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CASE STUDIES

Combining Lab-Based Analysis and Science Communication with an Experimental Citizen Science Approach: Does Biochar Improve Resilience of Plants to Drought Stress?

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Citizen science is a powerful tool for collecting data in inaccessible places and at scales that would otherwise not be possible. Studies using complex, laboratory-based technical analysis with samples derived from easy to conduct experiments could also capitalize on this approach, by including the public in the experimental undertaking. This approach offers practical communication opportunities to raise awareness about the scientific method. We used an experimental citizen science approach in order to communicate the concept of land-based carbon sequestration and the potential role of biochar (i.e. charcoal added to soil). At four gardening events (between 100 and 7,000 attendees) we encouraged participation in our pot-scale citizen science project. We aimed to assess drought resilience of pot plants in soils amended with biochar. Participants sent their mature plant samples to our laboratory for stable isotope analysis to get results and additional information on drought stress, that was otherwise not possible. We observed no significant negative or positive effects of biochar, neither on the water use efficiency, as determined by isotopic methods or on the growth of the bean plants. Our two-stage strategy (experimental citizen science and laboratory analysis) was an effective way of involving people. We identified some challenges sustaining commitment and made some improvements to the project design. Overall we successfully avoided the "learning deficit" trap by engaging the people in an experimental learning activity; demonstrating that combining experimental citizen science with lab-based analysis is a promising and inspiring approach for future studies.

Keywords: stable isotopes; biochar; water use efficiency; citizen science; science communication

Introduction

Studies utilizing observations reported via citizen science (CS) are on the increase (e.g., Heigl et al. 2017; McShea et al. 2016; Sullivan et al. 2014). These studies enable scientists to use large data sets to answer research questions and have sometimes been used in combination with lab-based analyses. For example, Fournier et al. (2017) combined stable hydrogen isotope measurements of feathers collected from Virginia Rails with data from CS observations to determine the most probable origins of this migrant species. Less attention has been given to CS involving experimental approaches with subsequent sample analyses in the lab, however, even though such approaches could likely benefit from including the public in the experimental data collection. Performing experiments at different locations can be costly and time consuming, therefore, multiple location data are often not available. Studies with easy-to-conduct experiments but technically complex lab analyses could specifically benefit from including the public in conducting growth experiments to enhance the number of location variables for investigations.

Furthermore, such active engagement in replicated, randomized experimental cultivation not only provides educational opportunities for the public, it also offers a demonstrative tool to communicate science and share information about novel scientific outputs. Recently, the CS soybean project "1000 Gardens" demonstrated that its experimental approach was a valuable tool for conveying vital information about the importance of legumes for sustainable agriculture to a broader public (Würschum et al. 2018). Public understanding of soil science also is important, but it can be difficult to stimulate interest in soils and in particular their potential role in combating climate change. Soils are slowly being recognized as a valuable finite natural resource on par with air and water. They also play an important role in global carbon exchange,

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resulting in a renaissance of soils research. Specifically, soils account for two-thirds of the terrestrial carbon pool (Schimel 1995), and the carbon flux to the atmosphere from soil respiration is ten times greater than that from fossil fuel combustion (Schlesinger and Andrews 2000). One approach to enhancing soil carbon stocks that has gained much attention in the past few years is adding biochar to soils; this has been heralded as the black revolution. Biochar is a form of charcoal, produced from the pyrolysis of preferably waste stream products. It is manufactured specifically to be added to soils to improve soil quality.

