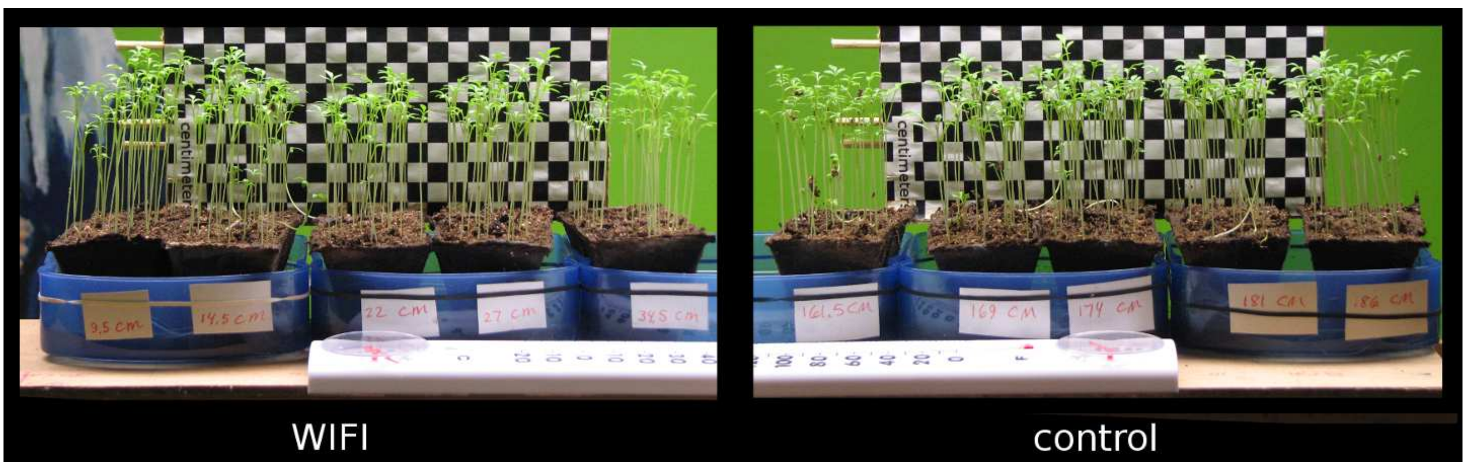
August 3, 2016

WIFI Didn't Affect The Sprouting, Height Or Weight Of Garden Cress



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1 Abstract

Previous research suggested that WIFI radio signals hurt a plant named garden cress.

This caused some concern, because if WIFI hurts plants, it might hurt people too.

It seemed important to me, so I tried to duplicate their results, while carefully controlling other things that affect plant growth.

I controlled light to 27 lux, humidity to 3%, and temperature to 0.1 degrees Celsius.

In my study, WIFI did not affect sprouting (p=.35), height (p=.19) or biomass (p=.38).

Maybe that's reassuring, but we still need to know if it's safe for people.

I don't use WIFI.

More research is needed.

Contents

2 Introduction

Thousands of studies have tried to determine if radio waves are safe[3].

In 2013 some admirably science minded students reported a particularly elegant one.

They put WIFI near a cheap and fast growing plant named garden cress[1].

It grows in only 2 weeks.

They said fewer seeds sprouted, fewer grew to full adult height, and their sprouts weighed less[2][5].

This worried me because

1. there are millions of WIFI hot spots[1,2] and
2. if it hurts plants, it might hurt people too.

So I thought it could be helpful if I tried to duplicate their results[3].

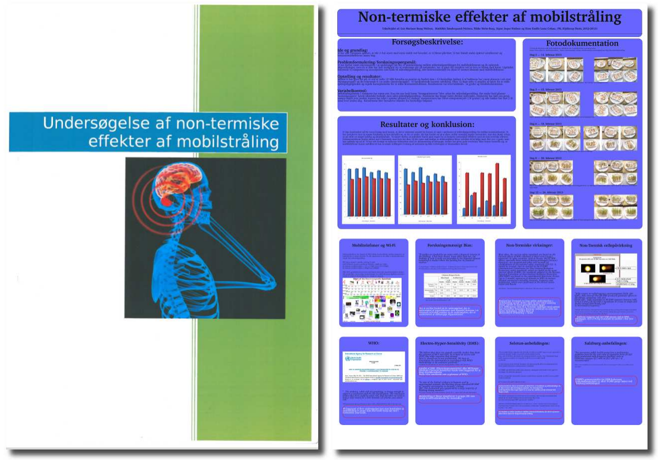
It turned out to be more work than I expected.

9 months later, I had an answer.

[1] Lepidium sativum
[2] Scientists call the dry weight of plants "biomass".
[3] I sought no funding, and received none.

3 Materials

3.1 the students' paper and final poster[5,6]



3.2 a laboratory

A crude translation of the Danish students' final poster said their WIFI and control sprouts grew in different rooms[6].

I'm worried that their rooms may have had different temperatures, humidities or lighting.

Any could have affected plant growth.

So I grew all of my sprouts in the same room, and under the same lights.

I used my grown son's old bedroom.

My excellent son's old bed room[4].

[4] Not that I'm biased, or anything. ;-)

3.3 lighting

1. window shades
   a blanket and
   an old comforter

2. 24 hour timer

   Woods
   #50001
   `http://www.colemancable.com`

3. fasteners
   ceiling

   4 eye screws, 3 mm ($\frac{1}{8}$ inch) x 75 mm (3 inches)

   fixture

   2 eye bolts, 6 mm ($\frac{1}{4}$ inch) x 25 mm (1 inch)
   2 eye bolts, 9 mm ($\frac{3}{8}$ inch) x 63 mm ($2\frac{1}{2}$inches)

4. rope
   6 mm ($\frac{1}{4}$ inch) x 6 meters (20 feet)

5. light fixture

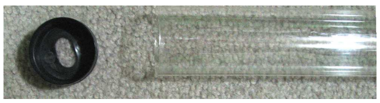
   

   for 2 T12 slimline bulbs
   Lithonia Lighting
   8' (2.44 meters) Standard 2 Lamp Striplight

6. bulbs (2)

Sylvania
Cool White Delux
F96T12/CWX
2.44 meters (8 feet) long
`https://www.1000bulbs.com/pdf/sylvania-29478-specs.pdf`

7. tube guards (2)



Cooper Lighting
clear polycarbonate
TG08
#11788203

3.4 plants

1. water reservoirs

   bottoms of plastic sandwich containers

2. peat pots

   Jiffy Strips 10

   JS50

   `http://www.plantationproducts.com/pages/cfJiffy.cfm`

3. seed starting mix ("dirt")

   Organic Seed Starting Jiffy-Mix

   40-50% Sphagnum Peat Moss, Vermiculite, Lime for pH balance, and organic wetting agent

   F-1431

   G310

   `http://www.plantationproducts.com/pages/cfJiffy.cfm`

4. seeds

   garden cress

   Catalog number OG101

   Baker Creek Heirloom Seed Co.

