BASALT DUST AND BIOCHAR INTERACTIONS AT NEW HARMONY FARM, MASSACHUSETTS

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INTRODUCTION

Biochar and rock dusts such as basalt are widely regarded as excellent slow-release, long-lasting, natural fertilizers by themselves, which should work even better in combination. Many field studies showing dramatic increases in productivity with rock powders or with biochar alone are shown in this book. But there are many reasons to believe that combining the two methods would synergistically increase both the magnitude and duration of biological responses to both of these natural plant growth enhancers.

Rock powders are sources of essentially all the biological elements except (in general) for nitrogen, while biochar is less a fertilizer *per se* since it largely consists of elemental carbon. However biochar acts physically and chemically as a sponge that absorbs and retains nutrients and water, making them available to plant roots via interaction with symbiotic fungi and bacteria (Ladygina & Rineau, 2013). So biochar and rock powders should be highly complementary, especially when combined with nitrogen-rich composts.

Nevertheless there are few studies of their interactions or optimal combinations. We have started a long-term study of biochar and basalt dust interactions in 32 plots, using combinations of 3 levels of biochar and 4 levels of basalt dust, with replicates and controls.

SITE LOCATION AND HISTORY

The site, New Harmony Farm (Figure 1), in West Newbury, Massachusetts, is a fertile soil that was the riverbed of the Merrimack River until the river suddenly cut a new channel during a catastrophic hurricane. Local historians claim this catastrophic event was the Colonial Hurricane of 1635 that caused devastation to the newly formed Massachusetts Bay Colony. A map of the area published in Woods, 1634 (Figure 2a), shows an island at the site. New Harmony farm was located in the southern river channel that was plugged up by hurricane-transported sediments (Figure 2b). This occurred before any deforestation for agriculture had taken place in the Merrimack watershed, as all English settlement at that time was along the coast. All descriptions of the hurricane come from coastal sites (http://en.wikipedia.org/wiki/Great_Colonial_Hurricane_of_1635)

The Merrimack River watershed includes most of the state of New Hampshire, including the eastern slopes of the White Mountains, and much of northeastern Massachusetts (Figure 3). The watershed was essentially entirely deforested for agriculture during the colonization of New England by European settlers in the late 1600s, 1700s, and early 1800s. Searches for a small watershed with primary (uncut) forest in the White Mountains for scientific research purposes found there were none at all; the best site was the Hubbard Brook watershed, which had been logged for yellow birch in 1918. This site was used to set up the Hubbard Brook Experimental Forest, in the uppermost reaches of the Merrimack watershed, now the longest monitored forest watershed in the world and site of many fundamental forest ecology and biogeochemistry studies (Bormann and Likens, 1979).

Cores in the Plum Island salt marsh, at the mouth of the river, show that the marsh grew very rapidly by trapping sediment from eroded soils after deforestation (Kirwan et al., 2011), connecting the mainland to Plum Island, which had previously been a separate island (Woods, 1634). This erosion decreased after most of the farmland in the hills was abandoned in mid 1800s and reverted to secondary forest (Bormann & Likens, 1979), and the sediment transport was blocked as the river was dammed upstream of the farm site for industrial purposes (Cumbler, 2001).

As a result of this history the soils are rich alluvial deposits with few fertility limitations, and so would not be expected to respond strongly to the addition of plant nutrients. Due to the low and nearly flat elevation, the chemical quality of the soil is quite uniform, but the physical properties are controlled by very small elevation differences of only around 10 centimeters that determine the depth to the groundwater table. The lowest points are permanently wet and are left as conservation areas in wetland vegetation that can't be farmed. The highest areas are ploughed and farmed, and intermediate areas are prone to spring snowmelt flooding and during very rainy summers. Russ Barry and Bonnie Silva purchased the land in 2007, planted the field in timothy grass and clover for hay production, and had the land certified organic. Prior to this, the soil had lain fallow for several years after many years of conventional corn production. In July 2011 Erin Stack purchased the land for a certified organic CSA (Community Supported Agriculture) farm with a mission to support research and educational efforts.

Because the benefits of both basalt dust and biochar become greatest after several years, long term changes in crop yields, elemental composition of soil and crops, carbon storage, and greenhouse gas emissions will be measured. The hope is to continue measurements for at least 3 to 5 years with two crops per year. This article describes the setting up and the first six months of results from the study.

Figure 1. New Harmony Farm. The plot of the Biochar/Rock Dust experiments is shown in the white rectangle. The Merrimack River is at lower left.

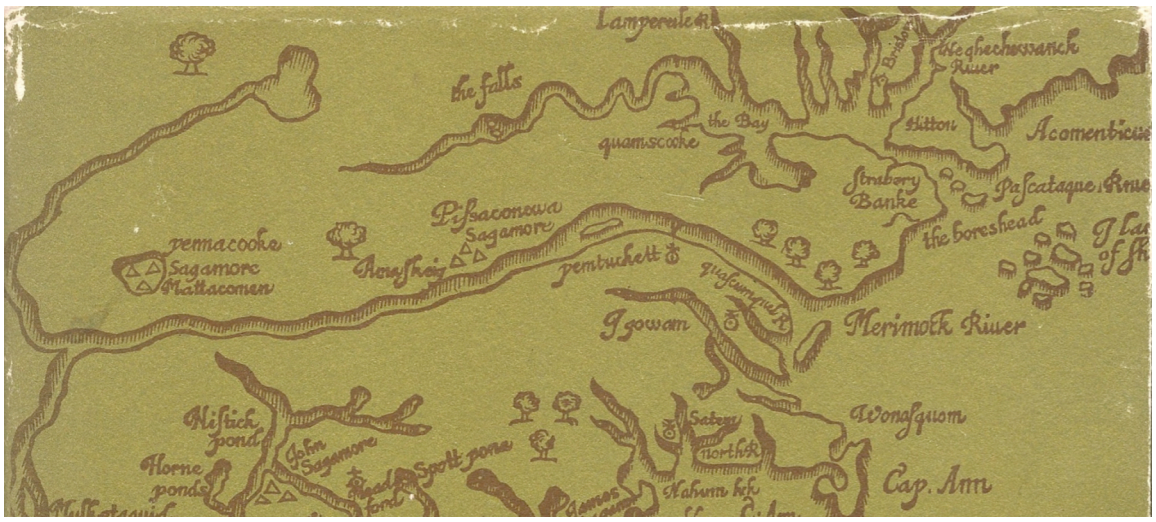

Figure 2a. A portion of William Woods 1634 map showing an island in the Merrimack River. New Harmony Farm is located on the southern channel, which was plugged up by the 1635 Hurricane.

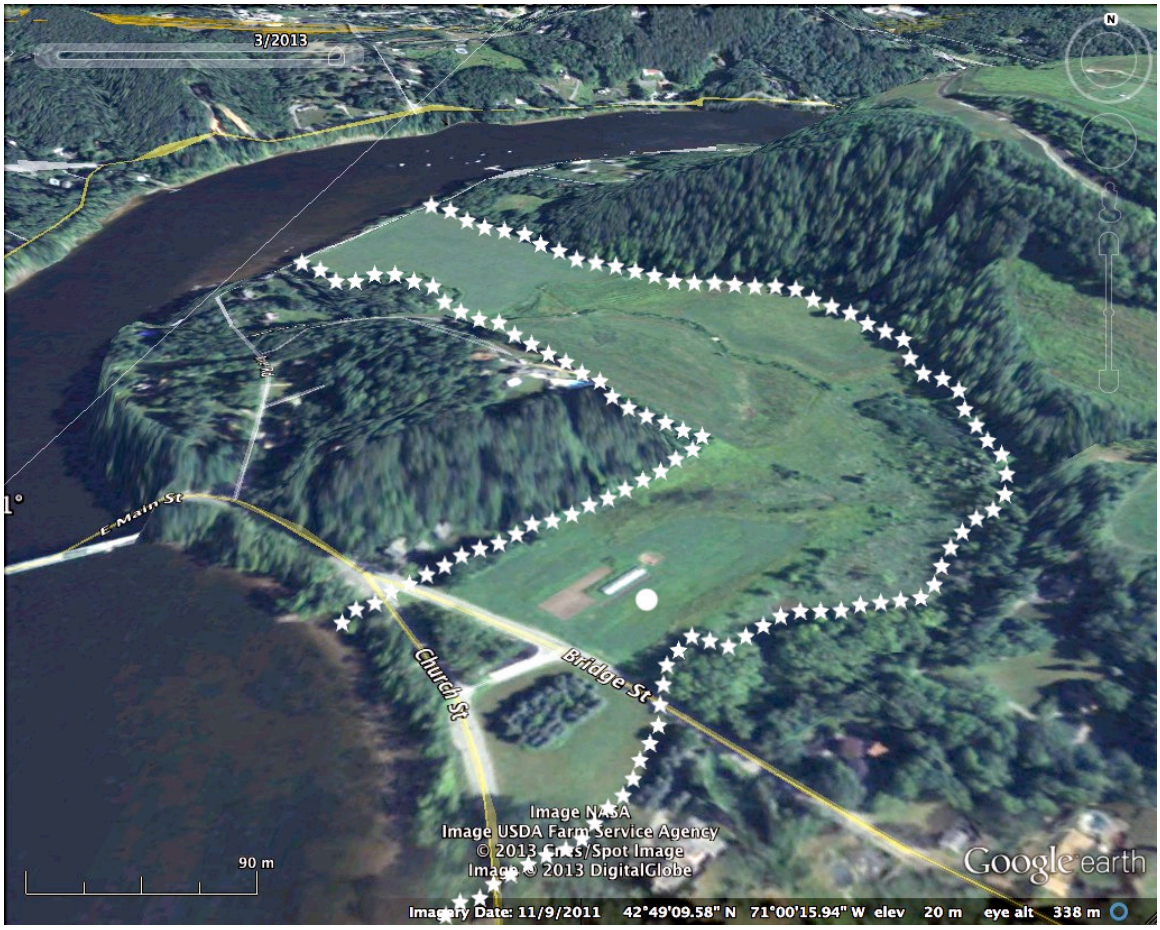

Figure 2b. A perspective view of the New Harmony Farm site. The white dot marks the project site. The approximate boundaries of the Merrimack River channel before the hurricane filled it are shown in the dashed stars, based on the topographic contours of the site.

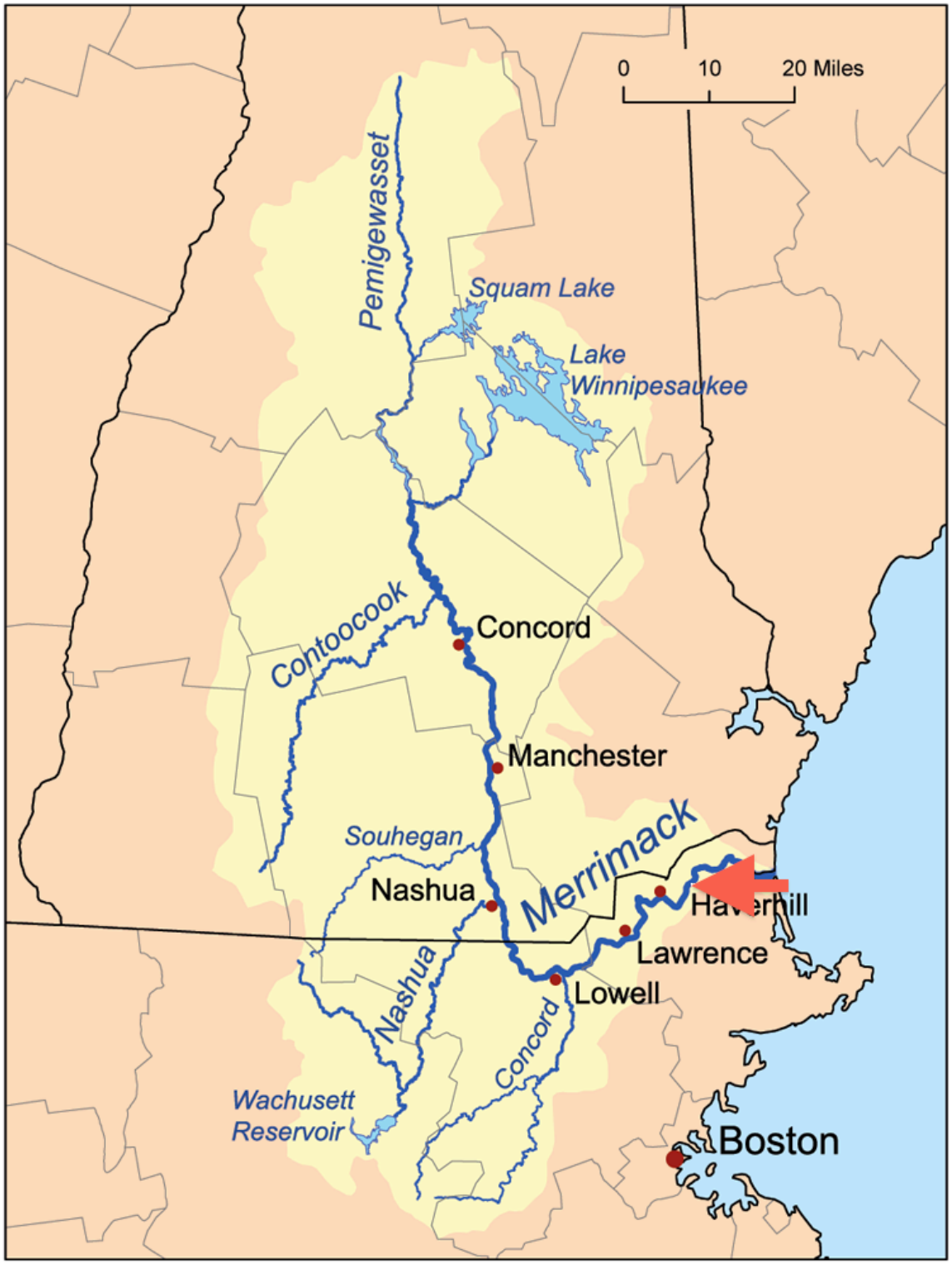

Figure 3. Merrimack River watershed, with the project site indicated by the arrow.