Biochar production followed by soil incorporation has a history dating back to ancient Amazonian practices of nurturing Terra Preta (black soil) through the addition of charcoal and other household organic wastes to soils. However, scientific research into biochar application is still a young field. A number of recent national and international projects have identified the phenomenal benefits of adding biochar to soils and the resulting impact on crop yield and the hydrogeological and biogeochemical cycles (Cao et al. 2017; Liu et al. 2018; Singh and Cowie 2014). These effects are particularly impressive in tropical degraded soils such as those common in Kenya, Uganda, and Sri-Lanka (Jeffery et al. 2017). But our research also has observed benefits of adding biochar in temperate Austrian cropping systems. Especially in drought years, the positive impact of biochar on plant water use efficiency prevented a significant decline in yield, despite sequestering considerable quantities of carbon, potentially for millennia (Hood-Nowotny et al. 2018; Karer et al. 2013). Addition of biochar to soil for the purpose of carbon sequestration and soil improvement is a win-win strategy. Nevertheless, public awareness of the benefits of adding biochar to soil as a low-risk carbon sequestration strategy is low. Based on hands-up counts at 10 lectures given by the authors, fewer than 5% of the audience members knew what biochar is.

The objectives of this project were (1) to collect data for lab analyses from a wide range of different soils across Austria using an experimental citizen science approach and (2) to communicate our research findings about biochar to a wider public through a participation model of communication by engaging the public in a horizontal dialogue on climate change. We set out to recruit the public at a number of targeted public events to participate in our pot-scale citizen science endeavour, collaboratively investigating the benefits of using biochar to increase drought resilience using state-of-the-art stable isotope techniques. We used a spoke and hub design, which is akin to a bicycle wheel, where the participants conduct the cultivation of the experimental plants in disparate environments and return them to a central analysis laboratory. We wanted to highlight and publicize the potential of adding biochar to soil to sequester atmospheric carbon dioxide and its potential role in combating climate change. The results of the project "Biochar NET-2-U" (note, nett translates from German as "nice") provide insights into some advantages and challenges of using lab-based analyses in an experimental citizen science approach.

Methods

In this project we capitalized on a growing interest in domestic gardening and a trend towards more sustainable solutions. We therefore visited gardening events and venues as well as general science events to solicit engagement with our target group (urban, rural, and wine gardeners aged 7–100 years).

Soliciting engagement

To raise public interest at events we used our portable conical structured flame curtain kiln "Kon-Tiki," because it provides a dramatic opportunity to present the biochar production process to the public and offers a focal point of interest and discussion. We fired up the kiln and let public curiosity take hold as people were drawn to the flames and warmth. We used this approach at four events and had excellent responses from people who were fascinated and keen to find out more about biochar and its role in combating climate change. We stressed to the public that the "Kon-Tiki" is not how we would envisage mass producing biochar in the European context, but that it was an excellent tangible communication tool. Once we had drawn people in and gained their interest, we further fuelled their fascination in biochar with a semi-permanent mobile exhibition about biochar and its past and future role in the global carbon cycle. The mobile exhibition was positioned next to the "Kon-Tiki" at these targeted events and facilitated stimulating conversation with visitors.

Additionally, we conducted an informal assessment of the state of knowledge about biochar and nature-based negative emission technologies (NETs), as well as the visiting publics' levels of engagement in climate change combating behaviours, through a focused line of questioning. We also asked people attending the display to fill in a short anonymous questionnaire, in German, and to place it in a polling box.

The questionnaire included the following questions and asked for a yes or no answer:

- Do you know the term "biochar"?
- Do you know why we are interested in using biochar?
- Did you ever hear about negative emission technologies – NETs?
- Do you know the term "carbon footprint"?
- Do you take actions to reduce your CO_2 impact?

Citizen science pot experiments

The positive impact of adding biochar to soil is very context dependent and highly dependent on the soil type and biochar source used (Kloss et al. 2012, 2014). We wanted to see if this increase in soil water holding capacity is a generic property of adding wood-based biochar to different soils across Austria. In temperate Austria we have identified that biochar could be particularly useful in extreme drought years. We saw ten percent greater yields in biochar-amended soils than in control soils in the very dry year of 2011 (Karer et al. 2013). We have preliminary evidence that biochar can reduce water usage and increase resilience to extreme heat events whilst capturing significant quantities of carbon and improving nutrient and soil retention (Burrell et al. 2016; Lehmann and Joseph 2009). We wanted to fully test this hypothesis using a citizen science approach to provide scientific evidence of biochar's water use improving properties in a wide range of Austrian soils. Therefore, at our public awareness events we also encouraged interested people to get involved with experiments about biochar and to learn about the scientific process.