   `http://www.rareseeds.com/`

5. water

   from Lake Whatcom in Washington State

   `http://lwwsd.org/wp-content/uploads/2012/07/South-Shore-CCR-2013.pdf`

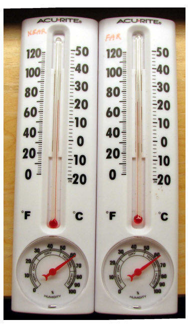
3.5 measuring instruments

1. light

Grow Bright digital lux meter
HTG Supply
ACC-GBLM100
`http://www.htgsupply.com/Product-GrowBright-Digital-Light-Meter`

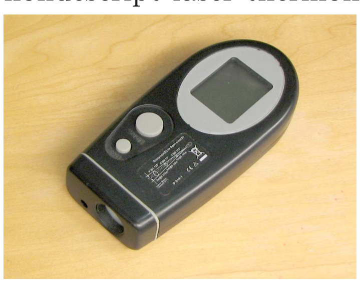
2. temperature and humidity

   (a) Acurite thermometers

   00339
   `http://www.acurite.com/environment/thermometers/8-5-thermometer-with-hygrometer-00339.html`

   (a) nondescript laser thermometer

3. biomass (weight)

American Weigh Scales, inc.

Gemini-20 scale

http://www.awscales.com/portable-precision-scales-01-gram/75-gemini-20-portable-milligram

4. WIFI strength

Trifield meter 100XE from AlphaLab Inc., bought from LessEMF

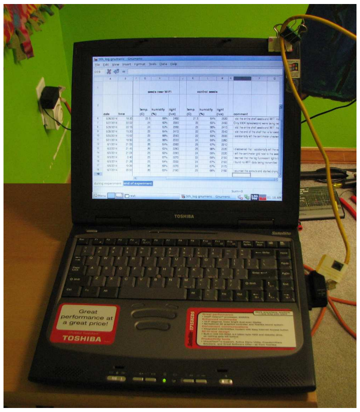
http://www.trifield.com/UserFiles/TF100XE%202012.pdf

3.6 WIFI

1. lab

   (a) hardware

      i. Toshiba Satellite 1715XCDS notebook computer



cdgenp01.csd.toshiba.com/content/product/pdf_files/detailed_specs/satellite_1715xcds.pdf

      ii. Danpex 32-Bit CardBus PnP 10/100Base-TX Network Adapter — FE-6550TX

http://www.danpex.com/products/nics/fe6550tx.htm

      iii. WIFI router

MediaLink
Wireless-N Broadband Router
Model No.: MWN-WAPR150N
"This router does not support Dual Band or 5Ghz wavelengths."http://medialinkproducts.com/docs/MWN-WAPR150N_FAQ.pdf
http://www.medialinkproducts.com/docs/MWN-WAPR150N_User_Guide.pdf

(b) software

i. operating system
Puppy Linux version 4.3
`http://puppylinux.org/main/Overview%20and%20Getting%20Started.htm`

ii. data logging

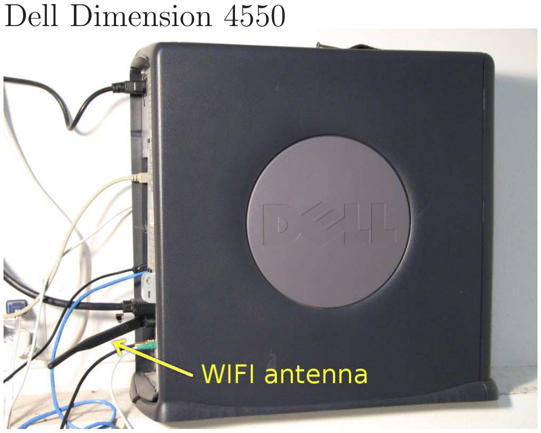
gnumeric spreadsheet version 1.8.2
`http://www.gnumeric.org/`

2. remote computer

(a) location
2 floors (7 meters or 22 feet) below the WIFI router in the lab

(b) hardware

i. Dell Dimension 4550



ii. WIFI

Linksys Wireless-G 2.4 GHz
PCI Adapter
model number WMP54GS

(c) software

i. operating system
Debian Linux 7.4 ("Wheezy")
`https://www.debian.org/releases/wheezy/`

ii. bandwidth monitor
system monitor version 3.4.1

3.7 Miscellaneous

1. spray bottle
2. spatter guard

   30 cm (11 inch) diameter
   1.5 mm (1/16 inch) mesh
3. software
   (a) ocrfeeder
   (b) tesseract
   (c) R version 3.0.2-1
   (d) gnumeric version 1.12.13-1
   (e) bash version 4.2.45(1)-release
   (f) GNU coreutils sort version 8.21
4. wood shelf

   2.1 meters long (7 feet) x 20 cm (8 inches) wide
5. tape measure

4 Methods

4.1 Translating the students' paper

I downloaded the students' paper[5].

It's written in Danish.

I needed to translate it into English to understand what they did.

However, language translation software uses character data, and the students' PDF file appeared to contain images.

I used optical character recognition (OCR) software named "ocrfeeder" and "tesseract" to convert the images to characters.

Then I translated it into crude English[7].

4.2 Pilot experiments

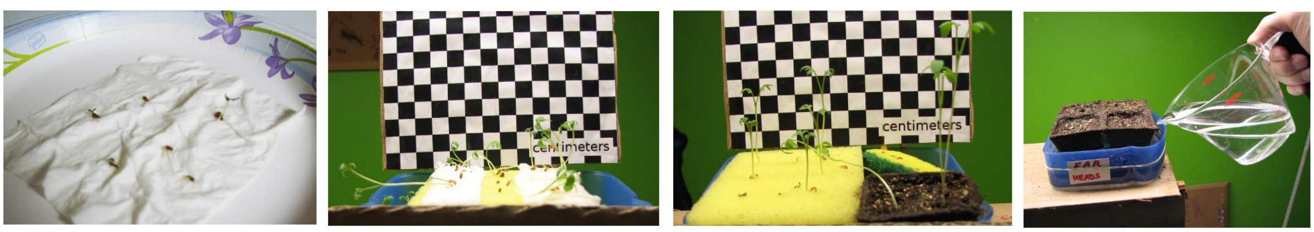
A pragmatic friend suggested a pilot test[8]. I performed several.

4.2.1 Learning how to grow garden cress

I experimented with growing garden cress on a variety of papers and sponges, a hand-towel, and in a seed starting mix.

Paper needed to be sprayed with water several times a day to keep it moist.

Garden cress grew well in the seed starting mix[5].



Seed Starting Jiffy-Mix was the best medium

Each peat pot could hold 16 seeds (4 x 4).

