benefits of harvest on yield are still lacking for most.

Many plants from this year - oats, fennel, wheat, tomatoes, sunflower seeds, and a wide range of others - have not yet been harvested and their data recorded for analysis.

Squash, melons and cucumbers require better followup with larger plants planted at a later date. Many other plants however could have benefited from earlier planting, and it is desirable to better quantify the cold-weather endurance limits of various species / cultivars.

The impact of heat and insulative materials on various pests and pathogens requires more research.

In the interest of increasing the diversity of cultivated plants, a wider range should be tested in follow-up, ranging from the small (more acmella / stevia tests) to the large, such as other species of bananas (or even hardy palms).

Gratitudes

As with last year, I would like to offer my thanks to Hjördís Sigurðardóttir for her assistance on this project, on everything from the application process to reviewing this report to even helping find people to donate the harvest to; finding recipients for twenty kilograms of kale at once can be a surprisingly difficult challenge!

I'd also like to thank Jón Guðmundsson, who in addition to always being a sounding board to discuss ideas, problems, and solutions, donated twelve 'Glima' strawberry plants for cultivation this year.

As always, thanks go out to Veitur and the City of Reykjavík for their cooperation with this project. Additionally, I'd like to thank Gæðamold for offering us a discounted rate on soil for trench infill in order to conduct our comparison experiments in trials #7 and #8.

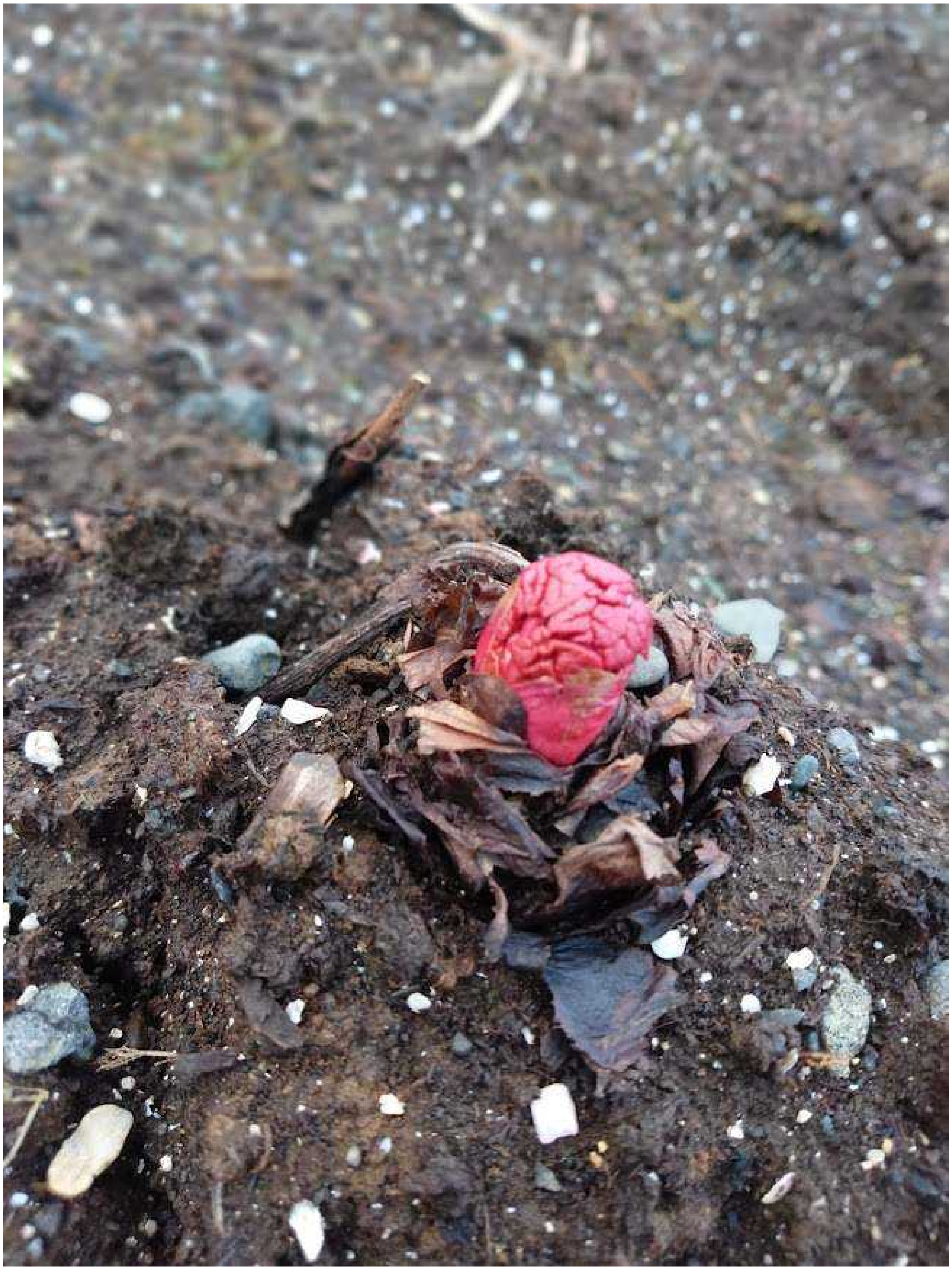
Thanks to all of you :)