We used a simple but state-of-the-art stable isotope technique to assess plant water use efficiency (WUE) (Farquhar et al. 1989) in conjunction with more traditional scientific observations, e.g., plant height, vigour. The beauty of this isotope method is that it gave the citizen scientists the chance to run the experiment from seed to harvest and to observe the effects of the biochar directly in their garden or on their balcony. The project therefore functioned at two levels: First, it provided participants with the opportunity to grow and see the effects of biochar on the plants with easy-to-conduct experiments about soil and needs of plants, and second, it provided an entry point for the citizen scientists to gain knowledge of the technical world of stable isotopes. As a result, we were able to assess WUE of the cumulative growing season and to collect data on the impact of biochar on WUE across a range of soils.

We provided the citizen scientists with a biochar starter pack (**Figure 1**). This explained the background and basics of the experiment and provided all materials to conduct it. It included instructions on how to use soils from participants' neighbourhoods or their own potting compost; how to mix the soil with the biochar provided (produced from beech wood at a pyrolysis temperature of 480°C; 10 g; volume 70 ml) or leave the soil mixed as the control (volume of soil/treatment 250 ml); and how to plant the bean seeds provided (*Phaseolus vulgaris* L. var. *nanus*) and to water the plants daily in an identical manner. We stressed the scientific concepts of replication, randomisation, and focusing on one variable while otherwise providing the same treatment. We also encouraged the citizen scientists to record plant height, make vigour measurements, and take photos. We tried to make sure that we had a standard, easy-to-follow protocol. After a period of six weeks the citizen scientists took plant samples in the form of small round discs of plant material from both treatments using an office hole-punch. They then sent these samples, packed in tin foil and taped to a provided postcard, to our laboratory of the University of Natural Resources and Life Sciences in Tulln for isotope analysis. This proved to be a simple and easily implementable method for sample delivery.

Isotope method used to measure water use efficiency in plants

To test whether the addition of biochar to soils protects plants from drought stress, we used the carbon isotope discrimination (CID) method (Farquhar et al. 1989). This technique allows non-destructive rapid and robust analysis of plant soil water status under artificial irrigation and rain-fed conditions and allows a simple comparison between different soil conditioner treatments, irrespective of fertilizer use or other compounding factors (Farquhar et al. 1989). For example, it has been used to assess genotypes of a common turf grass (Kentucky Bluegrass; *Poa pratensis*) during drought. Ebdon and Kopp (2004) concluded that CID is a useful selection criterion.

The background is that in nature there are two isotopes of carbon: Lots of light $^{12}CO_2$ and about 1% heavy $^{13}CO_2$. When the stomata, the holes through which plants absorb CO_2, are open and the plant is not water stressed, the plant discriminates against the heavier CO_2. As a result, the plant has a slightly different ratio of ^{12}C:^{13}C to that of the air from which it draws the CO_2. However, when the plant is water stressed, it shuts down its stomata in an attempt to reduce water loss; then the CO_2 is trapped in the stomatal cavities and the plant is forced to use the heavy CO_2 within the cavity. This phenomenon results in a different ratio of ^{12}C:^{13}C compared to the well-watered plant and allows determination of the impact of water stress on the plant independently of other factors such as plant nutrition (Farquhar et al. 1989; IAEA 2001). The beauty of the method is that it yields a very accurate assessment of

Figure 1: Left: The biochar starter pack included six pots (diameter = 5.5 cm; height = 5 cm; three pots/treatment), 15 bean seeds (*Phaseolus vulgaris* L. var. *nanus*), wood-based biochar (10 g), information about the background of the project, and instructions on how to conduct the experiment. Middle: "Kon-Tiki" biochar kiln. Right: CS experiment on a balcony. Photographs by the authors.

the plant water status and the influence of drought over both short and integrated time scales (Shaheen and Hood-Nowotny 2005).