4.2.2 Learning how to measure and control factors thought to affect garden cress

It seems to me that the sensitivity of my experiment to WIFI depended on how well I controlled other factors thought to affect plant growth.

Naturally I first needed to be able to measure them.

I focused on water, light and temperature.

I experimented with various instruments and measurement techniques.

[5] What are the odds? ;-)

1. Water

   I ultimately settled on seed starting mix in peat pots in the bottoms of blue plastic sandwich containers which acted as water reservoirs.

   Now several days could pass before I had to add water.

   I also experimented with how to measure water.

   I initially tried

   (a) counting how many times I sprayed the sprouts with water from a certain distance, but this ignored varying evaporation rates and air humidity, and
   (b) measuring how much water I added and the depth of water in the reservoirs, but these were only indirect measures of how much water touched the sprouts through the seed starting mix and air.

   Then I tried directly measuring the moisture content of the seed starting mix with

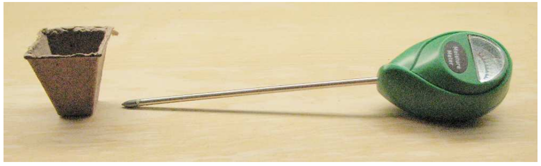
   (a) an electronic moisture meter intended for building materials

   but it

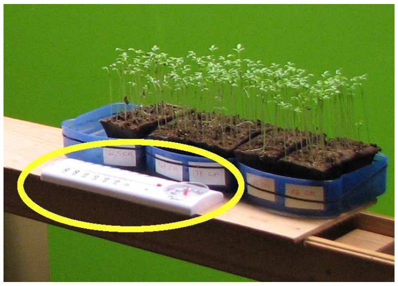
      i. only went up to 50% and
      ii. reported different readings depending on where its probes touched,

   (b) a gardening moisture meter

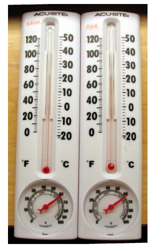
   but without thrusting its probe deeply into the starting mix[6], it gave erratic readings, and

   (c) an inexpensive combined humidity meter and thermometer.

   Placing the humidity meters side by side revealed that they tended to report slightly different humidities at the same time and place. I compared the humidity readings side by side on 3 days, and estimated that the average difference was only 1% (with a standard deviation of +/- 2%). I normalized the reported humidities accordingly.

[6] I planted 16 seeds in each peat pot and was worried about damaging fragile sprout roots.



I ended up using these because they gave repeatable readings and more directly measure water in the air next to the sprouts.

All in all, I had the most trouble measuring and controlling water.

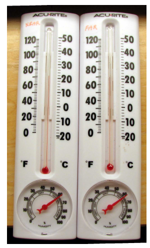
(d) Temperature

I read that temperatures between 18 and 25 Celsius (64 to 77 degrees Fahrenheit) are good for sprouting[9,10]. I started experimenting in the lab in winter, and noticed that temperatures in it were as low as 15 degrees Celsius (59 degrees Fahrenheit) near windows, especially far away from the room's heating vent.

I tried to warm up the lab by insulating the windows with a blanket and an old comforter. They probably helped, but I finally turned up the entire house's thermostat from 21 Celsius (70 Fahrenheit) to 27 Celsius (80 Fahrenheit).

This resulted in a desirable temperature of 24 Celsius (75 Fahrenheit) in the lab.

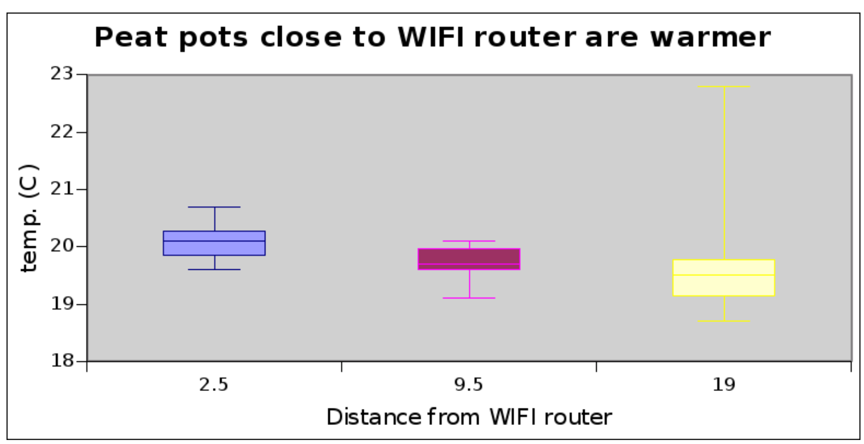
At first I measured temperatures with an laser thermometer, but its readings fluctuated. I settled on inexpensive plastic thermometers combined with humidity meters. They gave steady readings[7].



I tested the hypotheses that the WIFI router would heat sprouts close to it.

I measured the temperatures of wet starting mix at 2.5, 9.5 and 19 cm away from it using a laser thermometer.

distance from rounter (cm)	2.5	9.5	19
	20.7	19.8	22.4
	20.3	19.7	22.8
	20.1	20	22.8
	20.1	20	20
	20.3	20.1	19.7
	20.2	19.6	19.6
	20.3	19.6	19.8
	19.8	20	19.5
temperature in C	20.1	19.3	19.5
	20.1	20.1	19.3
	19.7	19.6	19.6
	20.3	19.9	18.7
	20	19.8	19.5
	19.7	19.1	19.1
	19.8	19.1	19
	20.2	19.7	18.9
	19.6	19.3	18.9
	20	19.6	19.3
mean	20.1	19.7	19.9
difference from 2.5		−0.4	−0.2
p value		7.1E−04	1.8E−01



2.5 cm away was significantly warmer[8], so I placed the closest sprouts at 9.5 cm in my main experiment.

[7] Placing the thermometers side by side revealed that they tended to report slightly different temperatures at the same time and place. I compared their readings side by side on 3 days, and estimated that the average difference was only 1 degree Celsius (with a standard deviation of +/- 1 degree). I normalized the reported temperatures accordingly.

[8] I used the non-parametric Mann-Whitney-Wilcoxon test because I didn't know if the temperatures were

2. Light

I read that plants and sprouts need from 501 to 2,500, and at least 2,000 lux of light[9,10]. It turned out that the first place I tried growing garden cress had as little as 400 lux.

I bought an economical light meter that seemed to work fine.

So I experimented with shade and various distances from the light bulbs.

Two T12 fluorescent bulbs about 23 centimeters (9 inches) above the sprouts provided about 2,300 lux, which seemed to work OK.

I wanted uniform light over a large enough distance for the WIFI signal's strength to appreciably weaken between the seeds close to the router and those far away.

So I bought the longest bulbs sold by a local store.

They're 2.44 meters (8 feet) long.

For consistency, I used an automatic timer to turn them on and off at 12 hour intervals.