MATERIALS AND METHODS

A. SOIL TYPES AND FERTILITY

Soils were classified by the USDA (Figure 4, Figure 5). Approximately 50 soil samples from all over the farm were pooled for an average chemical analysis (Figure 6).

Figure 4. New Harmony Farm showing the boundaries of New Harmony Farm and of soil types surveyed by the US Department of Agriculture. Soil types are classified in Figure 5. below. Note that the image was taken before the greenhouse (long white structure in Figure 1) was built. At the time this image was taken the land had been ploughed for hay.

Map Unit Legend

Essex County, Massachusetts, Northern Part (MA605)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
98A	Winooski very fine sandy loam, 0 to 3 percent slopes	1.7	24.6%
275A	Agawam fine sandy loam, 0 to 3 percent slopes	0.1	1.1%
405D	Charlton fine sandy loam, 15 to 25 percent slopes	0.6	8.5%
713A	Limerick and Rumney soils, 0 to 3 percent slopes	4.0	58.0%
718A	Saco variant silt loam, 0 to 3 percent slopes	0.5	7.9%
Totals for Area of Interest		**6.9**	**100.0%**

Figure 5. Soil types shown in Figure 4.

Figure 6. Soil chemical analysis for New Harmony Farm. Note the generally fertile conditions, with high organic matter and calcium, but deficiency in magnesium, potassium, and boron. These measurements were made on a composite sample made from mixing about 50 samples from all over the farm.

B. FERTILIZATION

The experimental plot was ploughed twice, once in each direction. The plot was then marked with stakes and strings into 32 subplots each measuring 5 feet by 10 feet, with replicates of each treatment and controls (Figure 7). Each subplot was then fertilized with various combinations of biochar or rock dust. Biochar plots received 0, 20, or 40 pounds of biochar per subplot. Rock dust plots received 0, 10, 20, or 30 pounds of rock dust per subplot. These were spread across each subplot and raked by hand into the soil three times to a depth of about 5 cm.

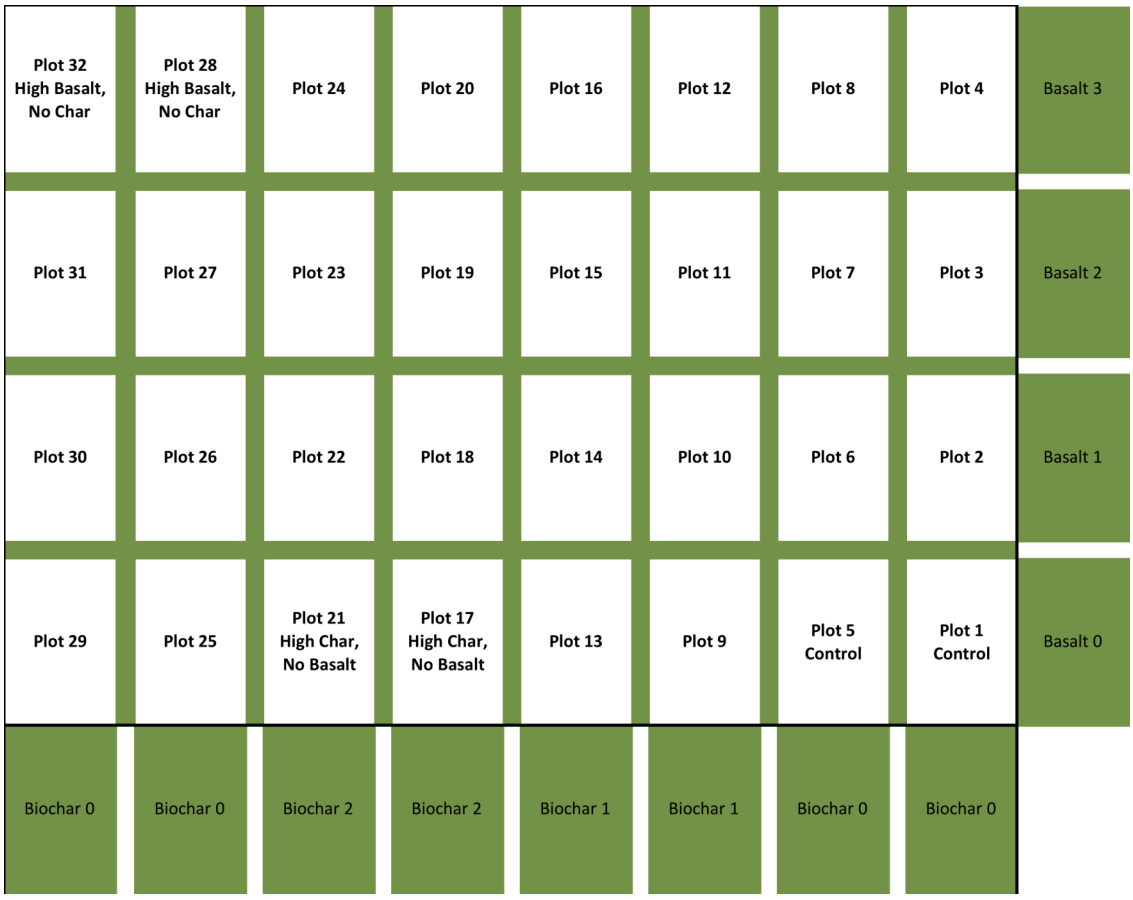

Figure 7. Arrangement of subplots used in this experiment. The legends at top and bottom show the relative amounts of biochar or rock dust in each column and

row respectively. Plots 1, 5, 17, 21, 28, and 32 were used for the initial greenhouse gas flux measurements.

Biochar was obtained from New England Biochar in Cape Cod, Massachusetts. The biochar had been made the year before, largely from oak and pine wood undergoing pyrolysis at a temperature of 450 degrees C, and had been mixed 50:50 with leaf compost, again predominantly oak and pine, and matured for a year prior to bagging and application. It should be noted that this compost is fairly acidic and poor in nitrogen.

Basalt rock powder was kindly donated for the project by Tom Vanacore of Rock Dust Local, in Vermont. The igneous basalt used at the New Harmony farm is from an extrusive igneous rock of geochemistry typical of 'a silica-over saturated basalt' from the Holyoke region. The geologic environment of its formation is primary magmatic lava flows. Typical mineralogy for the basalt: Essentials: Plagioclase (labradorite-bytownite, anorthite content greater than 50%), pyroxene (augite, pigeonite, hypersthene). Accessories: Magnetite, hematite, apatite, quartz, olivine, glass; Accidentals: Amphibole (titaniferous hornblende), biotite.

The quarried stone is extracted from hard rock ledge in central MA, crushed and pulverized without water. The screened and air floated gradations are recombined to produce the "BrixBlend". Gradation of the Basalt "BrixBlend": 100% passing 2mm and 60%+ passing the 200 mesh screen, of which at least 50% of the total is highly micronized air floated fraction (average estimated at 37 microns or 400 mesh). This material is 'virgin rock dust', unweathered.

Although the complex silicate crystalline matrix is technically insoluble the minerals appear to be highly reactive in the dynamic environment of agricultural soils that include soil biota, aqueous solutions and fluctuations in pH, which present a distinctly diverse environment from geologic stasis. Harvest weight in the first season field crop indicates rapid assimilation against the controls.

According to PCSM (Phil Callahan Soil Meter, Pike Agri) measurements of magnetic field strength in CGS units, the Basalt 'BrixBlend' generates a reading of 2400 (CGS X 10-6). Although the PCSM readings are skewed by iron, the Basalt measured against other rock powders generates a strong steady attractive force in comparison to other rock powders with equal or greater proportion of Fe producing either low magnetic readings or low momentary readings. The steady elevated field strength in the Basalt indicates the presence of paramagnetic and ferromagnetic elements or molecules. Paramagnetic atomic structures have one or more unpaired electrons in their outer shells and in totality produce a net attractive force in a magnetic field.

A chemical analysis of this basalt is listed below.

TABLE 1. CHEMICAL COMPOSITION OF BASALT

ELEMENT	WEIGHT FRACTION
SiO_2	49.38%
Al2O3	13.32%
Fe2O3	13.78%
MnO	0.2%
MgO	5.77%
CaO	9.21%
Na2O	3.14%
K2O	0.96%
TiO2	0.916%
P2O5	0.15%
Loss On Ignition	4.02% (probably carbon, hydrogen, oxygen, and nitrogen)
C-total	0.47%
S-total	0.04%
B	297ppm
Au	<1ppb
Ag	<0.5ppm
As	5ppm
Ba	137ppm
Be	<1ppm
Bi	<2ppm
Br	1.1ppm
Cd	1ppm
Co	43.1ppm
Cr	25.3ppm
Cs	<0.2ppm
Cu	81ppm
Hf	2.2ppm
Hg	<1ppm
Ir	<1ppb
Mo	0.6ppm
Ni	35ppm
Pb	12ppm
Rb	20ppm
S	0.054%
Sb	<0.1ppm

Sc	39.3ppm
Se	<0.5ppm
Sr	164ppm
Ta	2.3ppm
Th	2.6ppm
U	0.9ppm
V	324ppm
W	<1ppm
Zn	96ppm
Zr	88ppm
La	10.7ppm
Ce	22ppm
Nd	14ppm
Sm	3.07ppm
Eu	0.86ppm
Tb	0.9ppm
Yb	2.67ppm
Lu	0.21ppm

C. SITE MANAGEMENT

After the biochar and rock powder had been raked into the soil, 5 soil samples were taken from each subplot, one in the center, and four more, each taken two thirds of the way from the center towards each corner, and stored in a dark cool basement for later chemical analysis. Results of those analyses are not available at time of writing and will be reported elsewhere. Each plot was then seeded. The first crop of beet and radishes were seeded with a hand drawn seeder. As it was noted that seeding was not regular, with gaps and with several seeds (2 to 5) being inserted into the same holes, where they competed with each other, the second seeding of radishes was done by hand. The plot was then regularly hand weeded by a team of dedicated volunteers.

D. CROP YIELDS

At crop time each subplot had all beets and all radishes pulled up by hand, soil brushed off, and counted and weighed to provide total fresh weight for each crop in each subplot. Because of irregular seeding success, the data were presented as mean weight per plant for each crop in each subplot. Because the first crop was sown late in July and harvested in September, the second crop of radishes was started very late. They were harvested in November, but had been affected by early frost.

E. GREENHOUSE GAS FLUXES

Greenhouse gas fluxes were measured as a pilot study on September 28, 2012 from selected bare field plots, between crops, using a mobile gas analyzer system. Duplicate control plots with no biochar or rock dust, plots with the highest level of biochar and no rock dust, and plots with the highest level of rock dust and no biochar, were monitored, as shown in Figure 7. Gas fluxes into a cylindrical chamber with a circular soil surface area of 0.0639 m^2 were analyzed instantaneously with a cutting-edge technology in measuring trace gases, i.e., the new generation of cavity ringdown spectroscopy techniques. During the measurement, the chamber was attached to a pre-installed collar in the soil. The air inside the chamber was pumped through the CO2 analyzer and N2O analyzer and then back to the chamber in a closed loop. The gas flux was calculated based on the increase in concentration during an approximately 5-minute measurement period (depending on the gas flux rate) when the chamber was attached with the soil collar. The slope of a linear curve of concentration against time is used to calculate the flux.

RESULTS

A. CROP YIELDS

The first crop of beets and radishes showed very strong stimulation of plant productivity (measured as total fresh weight per plant at harvest in pounds) by basalt powder, up to 2.5 times greater for beet and 2.2 times for radish (Figure 8). We found inhibition of beet yields, but not of radishes, by biochar in the first crop (Figure 9), probably due to nutrient immobilization caused by the high C/N ratio. The maximum yield per plant for both crops was attained at 20 pounds of basalt per plot, with a small reduction at the highest loading. This suggests that some factor was in excess and inhibitory at the highest loading.

The full first crop data showing results from the interaction plots are shown in Figures 10-15).

The inhibitory effect of biochar and the stimulatory effect of the basalt largely disappeared by the second crop of radishes, which was sown late and affected by early frost (Figures 24-30). This is presumably because the microbial flora associated with the biochar and rock powder became more mature, and because base cations from basalt weathering were taken up on biochar cation exchange sites.