Leaf samples supplied by project participants were dried and weighed in tin capsules, and carbon isotope composition ($\delta^{13}C$) was analysed using an elemental analyser (organic EA, Flash 2000; Thermo Fischer Scientific Inc., Massachussetts, United States) connected to an isotope ratio mass spectrometer (Delta V Advantage; Thermo Fisher Scientific Inc., Massachussetts, United States). We calculated carbon isotope composition ($\delta^{13}C$) relative to the international standard Vienna Pee Dee Belemnite (V-PDB):

$$\delta^{13}C = ((^{13}C_{sample} / ^{12}C_{sample}) / (^{13}C_{V\text{-}PDB} / ^{12}C_{V\text{-}PDB}) - 1) * 1000$$

Analytical precision of $\delta^{13}C$ measurements was 0.2‰.

Thereafter we estimated carbon isotope discrimination ($\Delta^{13}C$) as:

$$\Delta^{13}C = (\delta_{air} - \delta_{sample}) / (1 + \delta_{sample} / 1000)$$

where δ_{air} reflects the ^{13}C composition of atmospheric CO_2, which is known to be –8.0‰ in Europe (Farquhar et al. 1989). Accordingly, the effect of water stress in plants is measurable as a decrease in $\Delta^{13}C$. These values are reported in international standard units, which allow global comparisons of data.

We communicated the results back to the citizen scientists through a dedicated Biochar-Facebook platform and provided updates using a Twitter feed. We provided more detailed information about the project on our project homepage.

Round-up, Big-Biochar Day

Near the end of the project we organised a Big-Biochar Day at which we communicated the findings of the project and our other biochar projects from around the world to the wider community, through presentations and the "Kon-Tiki" technology. We invited the citizen scientists involved in the project and other stakeholders, including biochar producers, local farmers, and wine growers. We also advertised the event to the general public so other people could participate if they were interested. We held the event at a major local show garden, "Die Garten Tulln," to increase the public's interest. The event comprised short scientific talks pitched at the general public and poster presentations. We also had a participatory-approach "world café" workshop on how to move forward with the outputs of the project. Moreover, we explored opportunities for innovative schemes to promote the adoption of negative emission technologies (NETs) globally and locally. Finally, we finished off with food, drink, and informal fireside discussions to foster cross disciplinary networking and promote collaborations.

Data analysis

The effects of both biochar and location on $\Delta^{13}C$ values of bean leaves were tested by Two Way Analysis of Variance (significance set at $p < 0.05$), and data were plotted using SigmaPlot 12.0 software (Systat Software Inc. USA). Values given throughout the text are means ± one standard deviation.

Results

We presented our exhibition and the "Kon-Tiki" at four major events across Austria in Spring 2017. More than 500 visitors came to our stand. We recruited 73 individuals to take up our citizen science challenge. From these individuals we received back 12 (16%) completed projects. We received some oral feedback of reasons why the remaining citizen scientists did not finish the experimental process, for example, the wind blew away the pots because they put them in unprotected areas or the participants went on holiday and plants were wilted when they came back. In addition, the initial setting up of the experiment was identified as a barrier of commitment.

From the citizen scientists' experiments with three replicate samples of each treatment (biochar and control), we received a total of 72 samples for stable isotope analyses. To give an idea of the potential scope or feasibility of such a project, laboratory analysis costs were approximately €1,500. However, we faced unforeseen technical issues with the new elemental analyser isotope ratio mass spectrometer, so we were able to successfully analyse only 23 and 21 samples, for the biochar and controls respectively, in the end.