Insulating the windows as described above also blocked sun light coming in, thus adding more consistency.

normally distributed.

3. WIFI


I tested if garden cress was affected by a WIFI signal strength above $\frac{0.1\,uW}{cm^2}$ [9]. This is easier said than done. $\frac{0.1\,uW}{cm^2}$ is less than my electro magnetic field (EMF) meter can detect, which I worked around by holding my meter closer to the WIFI router, and using the inverse square law to extrapolate how low the signal strength should be at greater distances[10].

Other complications were

(a) my EMF meter was confused by the fluorescent light fixture's ballast's 50 kHz signal,

(b) my WIFI router sends a stronger signal in some directions than others[11], and

(c) its signal strength fluctuates with time.

After some trial and error, I seemed to find that I could measure the WIFI signal's strength and control it[12] by

(a) turning off the lights while measuring EMF,

(b) configuring the WIFI router to use only 5% of its maximum power,

(c) pointing the top of the WIFI router toward the seeds,

(d) placing

   i. control seeds at least 161.5 cm away from the WIFI router and

   ii. intervention seeds no more than 34.5 cm from the WIFI router

My EMF meter said the lab computer emitted no radio signal, other than from its router.

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[9] $\frac{0.1\,uW}{cm^2}$ was recommended in the 2000 Salzburg resolution[12], in the 2007 BioInitiative Report[13] and in 2014 by someone who answered my phone call at the EMF Safety Shop (at the equivalent .6 volts/meter)[14].

[10] The inverse square law says signal strength is proportional to $\frac{1}{distance^2}$.

[11] A knowledgeable friend explained how to measure directional differences in the WIFI signal's strength[15].

[12] My goals were to keep the signal strength

(a) above $\frac{0.1\,uW}{cm^2}$ far enough away from the WIFI router to include enough sprouts for an adequate sample size (even while keeping them far enough away from the router to avoid its heat). Specifically, I think the signal strength stayed above $\frac{0.2\,uW}{cm^2}$ up to 37 cm from the WIFI router.

(b) below $\frac{0.1\,uW}{cm^2}$ far enough away from the other end of the light bulbs, away from the WIFI router, to include enough sprouts for an adequate sample size. These sprouts were the control group. Specifically, I thought the signal strength generally stayed below $\frac{0.05\,uW}{cm^2}$ beyond 161 cm from the WIFI router.

4. Other factors

   I expect plant growth is affected by other things too[13]. I tried to reduce their effects by randomizing the order in which I chose peat pots to plant, water, harvest, etc...[14].

[13] Like pH and nutrients, for example.

[14] I used the Linux bash shell and GNU's sort to randomly order peat pots. My code is

```
$ for distance in 9.5 14.5 22 27 34.5 161.5 169 174 181 186 ; do
    for closeness_to_door in near far ; do
        echo $distance $closeness_to_door
    done
done | sort -R
```

4.2.3 Learning how consistently I could grow garden cress

I needed to know how consistently I could grow garden cress to know how many seeds to plant to be confident that I could detect what the students reported. Statisticians call this the "standard deviation".

The sprouts I grew varied as follows

Criteria	Standard deviation per peat pot
full adult sprouts	1.5 sprouts*
crop failure	1.4 seeds
biomass	8.2 mg

* I was unable to find in my records the full adult height data from a pilot experiment. This is the standard deviation observed in my real experiment. I expect they're close.

4.3 Calculating how many seeds to plant

I wanted to plant enough seeds to be reasonably confident that I could detect what the students reported[15].

Each peat pot I used could hold 16 seeds (4 x 4).

I plugged

1. the relative effects they observed[16],
2. how much my sprouts varied in a preliminary test,
3. my desired statistical power of 95% and
4. a statistical "alpha" of 5%

into software that told me how many seeds to plant[17].

Of the three criteria (sprouting, height and biomass), the biggest sample size required was for biomass. The software said to use 16 peat pots, with 8 close to the WIFI router, and 8 far away.

I used 20, so unless I'm mistaken, my experiment should have had at least a 95% chance of detecting what the students reported.

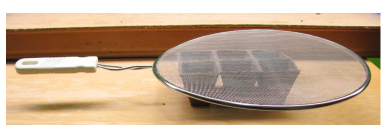
[15] Statisticians might call the number of seeds "sample size", and the confidence "statistical power". I chose to be 95% sure. Bill Kappele helped improve the statistical design of my experiments in several ways[16].
[16] My understanding of the students' results is on page 40.
[17] Details are in the appendix on computing how many seeds to plant.

4.4 Actually Performing My Experiment

Day 1

I planted 320 garden cress seeds divided evenly among 20 peat pots[18]. 10 peat pots were placed close to the WIFI router, and 10 further away.

Following the instructions printed on the sprouting mix's bag may have added some uncertainty to the seeds counts. The instructions said to plant the seeds and water the mix thoroughly. At least for me, thorough watering may have washed away some seeds. I tried again, holding the seeds in place with a common kitchen spatter guard.

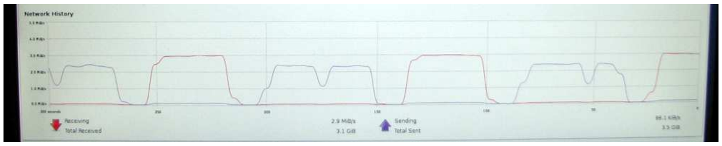


Some sprouting mix and possibly seeds stuck to its mesh, which I tried to brush back into the peat pot(s) with a finger. I'm concerned that this uncertainty may have increased the variation in crop failure rates. Hopefully watering the peat pots in a random order avoided introducing a bias.

[18] 16 seeds per peat pot.

Days 1-15

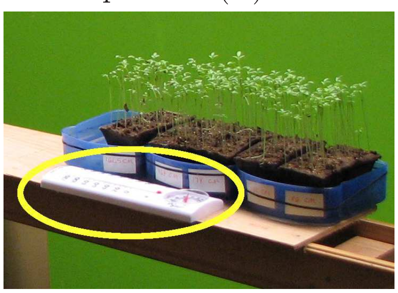
1. I measured
   (a) the speed at which data was being transmitted over WIFI

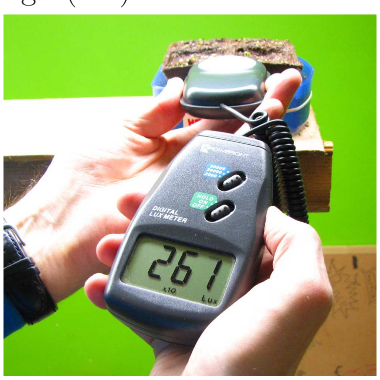
   (b) the minimum and maximum strengths of the WIFI signal near the router