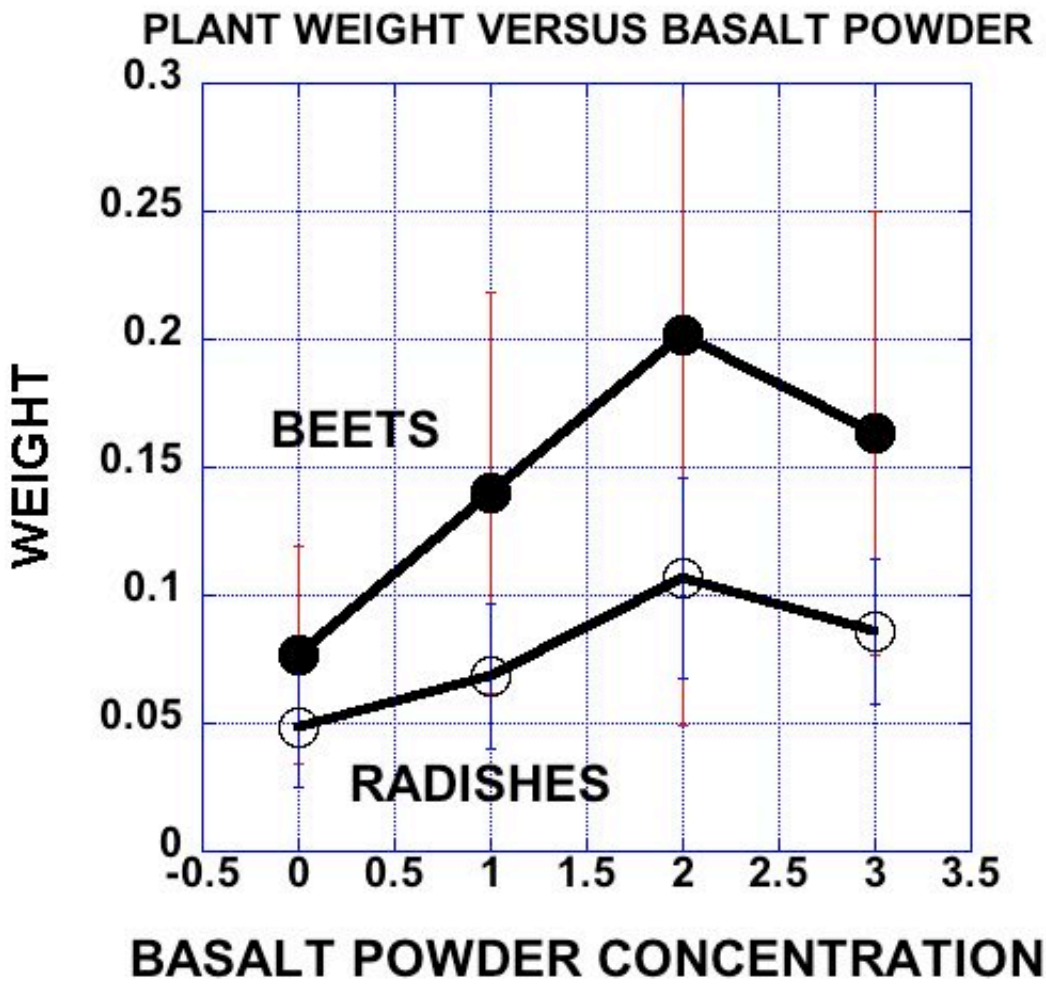

Figure 8. First crop yields in pounds per plant for beets and radishes as a function of basalt powder concentration. Note an increase with basalt, but an inhibition at the highest levels, indicating that that there is an optimal concentration above which benefits decrease. All graphs show means plus or minus standard deviations of replicate plots.

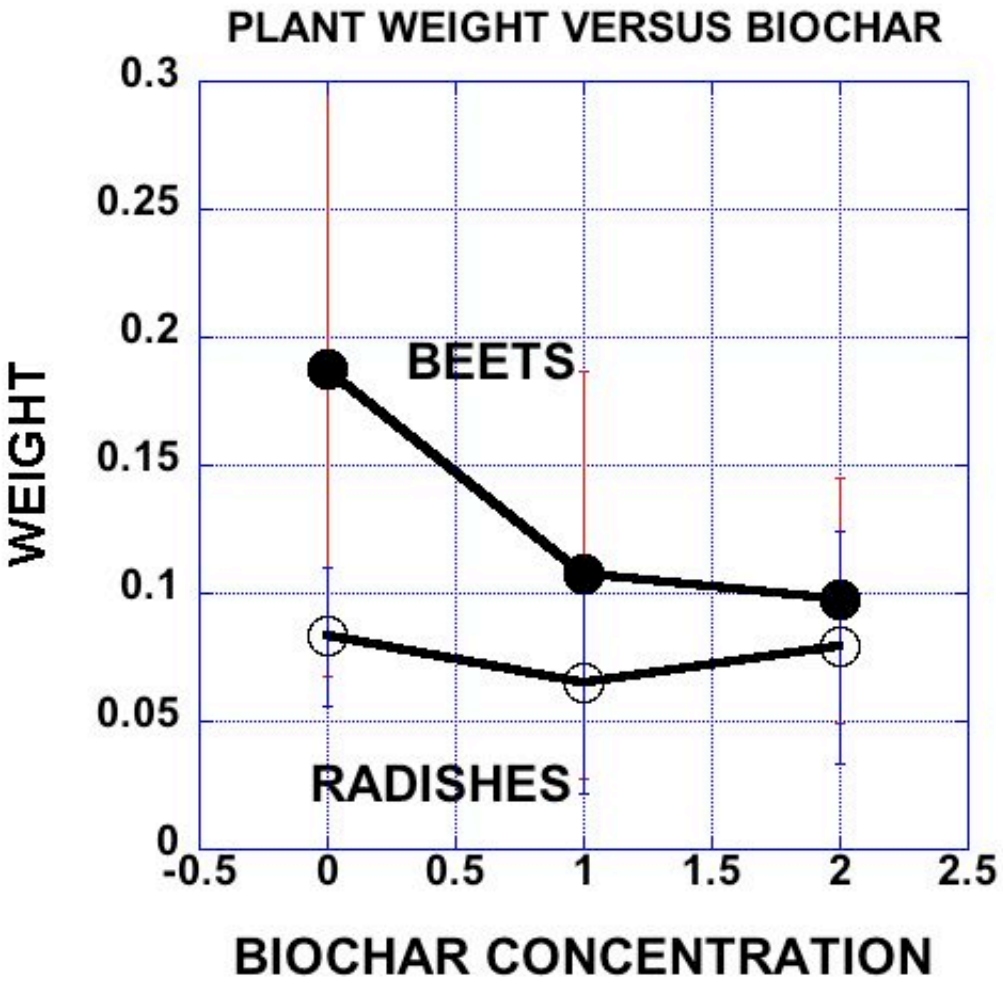

Figure 9. First crop yields in pounds per plant for beets and radishes as a function of biochar concentration. Note that the fresh biochar inhibited growth of beets but not radishes.

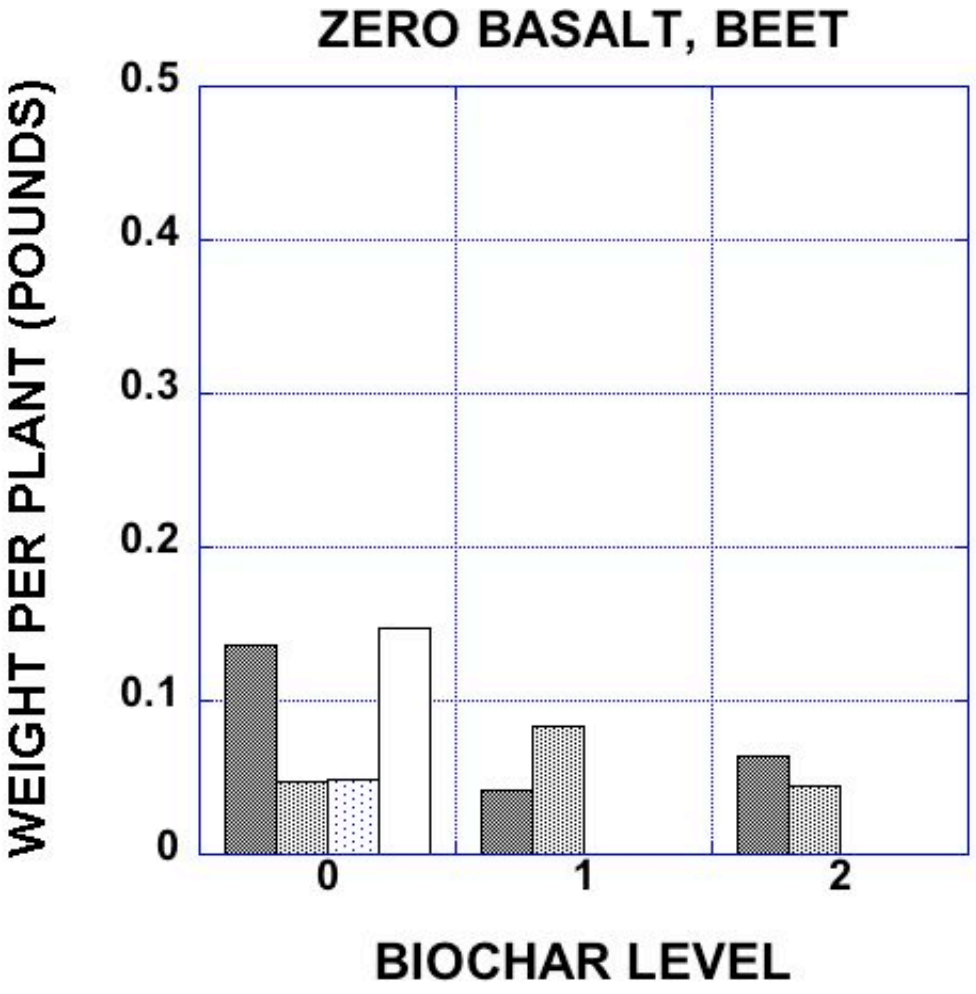

Figure 10a. First beet crop as a function of biochar with zero basalt.

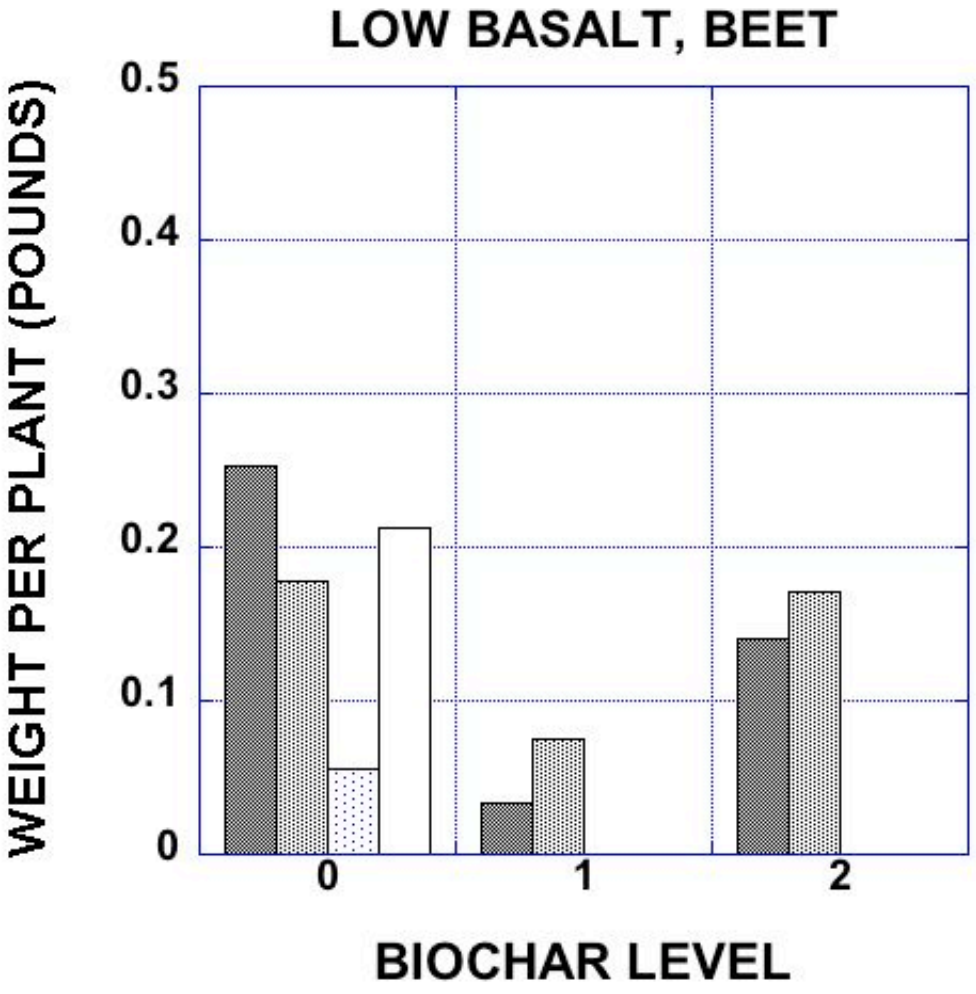

Figure 10b. First beet crop as a function of biochar with low basalt.

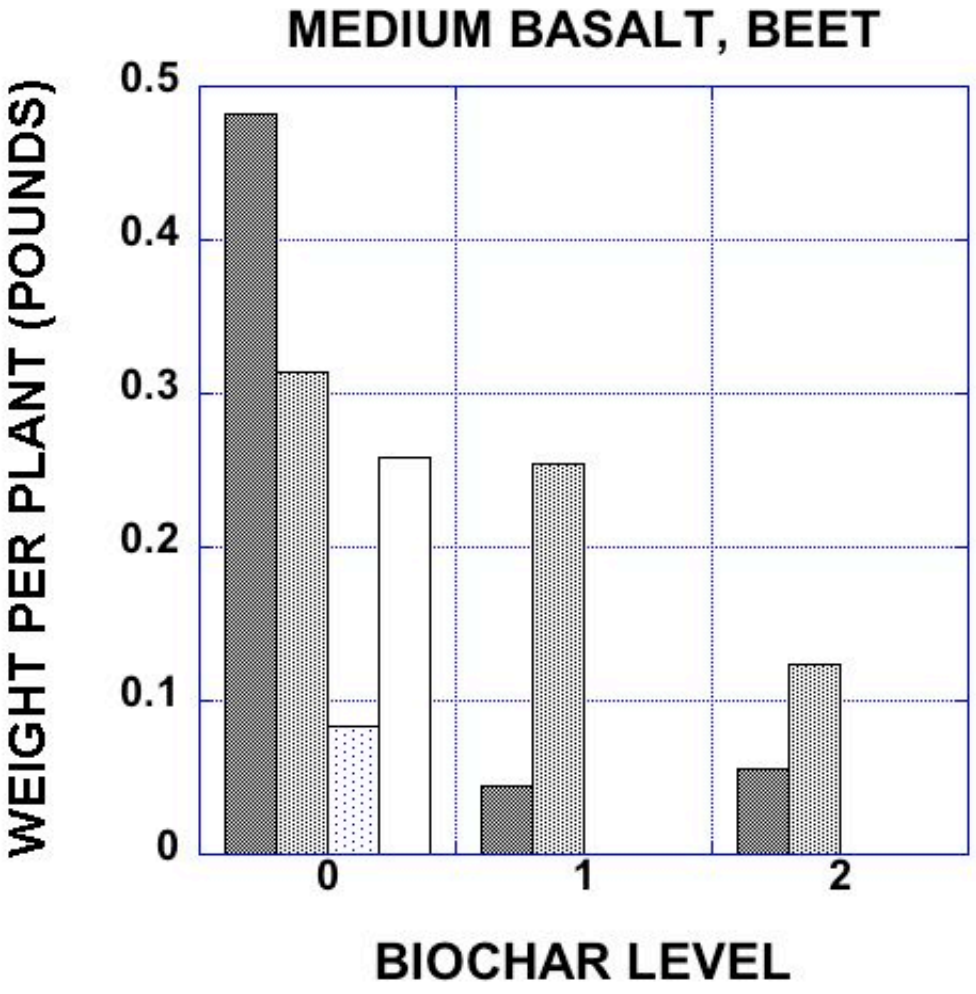

Figure 10c. First beet crop as a function of biochar with medium basalt.