Isotope analysis revealed that the leaf samples of the control treatment had lower $\Delta^{13}C$ values (23.56 ± 1.62), i.e., they were slightly more enriched in ^{13}C compared to leaf samples of the biochar treatment (24.15 ± 2.81; **Figure 2**). However, differences between control and biochar-treated plants were not significant ($P = 0.095$; **Table 1**), suggesting less but not significantly less water stress in the biochar treatment. There was a clear trend, which suggested an effect of the biochar, but there were not enough replicates or sites to overcome the high variance in the isotope data. Moreover, there was a significant interaction between biochar treatment and location ($P = 0.011$; **Figure 3**; **Table 1**), suggesting that some citizen scientists had put their plants under greater overall water stress than others.

Results of the assessment of knowledge prior to CS experiments showed that approximately half of the people who participated in the survey had heard the term "biochar," but fewer than 40% were aware of the rationale behind biochar application (**Figure 4**). Interestingly, the knowledge about negative emission technologies was very low; only around 15% of the participants were familiar with the term. In contrast, more than 80% of the participants were aware of the term "carbon footprint" and stated that they took specific action to reduce their own CO_2 impact.

Discussion

Including the public in scientific research to collect data in observational studies (Heigl et al. 2017; McShea et al. 2016; Sullivan et al. 2014) has been recognized as an effective strategy. However, few citizen science projects use experimental approaches (Birkin and Goulson 2015) and exploit the science communication opportunities therein

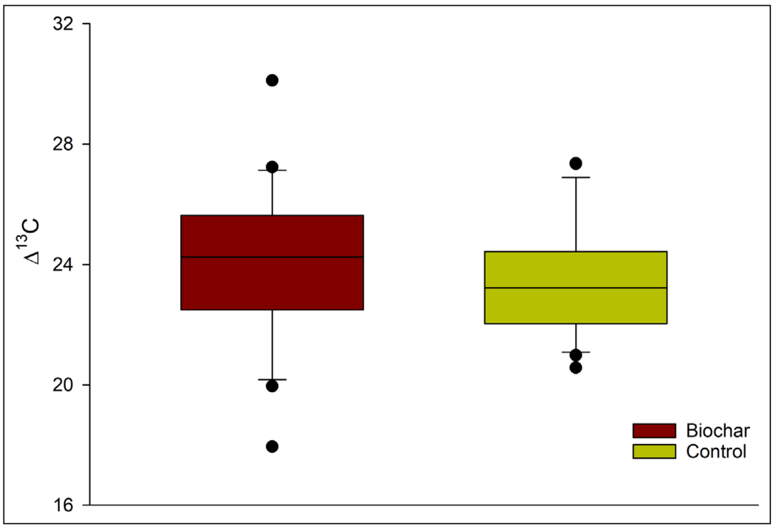

Figure 2: Overall effect of biochar on the $\Delta^{13}C$ values of bean leaves. Means ± SD, n = 21–23. This is the mean value from all locations and replicates of the CS experiments. Higher values indicate less water stress.

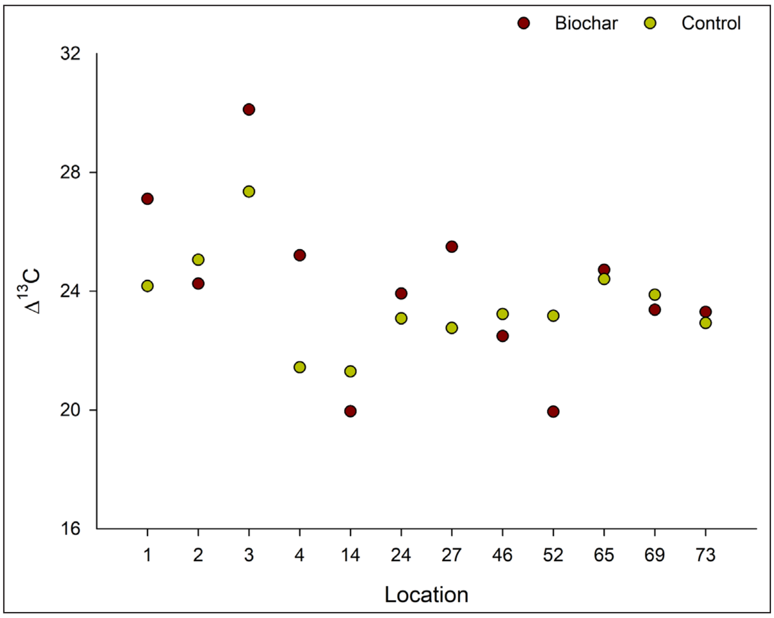

Figure 3: $\Delta^{13}C$ values of bean leaves at each location. Each location number (x axis) reflects one completed CS experiment. Mean value per treatment, n = 3 (target value).