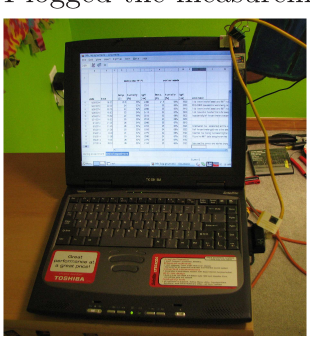
   (c) air temperature(C) and humidity(%)

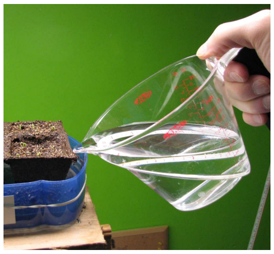
   (d) light(lux)

2. I logged the measurements into a spread sheet running on the lab's computer



3. If necessary, I added water to the reservoirs.



4. I photographed the sprouts.

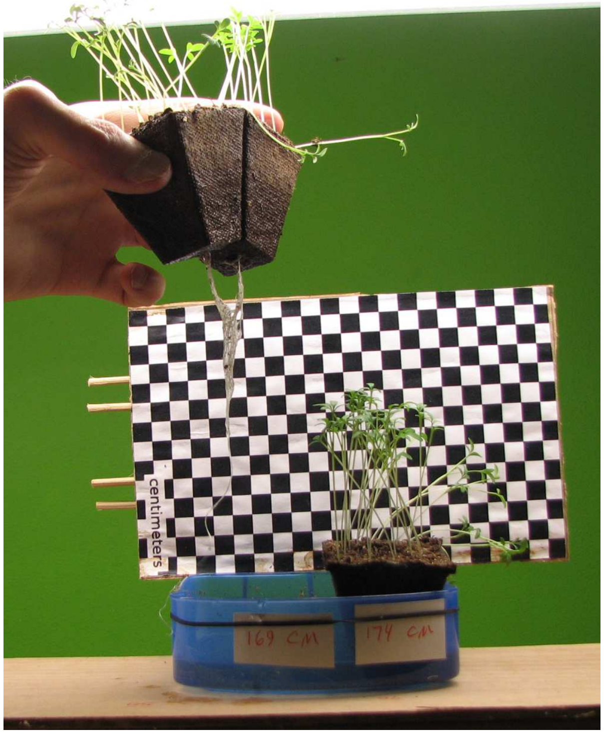
While watering the sprouts on the 4th day of the experiment, I accidentally spilled water on the thermometer/humidity meter near to the WIFI router. Its humidity immediately jumped from 55% to 92%. I gently dried it off, and its readings seemed to return to reasonable values, but I can not rule out the possibility that touching the humidity meter changed its calibration.

I noticed some dry spots in the bottoms of the reservoirs holding peat pots at 3.5 & 14.5 cm, 22 & 27 cm, and 181 & 186 cm from the WIFI router on the 11th day of the experiment. I wish I added water earlier, but photos I took on the previous day showed water still in the tubs, and I expect the starting mix also held water, so I doubt their sprouts got too dry.

Day 15

1. I counted and logged how many seeds failed to sprout and reach half of full adult height in each peat pot.

2. I carefully washed the starting mix off of each sprout's root and set them out to dry.



Day 29 I weighed the biomass of each peat pot's sprouts 5 times and recorded the average.

The standard deviation of the peat pots' biomasses was 5.0 milligrams. This is less, and therefore maybe better, than what my preliminary test found[19].

[19] 8.2 milligrams

4.5 Statistical Analysis

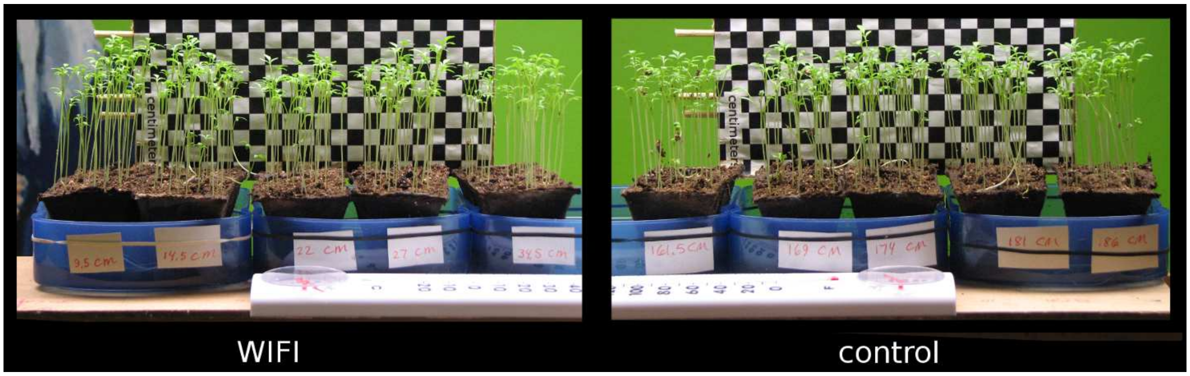
I analyzed the biomasses of groups of peat pots individually (16 seeds) and in pairs (32 seeds). 16 seemed to me to retain more information, and the central limit theorem is thought to work better with at least 30.

I assume the normal distribution approximated the binomial probabilities for sprout failure and full adult height because it was justified when I calculated how many seeds to plant[20].

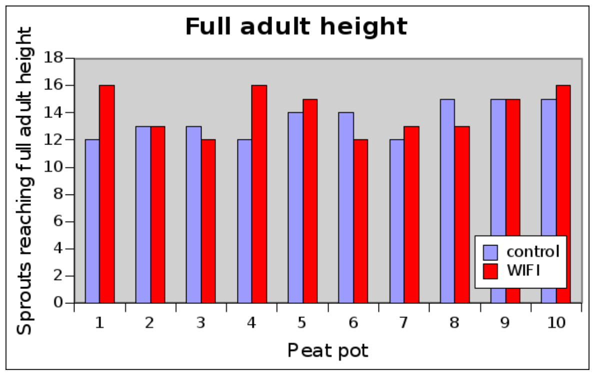
I calculated all the statistics with free and open source software named gnumeric and R.