References

1. Bruyninckx, H. (March 2020). Towards Europe 2030: resilient nature, sustainable economy and healthy lives. *European Environmental Agency*. Retrieved from: https://www.eea.europa.eu/articles/towards-europe-2030-healthy-people
2. Samband Íslenskra Sveitarfélaga (15 May 2020). Sjálfbært samfélag í kjölfar COVID-19. Retrieved from: https://www.samband.is/frettir/sjalfbaert-samfelag-i-kjolfar-covid-19/
3. Snjólaug Ólafsdóttir (24 May 2020). Sjálfbærni er leiðin út úr Covid-krísunni. Kjarninn. Retrieved from: https://kjarninn.is/skodun/2020-05-23-sjalfbaerni-er-leidin-ut-ur-covid-krisunni/
4. Þ. Ó. Halldórsdóttir, & Nicholas, K. A. (2016). Local food in Iceland: Identifying behavioral barriers to increased production and consumption. *Environmental Research Letters*, 11(11), 115004. doi:10.1088/1748-9326/11/11/115004

Appendix A: Gallery

Below: *One of the first harbingers of spring, rhubarb bursts from the ground.*



Left: *Tatsoi flourishing with heat.* ***Right:*** *Oats planted along the path of the heat pipes.*

***Left**: Young ‘Dazzling Blue’ kale. **Right**: ‘Valentine’ cherry tree in bloom.*

Left: *A smoothie made from the June harvest..* ***Right:*** *The oats soak up the June sun.*

***Left:** Rutabaga and 'Dazzling Blue' kale on 23 June (w/heat)* ***Right**: The same plants on 19 July*

Below: *Oats flowering in July*

Left: *Sunflowers on 4 August.* ***Right****: Rose 'Europeana' and wheat 'Red Fife' on 4 August*

***Left:** Karen harvesting rutabaga on 4 August. **Right:** leeks on 4 August.*

*18 August: **Left:** Rose ‘Europeana’ covered in buds. **Right**: second-year cabbage ‘Primo’*

Left: *Mustard allowed to bloom in mid-August.* ***Right****: pre-second-harvest oregano.*

Left: *Rose 'Europeana' in full bloom on 4 September.* ***Right****: Garden east side.*