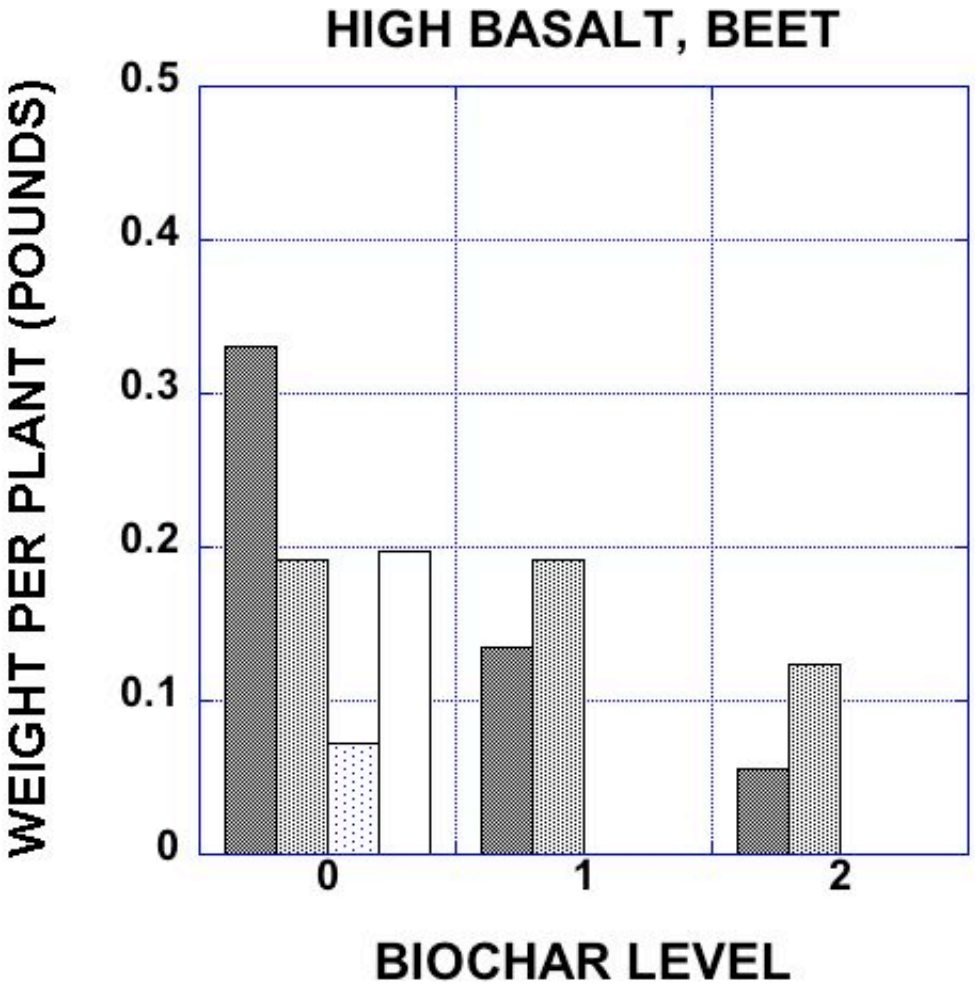

Figure 10d. First beet crop as a function of biochar with high basalt.

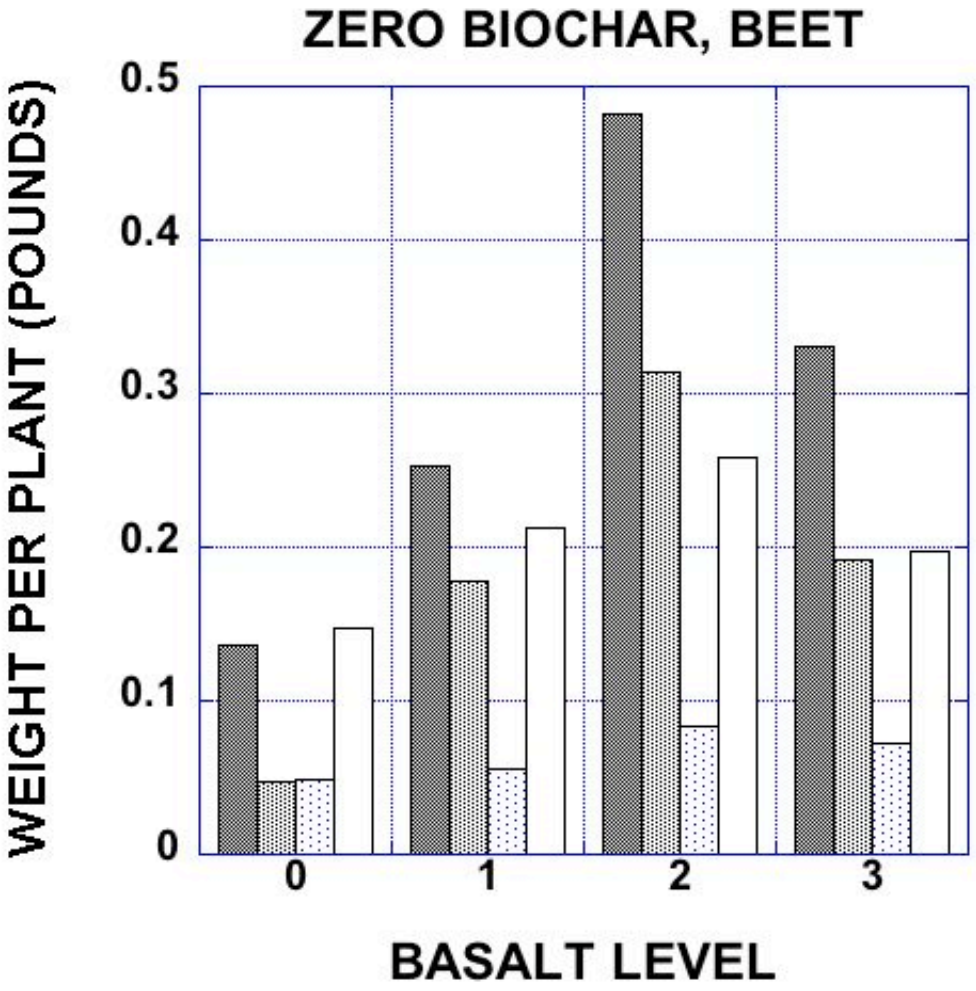

Figure 11a. First beet crop as a function of basalt with zero biochar.

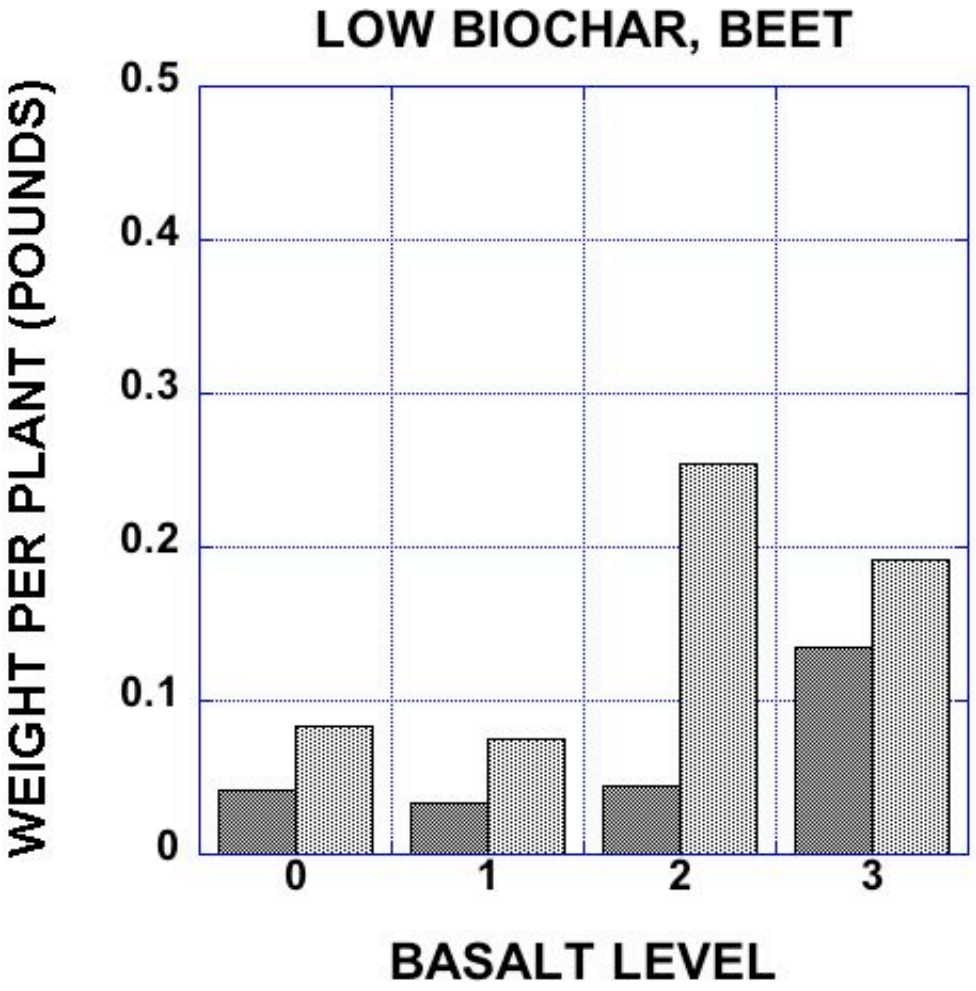

Figure 11b. First beet crop as a function of basalt with low biochar.

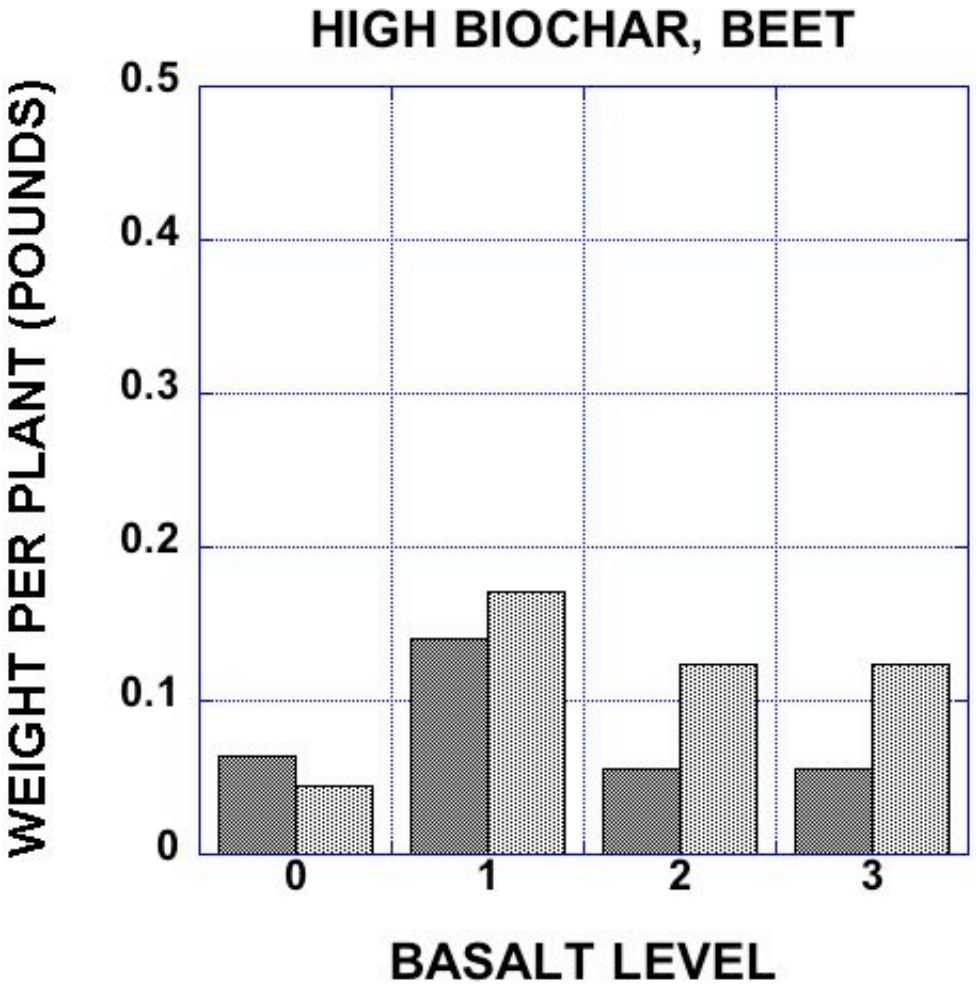

Figure 11c. First beet crop as a function of basalt with high biochar.