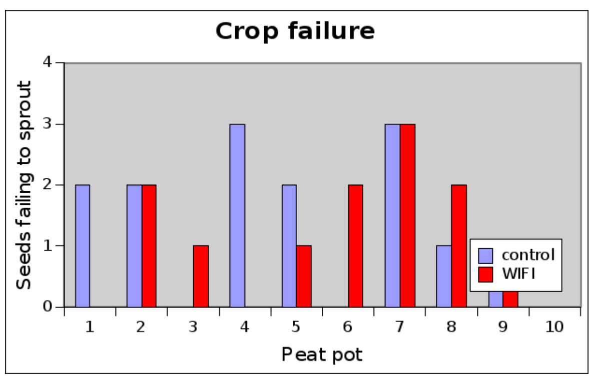
[20] See page 37

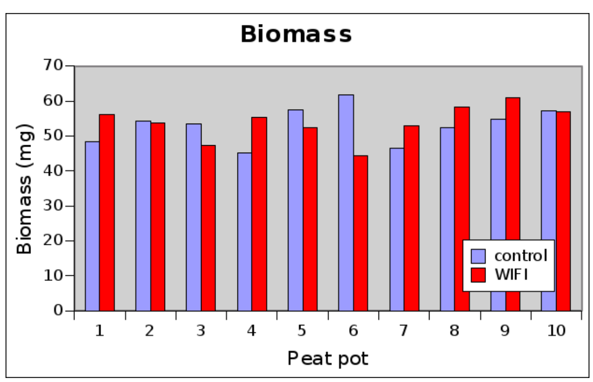
5 Results



I found no effect for WIFI on the sprouting, height or biomass of garden cress[21].







[21] The students reported that WIFI hurt all three. See my understanding of their results on page 40.

Over the course of the experiment, the sprouts near and far from the WIFI router appeared to have average normalized humidities of 64% and 67%, respectively[22] This is a 3% difference in humidity.

Likewise, it seems that when the router briefly radiated more power during its normal cycle (maybe 5-10% of the time), the control sprouts closest to the WIFI router may have been briefly exposed to a little more than the $\frac{0.1\,uW}{cm^2}$ recommended in the 2000 Salzburg resolution (0.11 $\frac{0.1\,uW}{cm^2}$).

[22] If one assumes the humidities were normally distributed and uses the Student t test to find that the so called "p value", it's a significant 0.0001. I chose to not use the non-parametric Mann Whitney Wilcoxon test because there were so many duplicate (ie: "tie") humidity values. However, I'm not convinced the humidities were normally distributed.

	average				hypothesis	
	control	WIFI	difference	p value	test	test justification
full adult sprouts (n)	13.5	14.1	+.6	.19	Student t (1 tailed)	normal approximation of binomial distribution
crop failure (n)	1.4	1.2	-.2	.35	Student t (1 tailed)	normal approximation of binomial distribution
biomass per 16 seeds (g)	53.2	53.9	+.7	.40	Student t (1 tailed)	central limit theorem
biomass per 32 seeds (g)	106.4	107.8	+1.4	.38	Student t (1 tailed)	central limit theorem
water (% humidity)	67%	64%	-3.0%	.000077*	Student t (1 tailed)	tied humidities thwart Wilcoxon-Mann-Whitney
temperature (C)	24.3	24.4	+.1	.42	Student t (1 tailed)	tied temperatures thwart Wilcoxon-Mann-Whitney
light (lux)	2333	2360	+27	.46	Wilcoxon-Mann-Whitney	used a non-parametric test because I didn't know if the light's brightness was normally distributed
estimated WIFI signal strength (mW/cm^2)+	.00011	.00073	+.00062	.0000014*	Wilcoxon-Mann-Whitney	used a non-parametric test because I didn't know if the signal's strength was normally distributed

* Statistically significant

+ Compares the WIFI and control sprouts exposed to the most similar electromagnetic fields (ie: the sprouts at 34.5 and 161.5 cm from the WIFI router).

6 Discussion

I'm not worried about some control seeds possibly exceeding the Salzburg WIFI limit by .01 $\frac{uW}{cm^2}$. It was only about 5-10% of the time, affected only some of the control seeds, the promulgated EMF safety standards vary by much more44, and my WIFI meter is not particularly precise.

Nor am I concerned by the small difference in humidity between the control and WIFI sprouts. It was only 3%, which less than 5% of the total humidity[23].

By all measures, the seeds closer to the WIFI router grew slightly better, but the difference is insignificant and should not be exaggerated. I noticed a similar effect on biomass in preliminary experiments, unless the WIFI router was not connected to the lab computer.

I considered how many seeds would need to be tested to see if the trends I observed become statistically significant. I think you'd have a 95% chance of seeing it if you use 46,000 seeds, which is driven by how much biomass varies and the small difference I observed. However, I think it would be impractical to squeeze half that many seeds close enough to the WIFI router to get enough EMF, while keeping EMF low enough at the other end of the 2.44 meter (8 foot) long light bulbs.

Of water, light, temperature and WIFI signal strength, water was the hardest to measure and control.

Maybe the rate at which data was transferred over the WIFI link varied so much (1.1 +/- 0.5 megabytes per second) because my router was configured to transmit at only 5% of its available power, and was therefore more vulnerable to interference from other nearby routers[24].

Here are a few possible explanations for why the students and I got different results:

1. My control sprouts were exposed to more WIFI.
2. Their sources of error are candidly listed in their paper.
3. I may have controlled factors thought to affect plant growth better.

	Difference between WIFI and control sprouts	
Factor	students	Kingsley
water	All hills (plates?) got 2 dl of water every other day. Made sure that each plate was exactly 274g. water.	3% humidity (p = .00077)
temperature	Computer-controlled.	.1 degree Celsius (p = .42)
light	Next to windows of the same area and facing the same direction, but in different rooms.	27 lux (p = .46)
WIFI	21.8 $\frac{uW}{cm^2}$[18] straddling the Salzburg 2002 indoor limit (0.0001 $\frac{uW}{cm^2}$) from two access points (APs).	.62 $\frac{uW}{cm^2}$ straddling the Salzburg 2000 limit ($\frac{0.1\,uW}{cm^2}$) from one access point (AP) (p = .0000014). No radio/WIFI signal detected from its computer.
	Constant communication, corresponding to internet browsing.	1.1 (standard deviation +/- .5) megabytes/second

4. Maybe I didn't control moisture well enough. There seemed to have been a small, but statistically significant difference.

[23] $\frac{3\%}{64\%} = 4.7\%$
[24] The remote computer reported several.

5. Even with the number of seeds I used, there's a small chance my experiment would overlook a real effect[25].

Although I didn't find it in the my crude translation of the Danish students' paper, it was reported elsewhere that they put the WIFI and control sprouts in different rooms[4]. This suggests to me that they may have had trouble controlling temperature, humidity and/or light.

Repeating the students' experiment turned out to be harder than I thought, but I think it's do-able.

Here are some humble suggestions for anyone interested in trying to duplicate my experiment:

1. Consider moving the closest sprouts further from the WIFI router to avoid heating even more.
2. Consider exposing the control sprouts to less EMF. $\frac{0.0001\,uW}{cm^2}$ was recommended by Salzburg in 2002, and $\frac{0.00026\,uW}{cm^2}$ was used by the Danish students[26]. It may be hard to find a lab with electrical power that's far enough way from other WIFI routers. They may have to be over 100 meters away. If one is too close, shielding may be an option. The magnetic part of EMF is harder to shield than the electric. Chicken wire won't work. Maybe the plants could be grown in Faraday cages from microwave ovens, but I'd be worried about squeezing enough light through the grating.
3. Use a more sensitive EMF meter which is not confused by ballasts in fluorescent lighting fixtures.