Table 1: ANOVA table of F– and P– values of the effects of biochar and location and their interaction on $\Delta^{13}C$ values of bean-leaves. D.f. = degrees of freedom.

	D.f.	F-value	P-value
Biochar	1	3.077	0.095
Location	11	11.999	<0.001
Biochar × Location	11	3.262	0.011

(Würschum et al. 2018). Of the 39 projects on the Austrian citizen science website, we are one of the few that adopts an experimental approach, with the majority being observational studies. One reason for this is a common assumption that the public is not capable of carrying out scientific studies, however, when the fundamentals and principles of the scientific method are clearly explained and communicated in easy-to-understand instructions, then experimental citizen science can be an effective and stimulating way of public data collection. In this study we used an experimental CS approach to communicate the concept of land-based carbon sequestration and the potential role of biochar to a wider public.

Many CS studies recruit participants through targeted media campaigns (e.g., articles in newspapers, websites, newsletters, social media channels). However, we attempted to recruit people using a face-to-face strategy. We were aware that communicating the importance of soils can be quite challenging, because we often experienced a general lack of empathy for soils provoked by both images and nomenclature such as dirt or creepy crawlers. In Vienna in particular, many residents live in apartments and have no connection with soil and therefore an inherent fear of soil, which we observed particularly in teenagers. We hypothesised that in our study, informal information

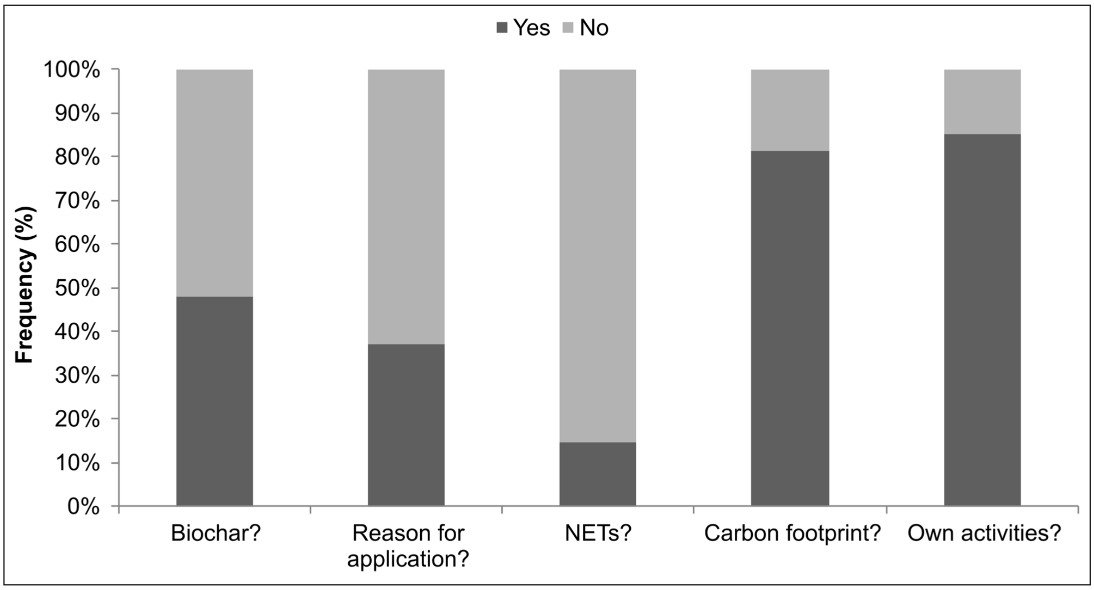

Figure 4: Assessment of knowledge prior to project participation showing the relative frequency (%) of questions answered with yes (dark grey) and no (light grey) (n = 27). The bars from left to right indicate the following questions: Do you know the term "biochar"? Do you know why we are interested in using biochar? Did you ever hear about negative emission technologies – NETs? Do you know the term "carbon footprint"? Do you take actions to reduce your CO_2 impact?