***Left**: Distributing the harvest ('Please take more!')* ***Right**: Tomato vegetative growth and blooms*

*8 September**: Left:** Fennel 'Florence'. **Right**: Tomato 'Polar Star'*

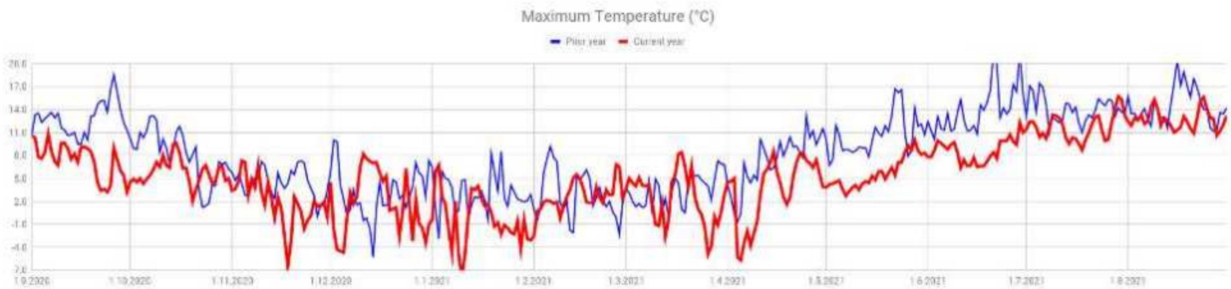
Top: *2-year-old cabbage 'Primo'.* ***Bottom****: Hjördís and 'Arikara' sunflowers.*

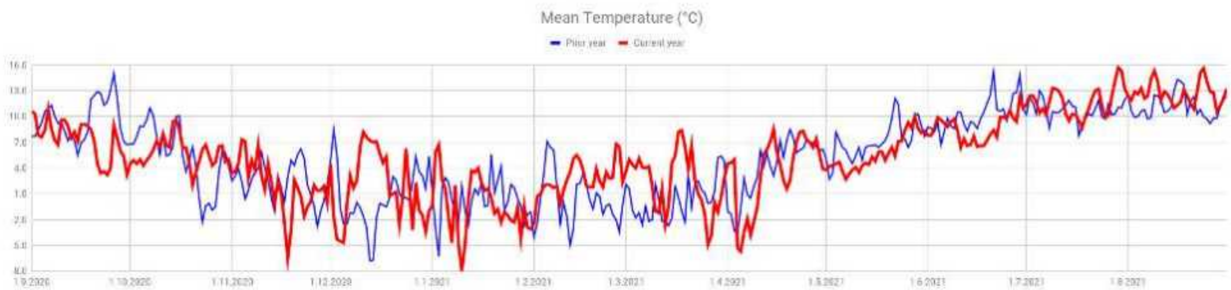
Left: *Leaf fly on blackcurrant.* ***Right****: Sunflower 'Arikara' (rear) and 'Sun Spot Dwarf Cola' (front*

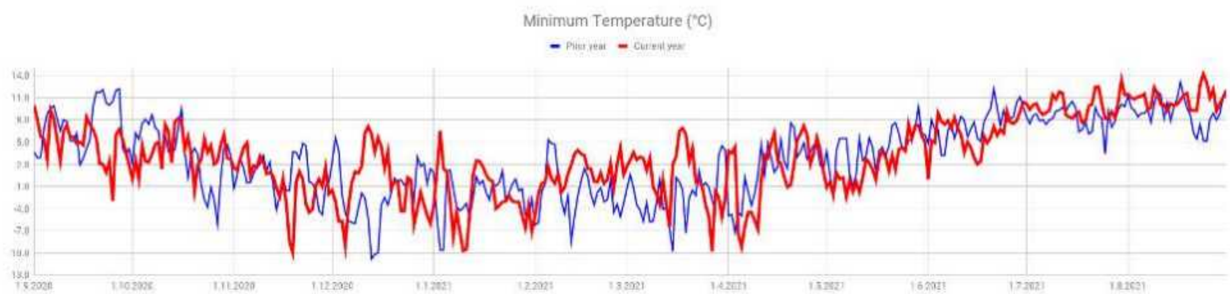
Top: *Beans 'succotash'.* ***Bottom:*** *Sunflower 'Arikara'.*