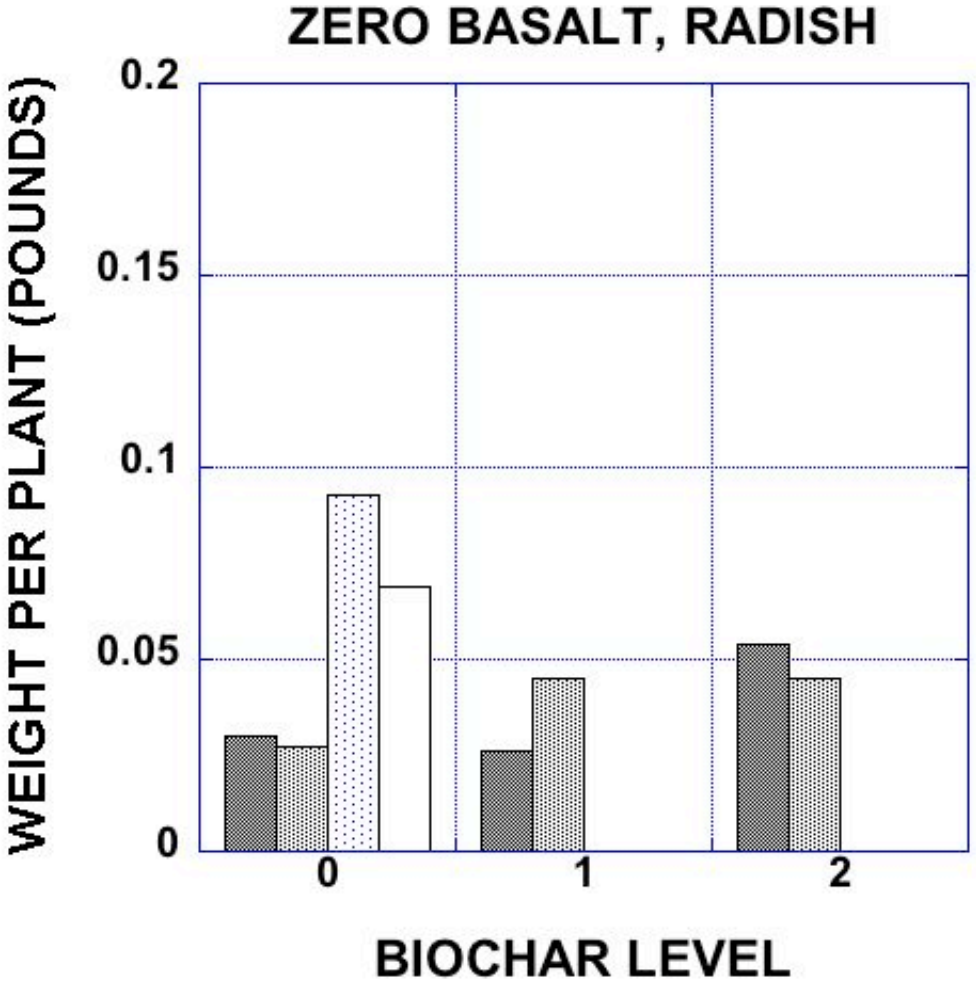

Figure 12a. First radish crop as a function of biochar with zero basalt.

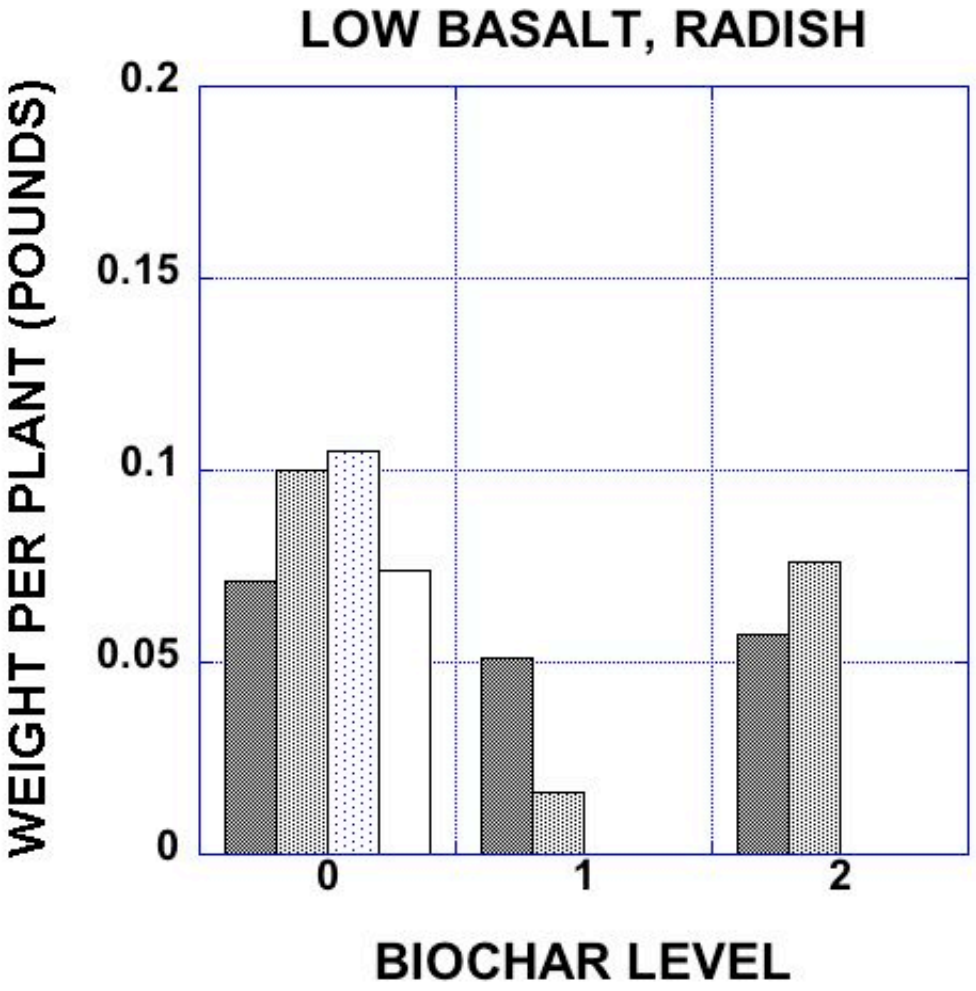

Figure 12b. First radish crop as a function of biochar with low basalt.

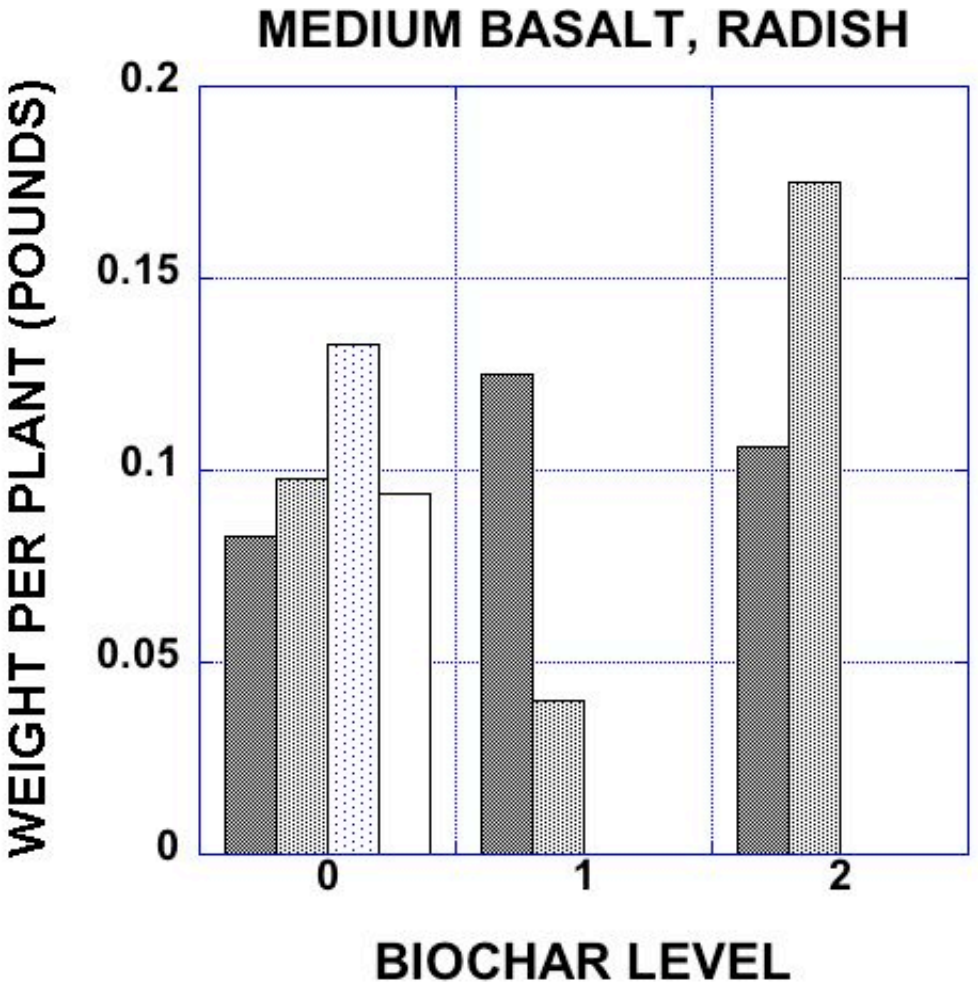

Figure 12c. First radish crop as a function of biochar with medium basalt.

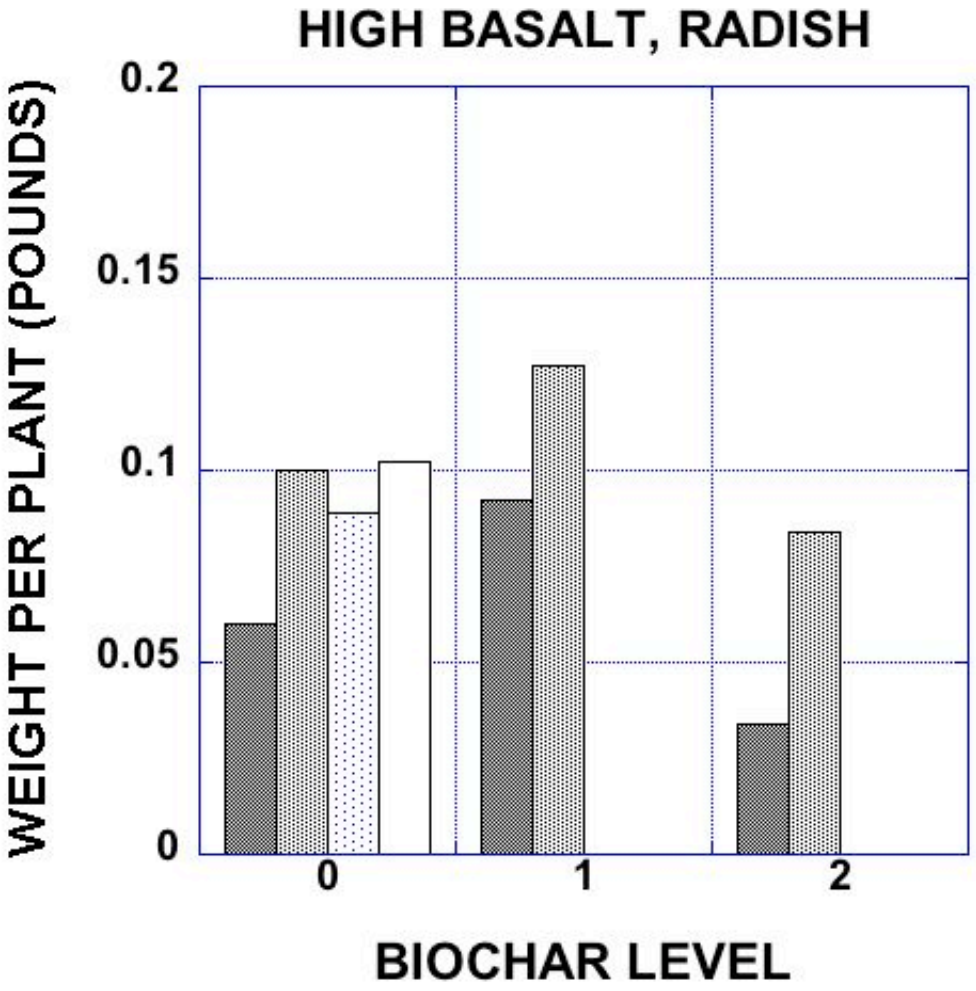

Figure 12d. First radish crop as a function of biochar with high basalt.