communicated through face-to-face exchange might be more effective than social media, because it would enable us to respond directly and individually to major public concerns. Even though other recruitment strategies such as big media campaigns allow a greater number of individuals to be reached, our approach yielded a reasonable response and data return level of 16%. This level is comparable with the study of Birkin and Goulson (2015) in which the public was asked to carry out manipulations in a pollination experiment, where 14.5% of the initial volunteers completed the required task successfully. However, the 12 individuals who completed experiments in our project represented too small a sample size for robust statistical analysis. Future studies using a face-to-face strategy might benefit from also using targeted media events to obtain a larger number of participants.

Isotope analyses of leaf samples showed no significant effect of biochar treatment on the water use efficiency (WUE) of the bean plants. However, results suggested a trend towards improved WUE in the biochar treatment. As explained above, the positive impact of adding biochar to soil is very context dependent (Biederman and Harpole 2013; Crane-Droesch et al. 2013), and a recent study of Jeffery et al. (2017) demonstrates that the yield-improving effects of biochar may be more valuable in soils with low nutrient and low pH status, such as those found in tropical regions. In temperate regions, however, the effect of biochar on plant growth may become apparent only during very dry conditions because of a more favourable soil water holding capacity (Hood-Nowotny et al. 2018; Karer et al. 2013) in biochar amended soil.

We instructed the citizen scientists to water their plants identically, but it is likely that the amount of water applied differed among the experimental locations and may explain the interaction between the location (single CS experiment) and the biochar treatment. In some experiments, plants probably experienced some dry periods, but in other experiments the citizen scientists applied sufficient water to ensure that their plants survived and never faced water stress. In a CS study in which participants were asked to grow *Vica faba* plants aimed to monitor pollination service, the authors considered the possibility that the gardening experience of participants might have affected results (Birkin and Goulson 2015). To enhance the return rate, they suggested recruiting more professional gardeners. However, in our approach, such pre-selection would have restricted participation and possibly excluded interested but inexperienced people, thus limiting the participation level. Furthermore, pre-selection would have limited the education and communication purposes of our project, which had the fundamental aim of reaching the public at large. Establishing organised learning or working groups of gardeners may offer an additional opportunity to offset differing knowledge levels of participants.

We also identified a number of possible improvements to the experimental design, which came to light only during the experiment. However, we also recognise that design iterations are an integral part of the learning curve for project developers. For example, we identified a number of issues in the protocol which led to potential errors, such as failing to provide the citizen scientists with clear instructions about how to pack the replicate plant discs of the treatments individually. Therefore, we were not able to distinguish between the single replicates. We realised that we could overcome this problem with a stacked concertina design of the folded foil. However, instructions must always be balanced between simplicity and sufficient detail to carry out the experiment, and too much detail may create resistance to implementation or put people off from completing the experiment because they think it is too complicated.

Furthermore, some unforeseen technical issues occurred during analysis. We had failed to build sufficient slack into our sampling procedure and, because sample margins were too low to compensate for the lack of sample quantity, we were not able to repeat these measurements. In the future we will ask the citizen scientists to send double the required number of samples, because this is a low-cost action for the participants (six rather than three leaf punches) but creates vital redundancy if lab-based problems occur. We did not ask the citizen scientists to send the whole plants to our laboratory because we suspected that high and costly effort for sending samples would discourage participants and lead to lower participation rates, and we wanted to keep implementation of the experiment and sampling as simple as possible.