   Currently, a distributor named "Less EMF" seems to be keeping its product line up to date with new meters. See `http://www.lessemf.com/guide.html`.
4. Use a more sensitive moisture meter. Check with Decagon (`https://www.decagon.com/en/soils/volumetric-water-content-sensors/` and `https://www.decagon.com/en/soils/`) and Watermark (`http://www.irrometer.com/sensors.html`). Evidently another technology is gypsum. Search for moisture meters on Google and Amazon.
5. Keep better records during the pilot experiments[27].
6. Consider using enough seeds to see if the trends I observed become statistically significant. I think you'd have a 95% chance of seeing it if you use 46,000 seeds. This large sample size is driven by how much biomass varied and how little difference I observed. Maybe you could use fewer seeds if you reduced the standard deviation of biomasses by

   (a) using a scale that measures weights more precisely than milligrams,

   (b) try watering the sprouting mix thoroughly with water *before* planting the seeds to avoid washing them away, and

   (c) consider trying to better control moisture by adding enough water daily to keep the reservoirs' depths about the same.

   However, please keep in mind

   (a) counting that many seeds would be a lot of work and

   (b) I think the half (23,000) near to the WIFI router would take up so much space that you might have to use different rooms, and thus make it harder to control humidity, temperature and light.

[25] I expect that chance is less than 5%.
[26] Kim Horsevad emailed the Danish number to me.
[27] I seem to have misplaced preliminary data on sprout heights.

7 Conclusion

WIFI didn't affect the sprouting, height or biomass of garden cress in this experiment.

We need to know if WIFI is safe for people.

More research is needed.

8 Appendices

8.1 Calculating how many seeds to plant (ie: the "sample size")

I used the "n.ttest()" function in the library named "samplesize" of the programming language named "R". I asked it to give sample sizes big enough to let me be 95% confident that I could detect what the students reported.

8.1.1 Biomass

The students seemed to report that the relative effect on biomass was 3.6 standard deviations[28].

1. 16 seeds per peat pot

   My preliminary testing suggested that the biomass of 16 seeds per peat pot would have a standard deviation of 0.0082 grams. So I wanted to check for a $3.6\,x\,0.0082\,gram = 0.030\,gram$ difference between the biomasses of peat pots containing WIFI and control sprouts.

   The R code to compute this is

   ```
   > library(samplesize) ; print(n.ttest(power = 0.95, alpha = 0.05, mean.diff = 0.030, sd1 = 0.0082, sd2 = 0.0082, k = 1, fraction = "balanced", design = "unpaired"))
   ```

   n.ttest() said to use 8 peat pots, split evenly between control and WIFI seeds. Planting 16 seeds in each peat pot leads to a total of 128 seeds.

   However, t tests depend on normally distributed data, and the conventional wisdom seems to be that the central limit theorem says at least 30 seeds would be needed to adequately normalize the means.

2. 32 seeds per pair of peat pots

   When I considered pairs of peat pots, 32 seeds were in each, so the central limit theorem and n.ttest() seemed more likely to work well.

   My preliminary testing suggested that the biomass of 32 seeds per pair of peat pots would have a standard deviation of 0.011 grams. So I wanted to check for a $3.6\,x\,0.0011\,gram = 0.040\,gram$ difference between the biomasses of peat pots containing WIFI and control sprouts.

   The R code to compute this is

   ```
   > library(samplesize) ; print(n.ttest(power = 0.95, alpha = 0.05, mean.diff = 0.040, sd1 = 0.011, sd2 = 0.011, k = 1, fraction = "balanced", design = "unpaired"))
   ```

   Now n.ttest() says to use 8 *pairs of* peat pots, split evenly between control and WIFI seeds. Planting 32 seeds in each pair of peat pots leads to a total of 256 seeds.

I used 20 peat pots, and a total of 320 seeds.

[28] See page 40

8.1.2 Crop failure

The students seemed to report that the relative effect on crop failure was -5.7 standard deviations[29]. My preliminary testing suggested I could expect a standard deviation of 1.1 seeds per peat pot. So I wanted to check for an average $-5.7\,x\,1.1 = -6.27$ difference between the number of seeds that failed to sprout in the peat pots near to, and far from, the WIFI router.

I assumed the normal distribution approximated the binomially distributed sprout failures because

1. I used enough seeds (n) and the probabilities (p) of them sprouting and growing to full height were close enough to 50%

   n = 160[30]
   p = $\frac{1.6}{16}$ = 0.1
   n * p = 160 * 0.1 = 16 (10 is thought to be good enough)
   n * (1 - p) = 160 * (1 - 0.1) = 160 * 0.9 = 144 (10 is thought to be good enough)

2. it allowed me to use n.ttest() again.

The R code to call n.ttest() is

```
> print(n.ttest(power = 0.95, alpha = 0.05, mean.diff = -6.27, sd1 = 1.4, sd2 = 1.4, k = 1,
fraction = "balanced", design = "unpaired")) $`Total sample size`
```

n.ttest() said to use 6 peat pots, split evenly between control and WIFI seeds.

[29] See page 40
[30] I wasn't sure whether to use the number of seeds per peat pot (16), the number of peat pots (10), or their product (160), but the later seemed to me to retain the most information.

8.1.3 Sprout height

I was unable to find in my records the full adult height data from a pilot experiment. Therefore I use the standard deviation observed in my real experiment here. I expect they're similar.

The students seemed to report that the relative effect on sprout height was 2.7 standard deviations[31]. My actual experiment found a standard deviation of 1.5 sprouts per peat pot. So I wanted to check for an average $2.7\,x\,1.5 = 4.05$ difference between the number of seeds that grew to full adult height in the peat pots near to, and far from, the WIFI router.

I assumed the normal distribution approximated the binomially distributed sprout failures because

1. I used enough seeds (n)[32] and the probabilities (p) of them sprouting and growing to full height were close enough to 50%

   n = 160[33]
   p = $\frac{135}{160}$ = 0.84
   n * p = 160 * 0.84 = 134.4 (10 is though to be good enough)
   n * (1 - p) = 160 * (1 - 0.84) = 160 * 0.16 = 25.6 (10 is thought to be good enough)

2. it allowed me to use n.ttest() again.

The R code to call n.ttest() is

```
> print(n.ttest(power = 0.95, alpha = 0.05, mean.diff = 4.05, sd1 = 1.5, sd2 = 1.5, k = 1,
fraction = "balanced", design = "unpaired")) $`Total sample size`
```

n.ttest() said to use 10 peat pots, split evenly between control and WIFI seeds.

[31] See page 40
[32] See the caveat about choosing n in "Crop failure", above.
[33] I wasn't sure whether to use the number of seeds per group (160) or per peat pot (16), but the former seemed to me to loose less information.