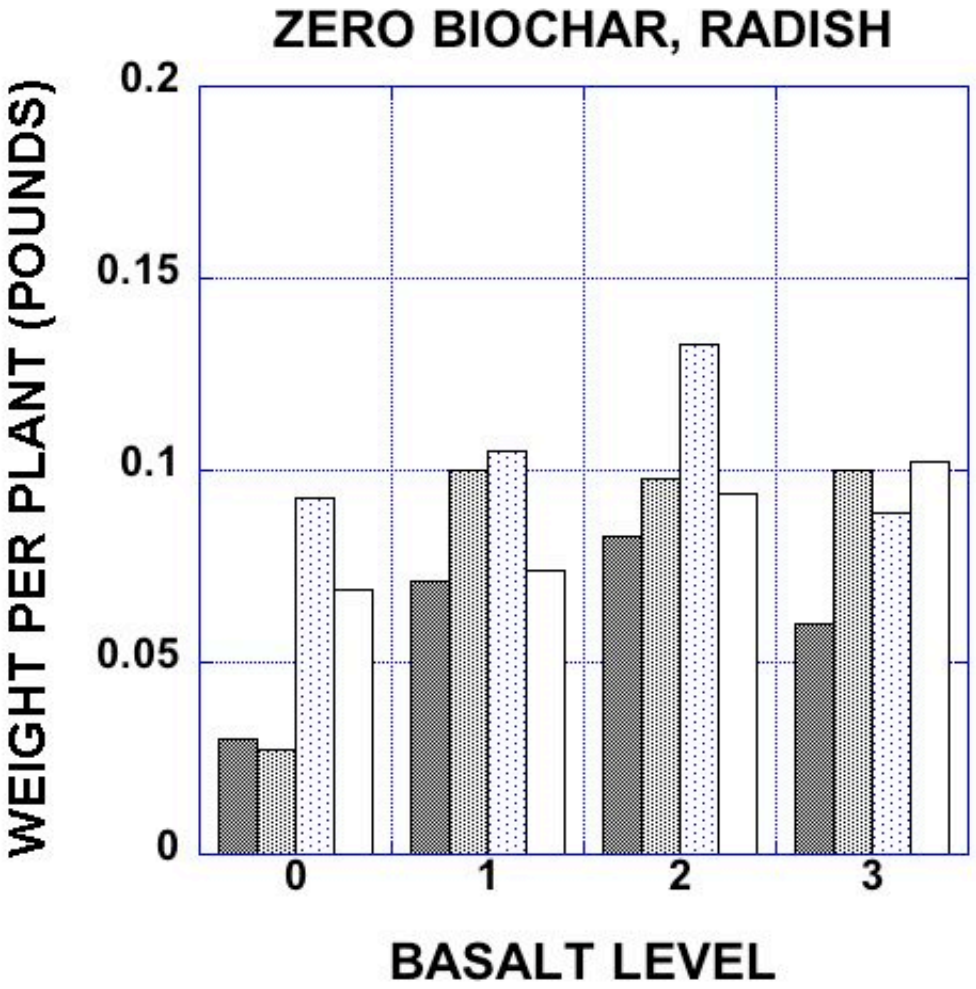

Figure 13a. First radish crop as a function of basalt with zero biochar.

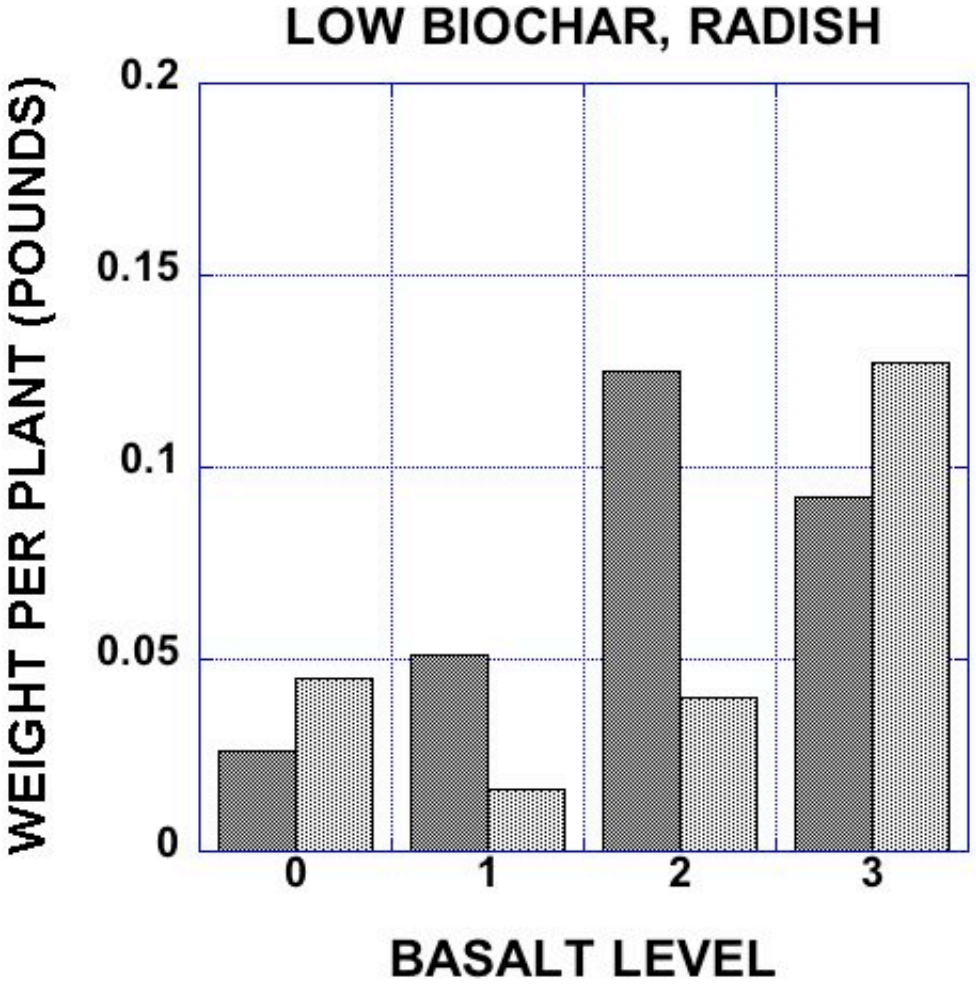

Figure 13b. First radish crop as a function of basalt with low biochar.

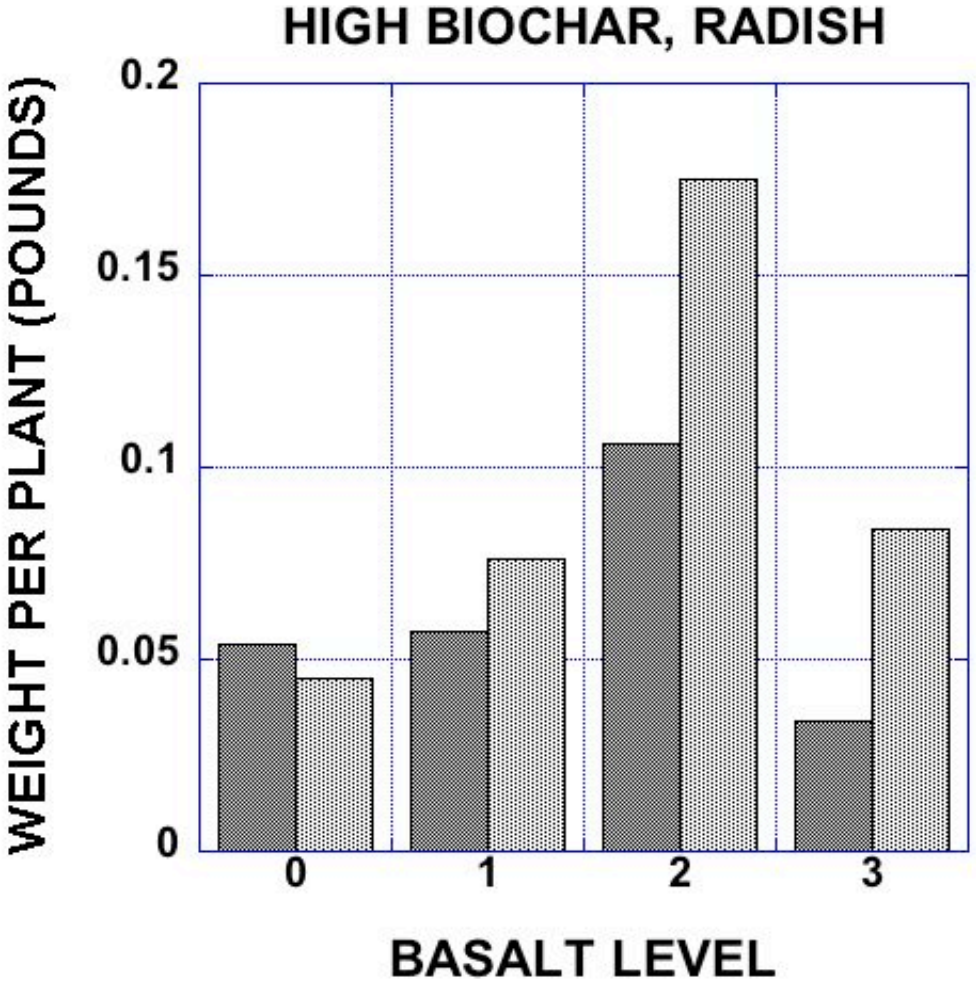

Figure 13c. First radish crop as a function of basalt with high biochar.

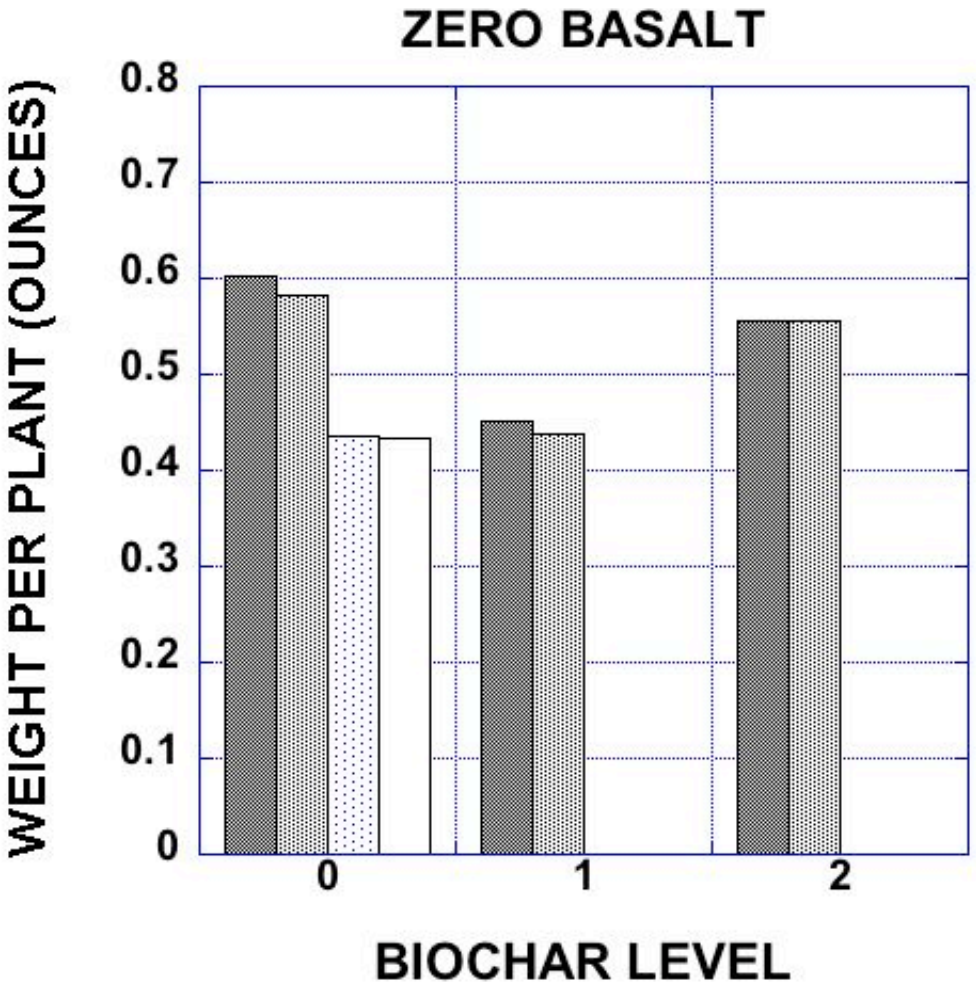

Figure 14a. Second radish crop as a function of biochar with zero basalt.

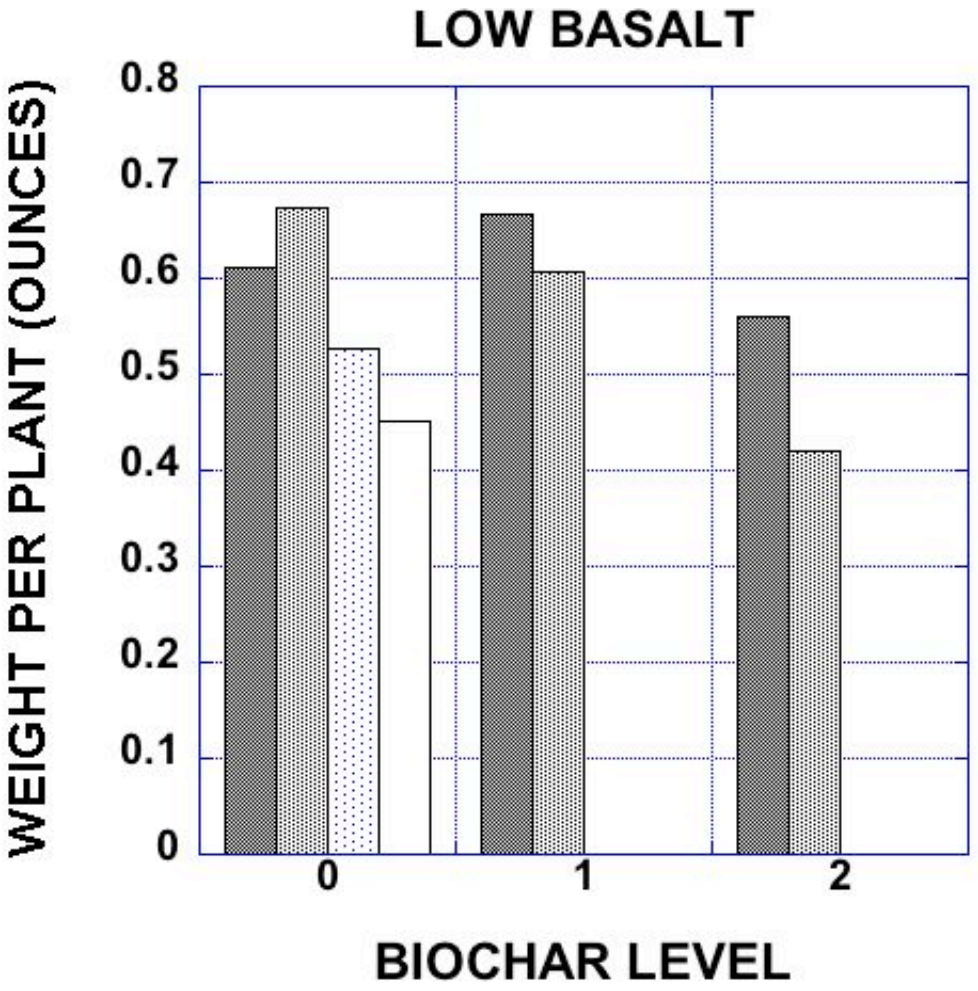

Figure 14b. Second radish crop as a function of biochar with low basalt.

