

Building a Spatial Database of Biochar Research and Practice with Web-GIS

by

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To my parents William and Waleen Babcock

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List of Abbreviations

| | |
|-----------------|--|
| AGOL | ArcGIS Online |
| ADE | Amazonian Dark Earths |
| API | Application Programming Interface |
| BfAMT | Biochar for Agriculture Mapping Tool |
| BMP | Best Management Practice |
| CFEP | Chigoe Flea Eradication Project |
| C | Carbon |
| CH ₄ | Methane |
| CO | Carbon Monoxide |
| CO ₂ | Carbon Dioxide |
| CSS | Cascading Style Sheets |
| CSV | Comma Separated Values |
| ERD | Entity-Relationship Diagram |
| FTP | File Transfer Protocol |
| GHG | Greenhouse Gas |
| GIS | Geographic Information Science or System |
| GPS | Global Positioning System |
| HTML | Hypertext Markup Language |
| HTTP | Hypertext Transport Protocol |
| IBI | International Biochar Initiative |
| IDW | Inverse Distance Weighted |
| IRB | Institutional Review Board |

| | |
|-----------------|--|
| IPCC | Intergovernmental Panel on Climate Change |
| JSON | Javascript Object Notation |
| Land PKS | Land Potential Knowledge System |
| MCDM | Multi-Criteria Decision Model |
| NGO | Non-Governmental Organization |
| NMVOC | Non-Methane Volatile Organic Carbon |
| NO _x | Nitrous Oxide |
| OGC | Open Geospatial Consortium |
| RDBMS | Relational Database Management System |
| REST | Representation State Transfer |
| SAAS | Software-As-A-Service |
| SQL | Structured Query Language |
| SSI | Spatial Sciences Institute |
| TLUD | Top-Lit Updraft |
| URI | Uniform Resource Identifier |
| USC | University of Southern California |
| VGI | Volunteered Geographic Information |
| WAB | Web App Builder |
| WFS | Web Feature Service |
| WISDOM | Woodfuel Integrated Supply/Demand Overview Mapping |
| WMS | Web Mapping Service |
| WRB | World Reference Base for Soil Resources |

Abstract

Climate change poses increasing risks to the world's ecosystems and agricultural systems as greenhouse gas emissions are contributing to the unprecedented warming of the biosphere. One mechanism for capturing and storing carbon dioxide (CO₂), a primary greenhouse gas, is the production and application of *biochar*, or carbonized biomass created in an oxygen-limited environment. The United Nations Intergovernmental Panel on Climate Change (IPCC) identifies biochar as stable organic carbon that can increase soil carbon sequestration, resilience, and fertility. Biochar researchers and enthusiasts have worked to identify scenarios that are conducive to the application of biochar and maximize its potential benefits. Researchers have addressed biochar feedstock, production technologies, physical and chemical properties, and biochar's potential in energy generation, environmental remediation, resource management, land rehabilitation, and agricultural production. The Biochar for Agriculture Mapping Tool (BfAMT), which integrates Esri's Collector for ArcGIS mobile application with a stand-alone web application developed with Esri's Web App Builder (WAB), was designed to collect and display volunteered geographic information (VGI) about biochar agricultural sites on a global scale. With its editable feature services and map-driven forms, the BfAMT allows users to document their site-specific research and experimentation with biochar, thereby creating a geodatabase of biochar project locations, site attributes, and file attachments that facilitates research, coordination, and information sharing within the biochar community. Feedback from biochar users who beta-tested the BfAMT and completed an online survey questionnaire are presented and discussed. Recommended improvements offered by first-time users help guide the development and customization of the BfAMT as a workspace, spatial database, and promotional tool for local, regional, and global biochar activities.

Chapter 1 Introduction

Global warming and climate change pose increasing risks to the world's ecosystems and agricultural systems as greenhouse gas (GHG) emissions from the burning of fossil carbon sources (e.g., petroleum, natural gas, and coal) are contributing to unprecedented warming of the biosphere. The consequences of a temperature increase of 1°C above pre-industrial levels are being manifested in the form of more extreme weather events (e.g., hurricanes, floods, droughts, and fires), rising sea levels, and diminishing Arctic sea ice (IPCC Press Release 2018). Further consequences of global warming include ecosystem disturbances, like loss of habitat and the spread of disease vectors (Babiker et al. 2018), and decreased agricultural production linked to the degradation of soil organic matter (Lal 2006).