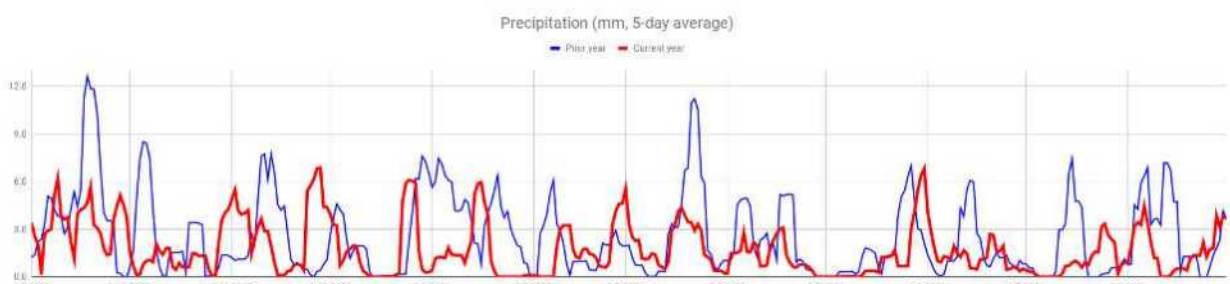
Below: *Sunflower 'Sun Spot Dwarf Cola' secondary flowers.*