8.2 My understanding of the students' results

If I understand their bar charts correctly, they observed effects of the following sizes between their WIFI and control sprouts:

	result	plates						mean	standard deviation
control	Full adult sprouts (number)	361.0	333.0	372.0	304.0	321.0	301.0	332.0	29.4
	Crop failure (number)	11.0	30.0	12.0	22.0	15.0	20.0	18.3	7.2
	Biomass growth (g)	17.7	17.8	18.2	16.1	17.1	16.3	17.2	0.9
WIFI	Full adult sprouts (number)	234.0	264.0	247.0	255.0	258.0	254.0	252.0	10.4
	Crop failure (number)	63.0	34.0	63.0	62.0	77.0	55.0	59.0	14.2
	Biomass growth (g)	13.9	14.1	14.7	14.2	14.1	14.0	14.2	0.3
		difference	p value (t test)		**Relative effect size = (control mean - WIFI mean) / standard deviation of control sprouts**				
summary	Full adult sprouts (number)	80.0	0.001		**2.7**				
	Crop failure (number)	−40.7	0.000		**−5.7**				
	Biomass growth (g)	3.0	0.000		**3.6**				

8.3 My data

8.3.1 Collected during the experiment

		WIFI strength w/ big fluorescent lights off (mW/ cm^2) at about 8 cm away from WIFI router			seeds near WIFI				control seeds				difference			
date	time	minimum	maximum	data transfer rate (MiB/s)	estimated minimum WIFI strength (mW/ cm^2)	temp. (C)	humidity (%)	light (lux)	estimated maximum WIFI strength (mW/ cm^2)	normalized temp. (C)	normalized humidity (%)	light (lux)	estimated WIFI strength (mW/ cm^2)	normalized temp. (C)	normalized humidity (%)	light (lux)
5/23/2014	23:00	0.02	0.05	1.7	1.1E−03	24	66%	2490	1.2E−04	24.1	65%	2500				
5/24/2014	16:15	0.01	0.03	1.8	5.4E−04	24	67%	2510	7.4E−05	23.1	67%	2580				
5/25/2014	22:50	0.01	0.05	1.7	5.4E−04	23	63%	2480	1.2E−04	23.1	63%	2510				
5/26/2014	18:20	0.02	0.06	1.1	1.1E−03	23.5	66%	2460	1.5E−04	22.6	65%	2520				
5/27/2014	22:02	0.01	0.03	0.35	5.4E−04	24	60%	2390	7.4E−05	24.1	64%	2450				
5/28/2014	22:16	0.01	0.03	1	5.4E−04	24	62%	2360	7.4E−05	24.1	67%	2410				
5/29/2014	15:30	0.015	0.04	0.5	8.1E−04	23	64%	2410	9.8E−05	23.1	68%	2340				
5/30/2014	15:52	0.012	0.04	0.5	6.5E−04	23	66%	2380	9.8E−05	23.1	69%	2300				
5/31/2014	18:50	0.02	0.05	1.5	1.1E−03	25	66%	2330	1.2E−04	25.1	69%	2260				
6/1/2014	21:03	0.01	0.04	1.3	5.4E−04	26	64%	2360	9.8E−05	26.1	68%	2310				
6/2/2014	21:45	0.015	0.05	1	8.1E−04	26	63%	2280	1.2E−04	26.1	67%	2220				
6/3/2014	21:08	0.01	0.05	1.3	5.4E−04	25	63%	2280	1.2E−04	25.1	69%	2220				
6/5/2014	0:40	0.01	0.05	1.2	5.4E−04	23	67%	2270	1.2E−04	23.1	69%	2190				
6/5/2014	21:26	0.01	0.025	0	5.4E−04	25	64%	2300	6.1E−05	25.1	68%	2190				
6/6/2014	19:39	0.015	0.06	1.3	8.1E−04	26	63%	2270	1.5E−04	25.1	68%	2170				
6/7/2014	20:32	0.02	0.07	1.1	1.1E−03	26	63%	2190	1.7E−04	26.1	67%	2160				
6/23/2014	21:00															
average		0.01	0.05	1.1	7.3E−04	24.4	64%	2360	1.1E−04	24.3	67%	2333	6.2E−04	0.1	−3.0%	27
p value													1.4E−06	4.2E−01	7.7E−05	4.6E−01
standard deviation		0.004	0.013	0.5	2.3E−04	1.2	2.0%	93	3.1E−05	1.2	1.9%	143				
coeficient of variation		32%	28%	48%	32%				28%							

8.3.2 Collected at the end of the experiment

	distance from WIFI router to Jiffy pot (cm)	9.5		14.5		22		27		34.5				161.5		169		174		181		186						
	relationship of peat pot to me	near	far	near	far	near	far	near	far	near	far	average near WIFI	all near WIFI	near	far	near	far	near	far	near	far	near	far	average far from WIFI	all far from WIFI	difference	p value	total near and far from WIFI
biomass (mg)	1st measure	56	53	46	55	52	45	54	58	62	57			49	56	54	46	59	63	46	52	56	57					
	2nd measure	57	55	48	57	53	44	54	59	61	57			47	55	53	46	57	62	46	52	55	58					
	3rd measure	55	53	48	55	53	44	53	59	61	57			48	52	54	46	57	62	48	53	55	57					
	(4th measure)	57	54	47	55	52	45	52	58	60	57			49	54	53	42	58	61	47	53	54	57					
	5th measure	56	54	47	55	52	44	52	58	61	57			49	55	53	46	57	61	46	52	54	57					
	average per peat pot	56.2	53.8	47.2	55.4	52.4	44.4	53	58.4	61	57	53.9	538.8	48.4	54.4	53.4	45.2	57.6	61.8	46.6	52.4	54.8	57.2	53.2	531.8	0.7	0.38	
	average per 2 peat pots	110		102.6		96.8		111.4		118		107.8	538.8	102.8		98.6		119.4		99		112		106.4	531.8	1.4	0.40	
	standard deviation (per peat pot)												5.0												5.2			5.0
	standard deviation (per 2 peat pots)												8.2												9.1			8.2
crop failure (n)	sprouts	16	14	15	16	15	14	13	14	15	16	14.8	148	14	14	16	13	14	16	13	15	15	16	14.6	146			
	crop failure	0	2	1	0	1	2	3	2	1	0	1.2	12	2	2	0	3	2	0	3	1	1	0	1.4	14	−0.2	0.35	
	standard deviation												1.0												1.2			1.1
full adult height (n)	short sprouts	0	1	3	0	0	2	0	1	0	0		7	2	1	3	1	0	2	1	0	0	1		11			
	full adult sprouts	16	13	12	16	15	12	13	13	15	16	14.1	141	12	13	13	12	14	14	12	15	15	15	13.5	135	0.6	0.19	
	standard deviation												1.7												1.3			1.5

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