An emerging technology in global efforts to address the impacts of climate change is *biochar*. Draper (2018, 1) defines biochar as “a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment”. More generally, biochar is carbonized organic material that is intended for use as an agricultural soil amendment. Chapter 1 provides background information on biochar and its potential to sequester carbon, reduce GHG emissions, and improve soil fertility.

1.1. Background and Motivation

1.1.1. Biochar and Climate Change

In October of 2018, the Intergovernmental Panel on Climate Change (IPCC)—the United Nations body that assesses science related to climate change—released a Special Report (SR1.5), entitled “Global Warming of 1.5 °C”, or IPCC SR1.5, highlighting climate change impacts that could be avoided if global warming is limited to 1.5 °C above pre-industrial levels. The IPCC's SR1.5 report warns that limiting global warming to 1.5 °C will require a swift, far-ranging, and

unprecedented societal transition to ensure that CO₂ emissions are reduced by 45% (from 2010 levels) by 2030 and become ‘net zero’ by 2050 (IPCC Press Release 2018, 1-2). One mechanism for capturing and storing carbon dioxide (CO₂), a primary greenhouse gas, is the production and application of *biochar*.

In Chapter 4 of the IPCC SR1.5 report (Babiker et al. 2018), biochar is mentioned in Section 4.3.7. (*Carbon Dioxide Removal*) and subsection 4.3.7.3. (*Soil Carbon Sequestration and Biochar*). The IPCC identifies biochar as recalcitrant (i.e., very stable) organic carbon that can increase soil carbon sequestration, resilience, and fertility. Although the IPCC report considers biochar’s benefits as potentially significant at local scales, it questions the impact that biochar will have on global carbon sequestration. Reasons given include “a lack of large-scale trials of biochar applications to agricultural soils under field conditions”, perceived “limitations in biomass availability”, and possible constraints on the “maximum safe holding capacity of soils” (Babiker et al. 2018, 48). However, the report does not consider alternative uses for biochar, including its incorporation as a material in bio-engineering (e.g., water management, wastewater treatment, solid waste management, and building construction).

1.1.2. Biochar Applications

Biochar technology was practiced to varying degrees by ancient agricultural societies (Cornelissen et al. 2016), although its potential as an agricultural soil amendment and carbon sequestration method has only been studied for the last ten to fifteen years. Thousands of years ago, agricultural societies of the Amazon Basin in South America established a system of amending their acidic, nutrient-poor tropical soils with organic waste, human waste, and charred biomass (Lehmann et al. 2006). This process resulted in physical and chemical soil conditions that served as the basis for sustained agricultural production. Today, these cultural soils of the

Amazon Basin are colloquially known by their Portuguese name *Terra Preta de Indio*, or *Amazonian Dark Earths* (ADE). Biochar applications are not limited to acidic, tropical soils, and could be most beneficial for amending previously cultivated, degraded soils with low organic matter content, coarse texture, and poor water and nutrient retention (Lehman and Joseph 2009; Scholz et al. 2014; Sohi et al. 2010).

Biochar is a highly porous material with a variable surface charge for nutrient adsorption and a high internal surface area (i.e., porosity) that serves as a substrate for microorganisms and a sink for water and nutrients (Lehman and Joseph 2009). It can be produced from “waste” biomass sources, does not require expensive equipment or electricity to produce, and is resistant to physical and chemical breakdown. After raw biochar is pulverized into small particles, it is typically enhanced with nutrients, microorganisms, and minerals to improve soil properties and resource use efficiency (Draper, 2018).

The two major thermochemical conversion technologies used to make biochar are *gasification*, which allows for the presence of some oxygen, and *pyrolysis*, which effectively excludes oxygen (Draper 2018). After pyrolysis between 250°C and 600°C, about 50% of the carbon (C) contained in biomass, which is 40-50% C by weight, is converted to stable C in the form of biochar, which contains 70-80% C (Lehmann and Joseph 2009). The conversion efficiency of biomass-C to biochar-C using simple kiln techniques (50%) far exceeds the amount of soil carbon retained after biomass burning (3%) and natural decomposition (< 10-20% after 5-10 years) (Lehmann et al. 2006). Thus, according to Lehmann et al. (2006), the conversion of biomass to biochar fundamentally transforms C sequestration dynamics and leads to a much higher C content in soil than the application of un-charred organic matter.