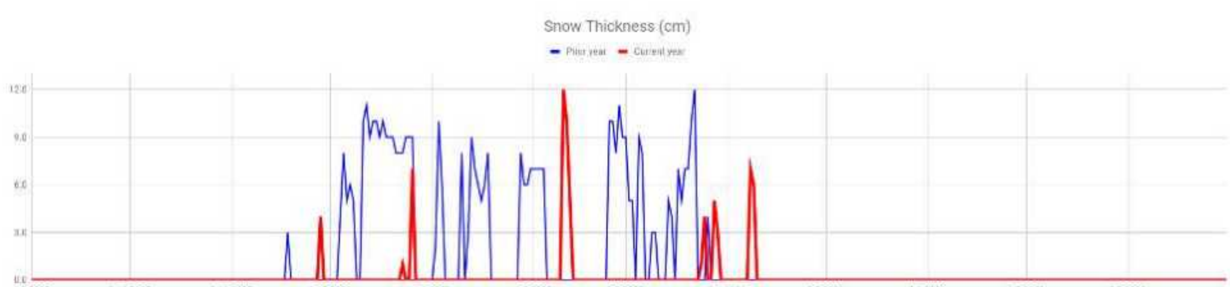
Appendix B: Weather Data

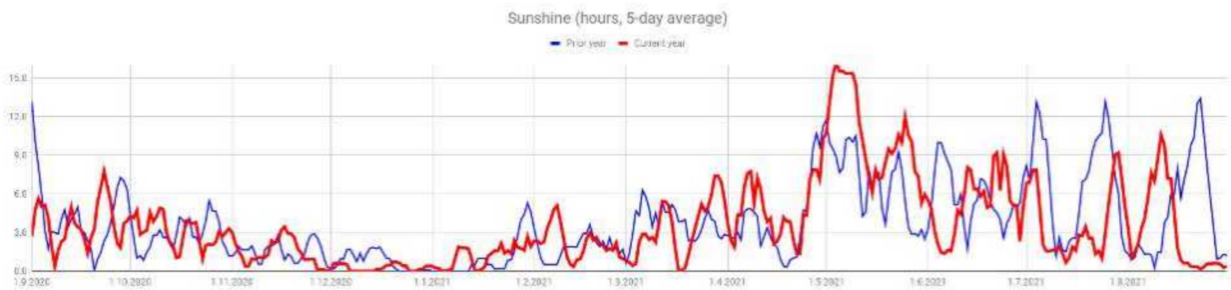


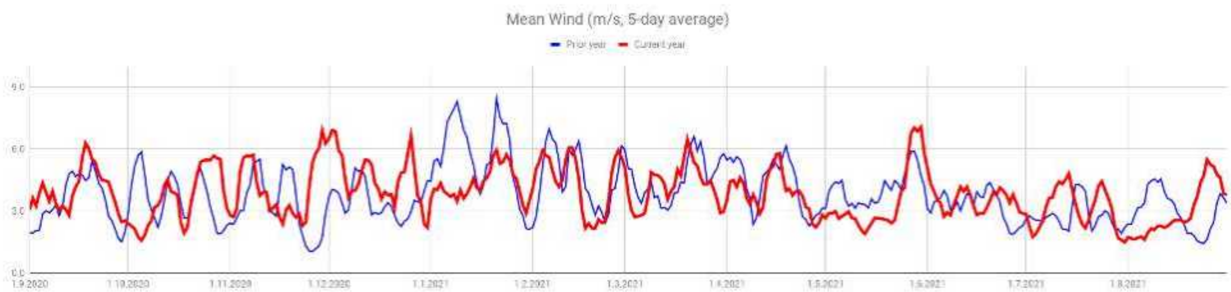


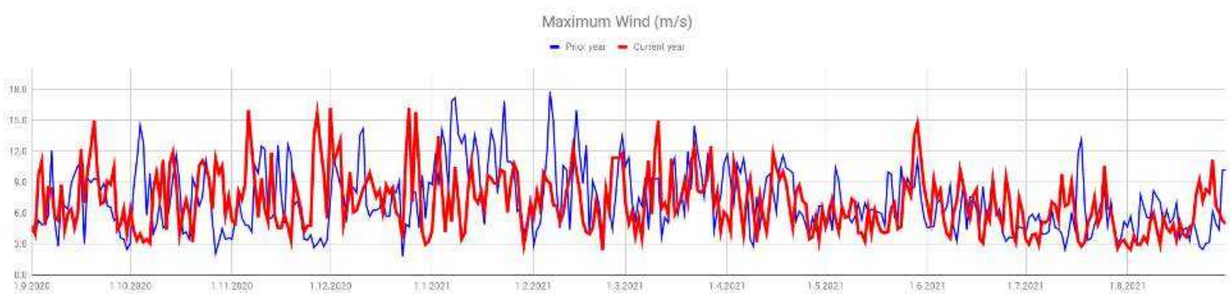


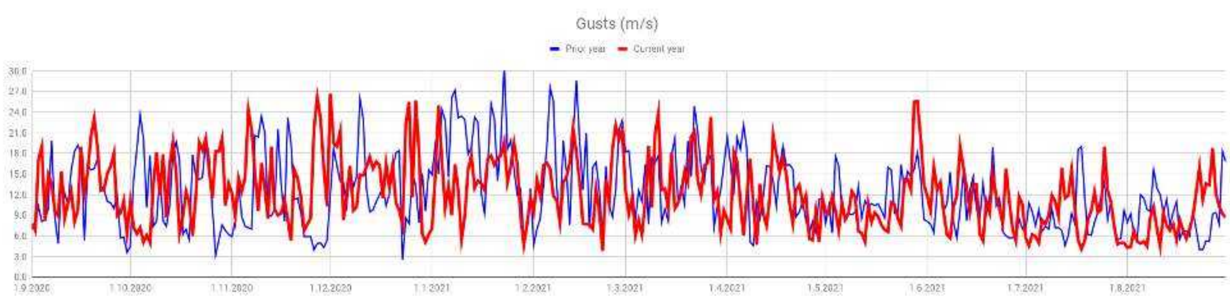





Sunshine (hours, 5-day average)
Prior year
Current year


Mean Wind (m/s, 5-day average)
Prior year
Current year


Maximum Wind (m/s)
Prior year
Current year


Gusts (m/s)
Prior year
Current year

Signatures

Þetta verkefni var unnið af:

Karen Rós Róbertsdóttir

Umsjónarmaður:

Hjördís Sigurðardóttir