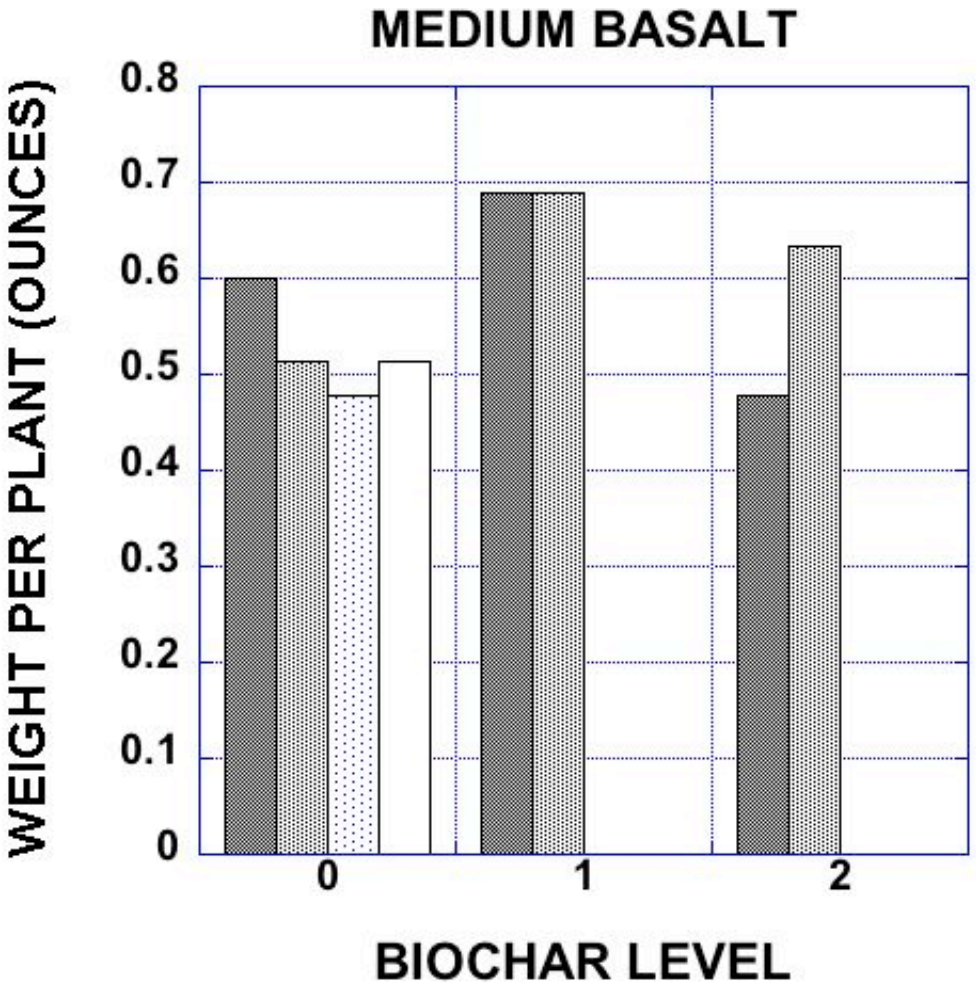

Figure 14c. Second radish crop as a function of biochar with medium basalt.

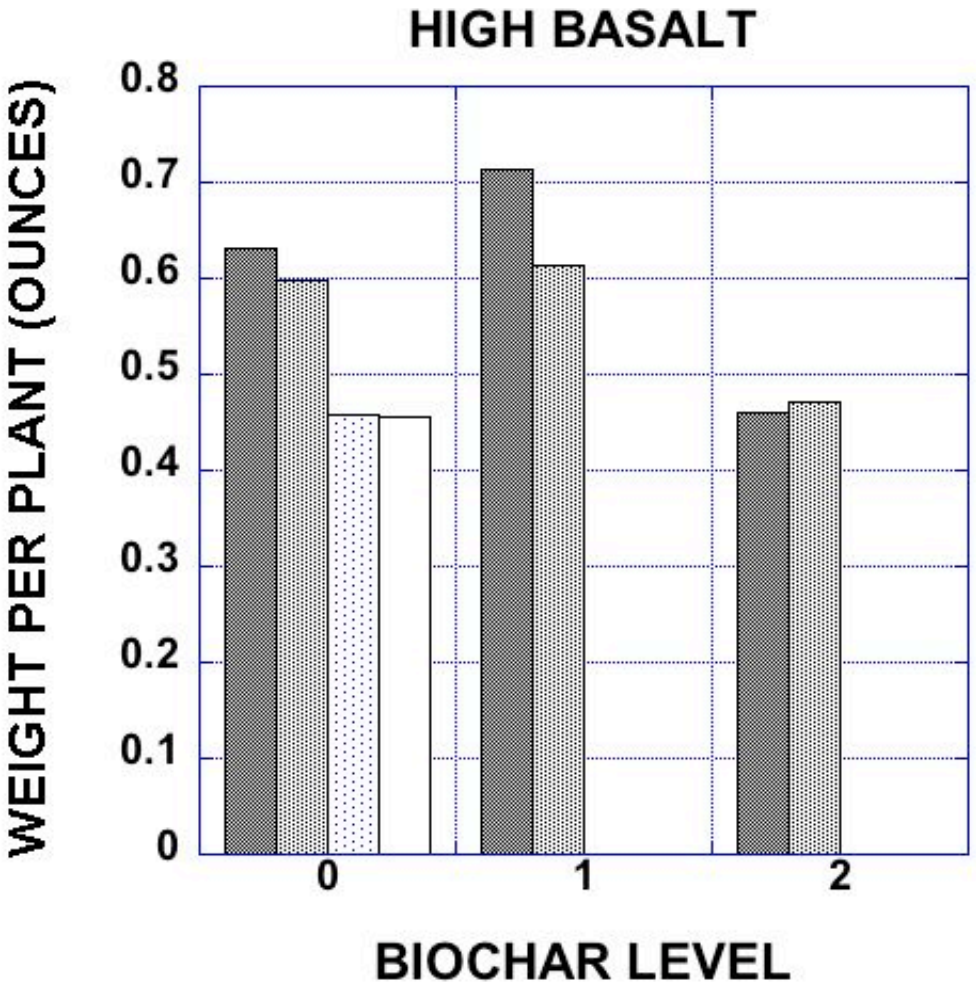

Figure 14d. Second radish crop as a function of biochar with high basalt.

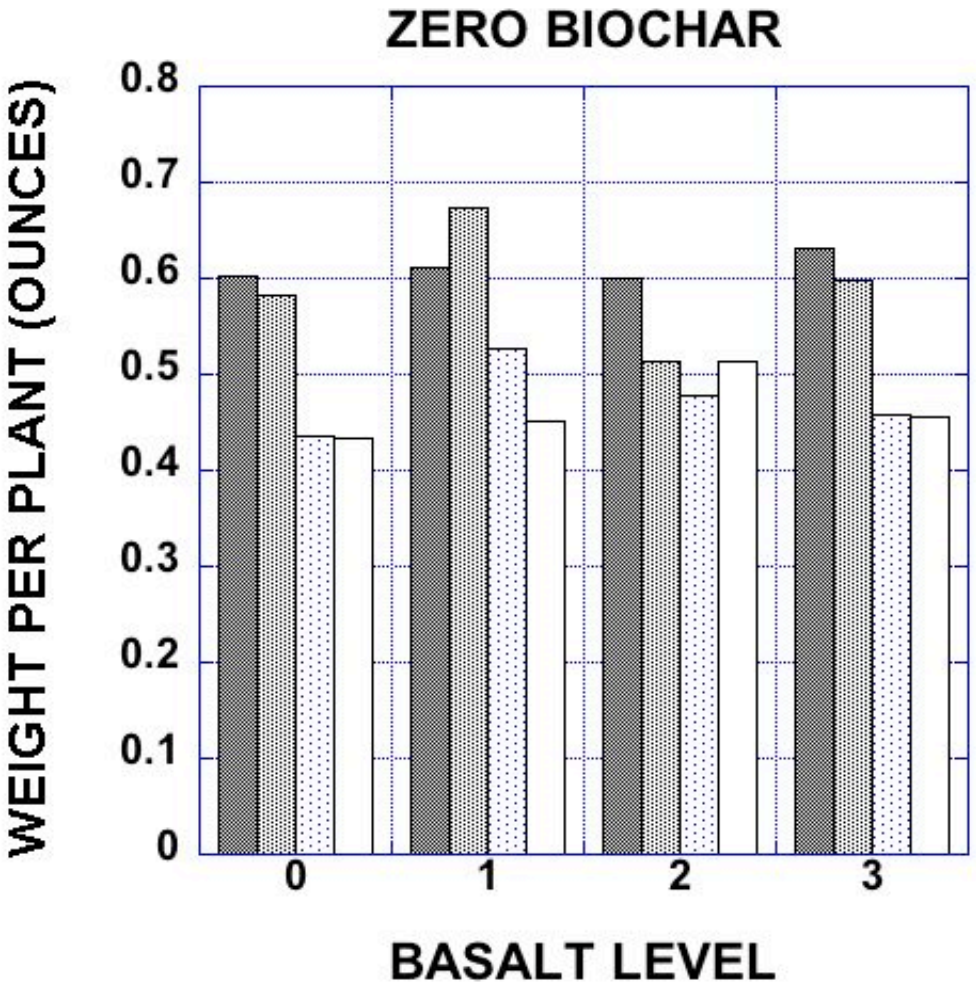

Figure 15a. Second radish crop as a function of basalt with zero biochar.

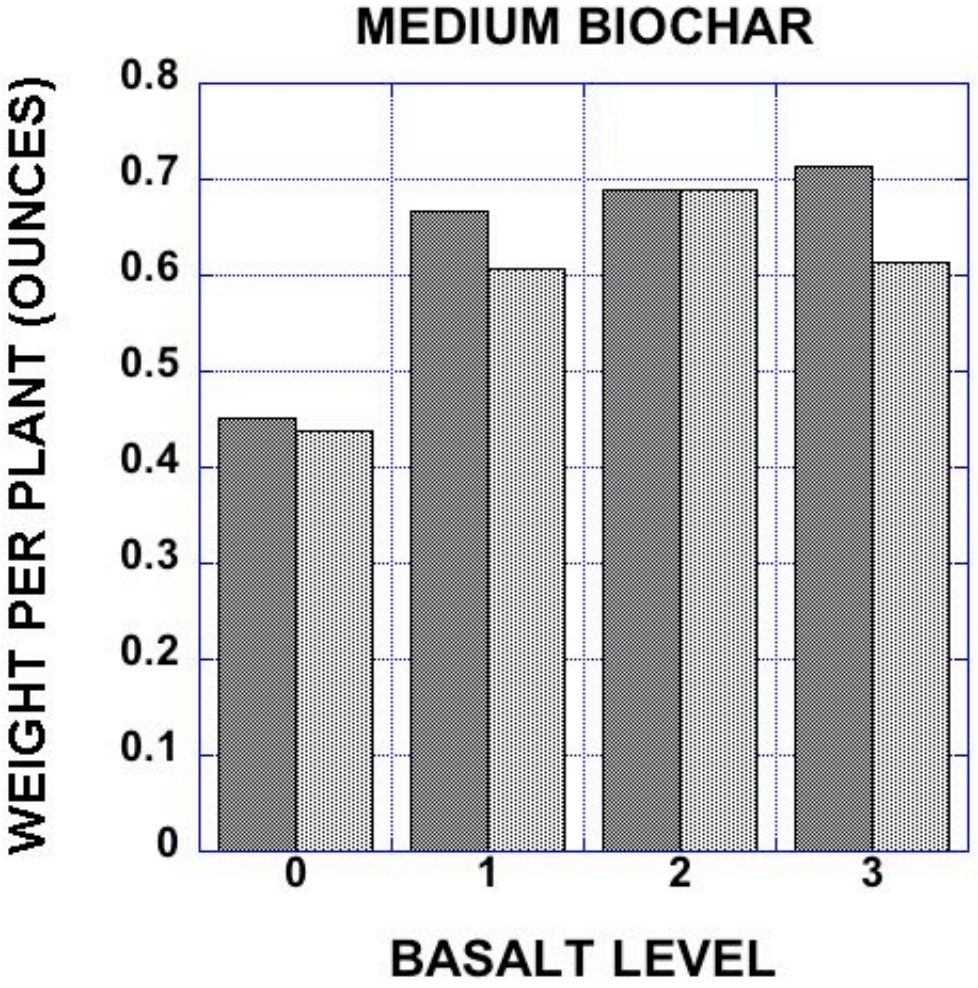

Figure 15b. Second radish crop as a function of basalt with low biochar.