To improve statistical power, we would need more people to provide samples. One approach is to identify patterns of motivation, so that participants will maintain their commitment and take care of the plants for a duration of six weeks. Even though we tried to make the description as simple as possible and underpinned the step-by-step procedure with guiding pictures, the complexity of the project may have discouraged people from joining. In 2018 in our follow up project "Biochar NET-2-U-2", which set out to investigate the benefits of using biochar to improve nodulation of legumes (Rondon et al. 2007), we provided the opportunity to undertake the activity and to set up the experiment at the local venue where we were exhibiting, with the hope to increase uptake and return level. With this approach we were successful in involving children, who were curious about the project and had a lot of fun getting their hands dirty. This approach also opened up a new avenue of communication by starting relaxed conversations with parents, who otherwise would have passed over our exhibition stand. Indeed, our "hands-on, take home station" at events appeared to overcome some of the uptake barriers, increasing our uptake levels by around 35%. Another improvement was to state on our project home page that we would send a biochar starter pack by post for people who could not visit one of our events, and some have taken us up on this offer.

While our uptake levels increased, however, the return rate did not. Continuous communication strategies such as newsletters or social media channels are necessary to build a sense of community and are suggested to be important in retaining participants (Dickinson et al. 2012). We tried to stay in contact with our participants via social media channels, also aiming to build a community in which citizen scientists could exchange their experiences. However, very few made use of this possibility, perhaps because the participants were not required to register for the project online. We wanted to keep barriers of participation as low as possible and to be as inclusive as possible, so we did not ask for registration or special scientific or gardening experience and participation was kept anonymous, due to concerns about data protection. In future studies we want to find a balance between keeping barriers low but developing strategies to retain interest, i.e., specific interest-retention tools that could ensure sustained participation, for example, asking for permission to get in touch via email or Instagram with motivational prompts to care for their plants. We experienced that our project duration was too short and that the community-building process was just starting to develop in the closing months of the project.

We found that our engagement with participants was valuable for increasing public awareness about the important role of soils in combating climate change. In 2018, we improved our assessment of public prior knowledge by displaying a large poster board on which people visiting our exhibition could complete the questions with coloured stickers. This approach improved public response, possibly because people experienced it more as a game. In our current project, which is an extension of the project reported here, we also ask people if they are interested to get more information about biochar, and more than 70% claim that they are, indicating strong public interest in this topic.

Conclusion

Our experience shows that using an experimental citizen science approach to obtain samples for laboratory based stable isotope analysis, or any other complex analysis, is practical, fun, and feasible when using the spoke and hub design described herein, particularly in an age of social media. Moreover, when backed up with exhibitions and background information, experimental CS approaches can provide a useful tool to communicate the research process and findings to a wider public and to get people involved in gathering data. Although our return rates were lower than expected, we identified a number of ways that we could improve them, such as immediate commitment and engagement and regular dialogue with the participants. We found that creating a simple and easy-to-understand protocol is crucial, and again social media helped, allowing further enquiries to clear up any issues. One of the key learning points was to build essential redundancy into the protocols where possible, as long as the costs and efforts for participants are kept low (e.g., citizen scientists are asked to provide more than the minimum required sample quantity). This redundancy can be important because it provides backup against risks in the lab. We also recognized that continuous communication strategies are essential for building a sense of community, but this takes time for development and requires a well thought out strategy and planning from the beginning of a project.

Data Accessibility Statement

The Stable Isotope Data of the citizen science project "Biochar NET-2-U" can be found as follows: DOI: 10.5281/zenodo.2653620.

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Rebecca Hood-Nowotny and Elisabeth Ziss contributed equally to the paper and both designed, wrote, and carried out the project and CS experiments. Anna Wawra and Andrea Watzinger assisted with the experiment implementation and organizing the events. Elisabeth Ziss, Rebecca Hood-Nowotny, and Anna Wawra wrote the manuscript together.

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