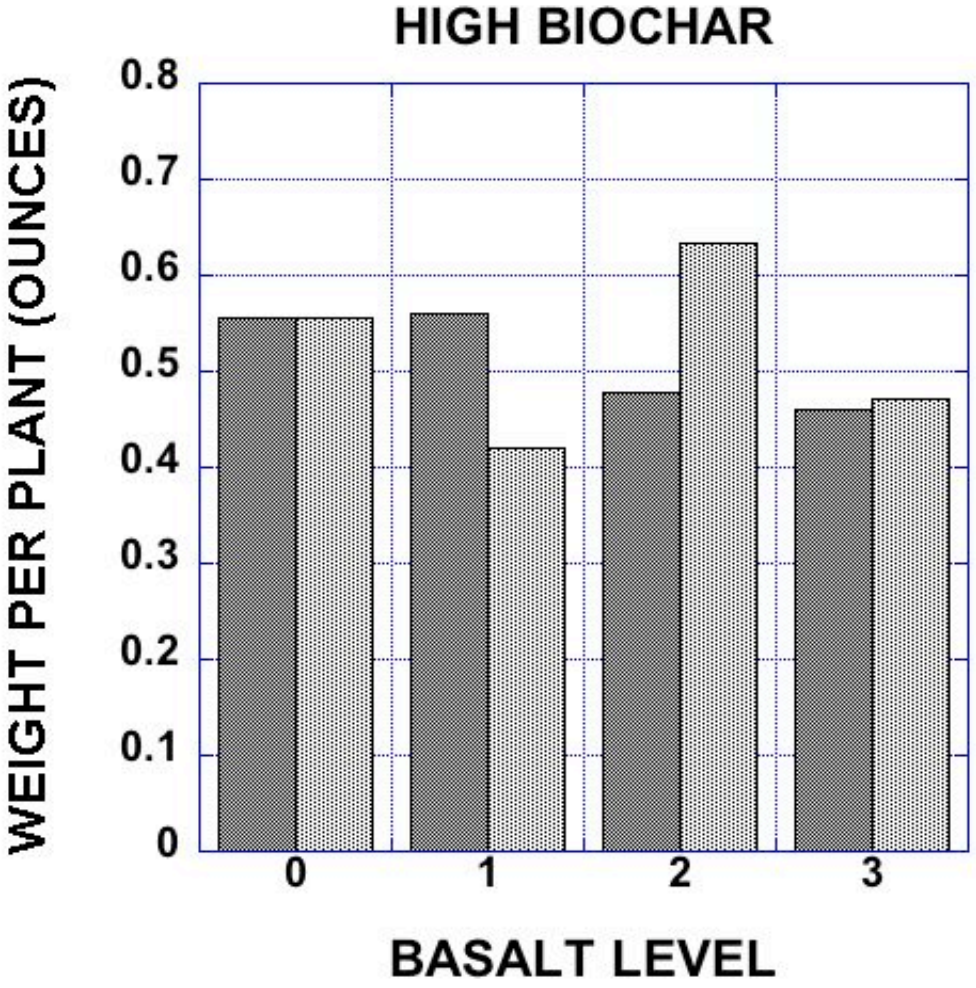

Figure 15c. Second radish crop as a function of basalt with high biochar.

B. WEED GROWTH

A strong gradient in weed growth was noted along the paths between the plots. The biochar made little obvious difference in the amount and type of weeds, but weeds grew much faster next to the higher basalt dust plots. In addition there was a very marked difference in the types of weeds as a function of the amount of basalt added. In the areas with no basalt, the weeds were dominated by sedge, but with increasing basalt the weeds were dominated by large grasses with runners, and weeds with deep roots. Note that neither basalt dust nor biochar was applied to the paths or raked into them, so this effect could represent wind blown material from the plots, translocation by earthworm castings, or that the roots of the weeds in the path grew into the adjacent soil plots. Weeds were indeed concentrated along the edges of the plots and not in the centers of the grass strips between them.

C. EARTHWORM ACTIVITY

Basalt powder was observed to strongly increase earthworm activity. Between reaping the first crop and sowing the second crop a period of heavy rain, followed by a few dry days resulted in earthworm castings being clearly visible as dry light-colored clods on top of dark, wet soil. We photographed the areas where the chambers were used to measure greenhouse gas fluxes in control plots, high biochar only plots, and high basalt dust only plots. The number of earthworm castings was counted in each. These numbers are underestimates, especially for the basalt plots, where the castings were so numerous that they made large lumps joined to each other, which were generally counted as single castings although they were likely from 2 to 10 separate lumps combined. The control plots had 3.5 $\pm$ 2.12 castings, the high biochar only plots had 8.0 $\pm$ 4.24 castings, and the high basalt dust only plots had 86 $\pm$ 16.97 castings. Addition of biochar more than doubled the number of castings above the controls, and addition of basalt powder increased them more than 20 times higher than controls. Results are shown in Figure 16. Increased earthworm activity is associated with many benefits for soils (Darwin, 1881) including better soil granulation, larger soil pores, increased aeration, and increased microbial and fungal activity.

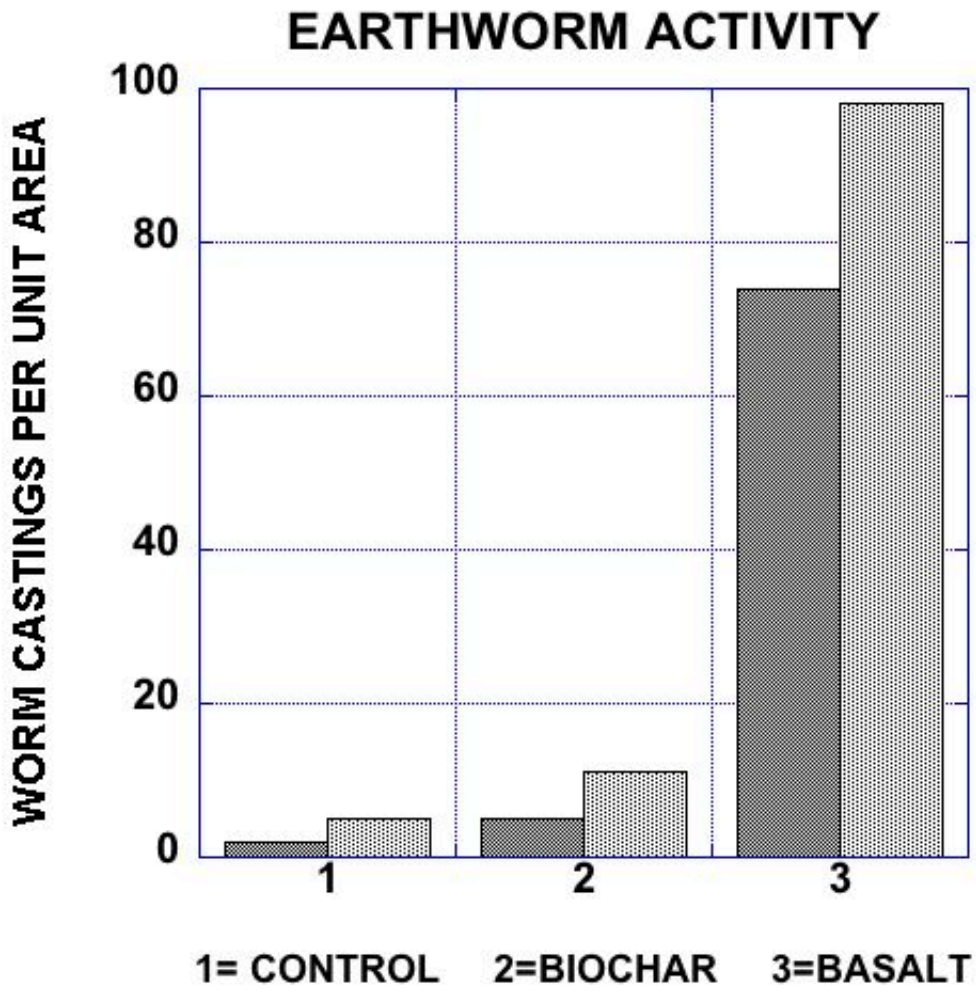

Figure 16. Earthworm castings per unit area.

D. GREENHOUSE GAS EMISSIONS

Preliminary gas flux measurements suggest that the high basalt and high biochar plots release less carbon dioxide to the atmosphere than control plots. The basalt

plots had lower releases of nitrous oxide but biochar plots had higher emissions, and that both basalt and biochar reduced absorption of nitric oxide from the atmosphere (Figure 17). As these measurements were made at one time, on a wet day, and since methane fluxes were not measured, measurements need to be made throughout the season for a better understanding of the patterns of gas emissions between soil and the atmosphere. While these preliminary patterns are interesting, since there were only two measurements per treatment, more measurements are needed to determine if these differences are statistically significant.

A recent paper (Lubbers et al., 2013) predicts that CO2 emissions should increase by 33% and N2O emissions should increase by 42% with earthworm activity due to the increased exchange of gases through earthworm burrows, and because worm castings and worm burrow linings may be sites of enhanced microbial activity that could affect greenhouse gas production and consumption. That prediction was largely based on lab experiments rather than field data, because it is difficult to manipulate earthworm density in the field.

Our experiment provides a natural experiment that has increased earthworm activity about 20 fold, but there seems to be no corresponding increase in fluxes except for nitrous oxide. Our preliminary results suggest that basalt dust with high earthworm activity appears to reduce both CO2 and N2O emissions, in contrast to predictions. This could result from basalt powder acting as a CO2 sink through chemical weathering.

Some papers have suggested that biochar should reduce N2O and CO2 emissions, (Spokas and Reicosky, 2009; van Zwieten et al. 2010; Scheer et al., 2011, Case et al., 2013). While we confirm the CO2 decrease, our results seem to show an increase in N2O emissions with biochar. The patterns appear to be complex and highly variable, depending in part on the available compost nitrogen and the level of soil oxygenation. Much further work is needed to resolve these patterns

In addition, rock mineral weathering should serve as a CO2 sink by converting it into bicarbonate ions. Measurements of soil alkalinity changes are needed to clarify this. It is clear that further work will be needed to better understand the long-term impacts of biochar and rock powder on soil greenhouse gas emissions.

In summary, the effect of basalt and biochar treatments on greenhouse gas emissions is complicated and involves biological (microbial and invertebrate communities), chemical (pH values, redox conditions, carbon to nitrogen ratios), and physical (soil properties) processes. Short-term effects may be different from the long-term. To evaluate the contribution of basalt and biochar to greenhouse

gas emissions and carbon sequestration, long-term measurements that cover the seasonal variation and periodic events (rain, snow, flooding) are needed.

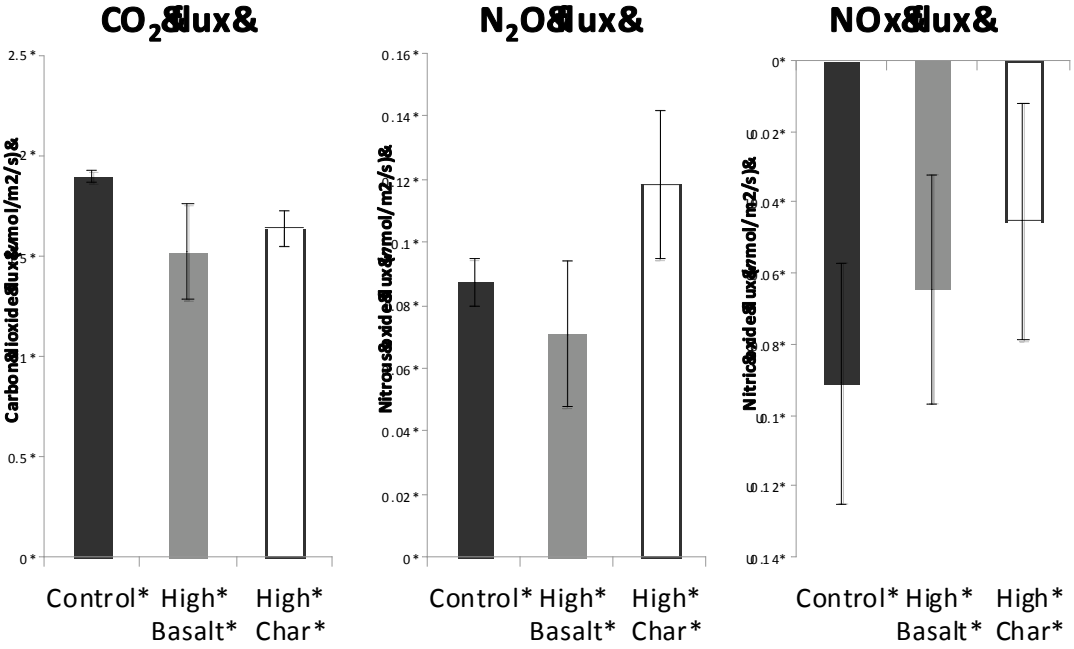

Figure 17. Gas emissions from plots measured between crops.

CONCLUSIONS AND FUTURE PROSPECTS

The strong immediate response to basalt powder was a surprise, as we had thought soils at this site were highly fertile, but the results indicate significant mineral deficiencies in the soil that were remedied by the added materials. We had initially thought that the soils at the site were derived from river channel deposits that were composed of farm and forest soils that were eroded from upstream in the watershed following deforestation and agriculture, and which would have been among the richest soils in the watershed. But the fact that the hurricane that plugged the channel took place before regional deforestation means that New Harmony soils represent natural river sediment before it was enriched by erosion of forest and farm soils, which may explain the unexpectedly strong response to basalt powder fertilization.

Interactions between biochar and rock powder, and with soil biology, all of which lead to effects on plant nutrient uptake, growth, and nutritional quality, will be

smallest at the very start of this long-term experiment, and should change in the subsequent years as the materials mature and interact.

Our results to date represent only the very first steps on a long journey. Already they have revealed surprises, and we expect more to come. We intend to apply a much larger suite of measurements, including detailed soil elemental analysis, carbon and nitrogen isotope analysis, measurements of a larger suite of climatically active gases that are involved in soil biochemical metabolism, and measurements of crop nutritional quality in future work.

We expect that the agricultural productivity, crop nutritional quality, soil carbon storage, and greenhouse gas emissions will evolve as biochar and basalt powder continue to mature and interact. The long-term results will provide useful guidelines for managing biochar/rock dust combinations to optimize their economic, environmental, ecological, and climate change benefits.

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