The relatively smoke-free pyrolysis process used to produce biochar is energy efficient and releases few pollutants during the conversion of biomass to stable carbon. Thus, biochar technology could provide economic and health benefits to the approximately 2.4 billion people worldwide who depend on woodfuel resources to cook and heat their homes (FAO 2017). Biochar cookstoves (made from tin, clay, brick, steel, etc.) have been developed that can produce biochar from dried biomass (e.g., small-diameter twigs, corn cobs, nut shells, rice husks, and straw fabricated into pellets) and use the generated heat for cooking. Greater quantities of biochar can be produced using top-lit updraft (TLUD) ovens, retorts (i.e., sealed vessels), and flame curtain kilns that can be loaded with large-diameter feedstocks (e.g., tree branches, woody shrubs, bamboo, and fruit stones). Thus, the potential for using cooking devices and low-cost ovens and kilns to produce biochar locally for use in agricultural applications could be substantial. Figure 1 below contains photos of low-cost biochar production devices, biochar, and biochar-amended soils of the Amazon Basin (i.e., Amazonian Dark Earths), and Figure 2 below contains photos of biochar, biochar-soil applications, and biochar cookstoves.

According to Cornelissen et al. (2016), flame curtain pyrolysis is an effective method for the combustion of pyrolysis gases. Flame curtain kilns, also known as flame cap kilns, are fabricated from steel or brick into cone-, pyramid-, cylinder-, and box-shaped devices for producing biochar (Wilson 2018). They can also be made by forming a pit in the ground. A small pile of wood is generally placed in the bottom of the kiln (or pit) and then lit at the top. After the initial wood burns to coal, new wood is added until a flame curtain develops across the entire surface of the kiln. This flame curtain serves to exclude oxygen and preserve older layers of char (Wilson 2018). Cornelissen et al. (2016) demonstrated that flame curtain kilns emitted significantly lower amounts of combustible gases and particles—including carbon monoxide



Source: Author



Source: Author



Source: Author



Source: Author



Source:
<http://www.panna.org/blog/guest-blog-whats-biochar-movement>



Source:
<http://www.ultrakulture.com/2015/10/25/terra-preta-amazonian-super-soil-ancient-ways-of-bio-designing-rainforests/>

Figure 1. Clockwise from top left: Pyramid kilns with flame curtain, cone kiln containing wood biochar, in-ground pit for making biochar, Amazonian Dark Earths, finely processed biochar, Jolly-Roger oven made from a 55-gallon steel drum



Figure 2. Clockwise from top left: Women tilling biochar into topsoil, biochar applied around a coffee tree's dripline, TLUD Champion stove with cooking tripod, TLUD Champion stove combustion chamber containing corn cob biochar, biochar compost applied to young coffee trees, small twig biochar

(CO), methane (CH₄), aerosols (i.e. suspended particles - PM₁₀), non-methane volatile organic carbon (NMVOC), and nitrous oxides (NO_x)—compared to traditional kilns used to make charcoal fuel from biomass. Other studies have demonstrated that pyrolysis systems for cooking and charcoal-making can produce 75% less deleterious gas emissions (mainly CO, CH₄, and aerosols) than traditional systems (Cornelissen et al. 2016).

Wilson (2018) sees biochar as an emerging technology that provides an outlet for biomass generated from farm and forest management operations (e.g., woody debris, crop residues, invasive species, and livestock manure) with benefits that include the addition of a long-lasting carbon source to depleted soils and a potential revenue source for low-income, rural communities. In addition to farm and forest management, biochar has potential in wastewater treatment, stormwater management, mitigation and sequestration of toxic substances, and inclusion in building and packaging materials (Wilson 2018; Draper 2018). Furthermore, biochar's ability to 1) mitigate the release of GHGs from soil, 2) co-produce energy at the local level, 3) sustain healthy populations of beneficial soil microbes without the need for continued inputs like inorganic fertilizers and pesticides, and 4) remove carbon from the atmosphere by converting biomass to stable carbon resources are some of the reasons why biochar has been presented as a viable carbon management and climate change adaptation strategy (Draper 2018; Wilson 2018; Latawiec et al. 2017; Scholz et al. 2014).

1.1.3. Biochar System Suitability

Biochar's beneficial properties and agricultural benefits have been the subject of ongoing research and experimentation as biochar researchers and enthusiasts have worked to identify scenarios that 1) are conducive to the application of biochar and 2) serve to maximize its potential benefits. Research topics have addressed biochar feedstock, biochar production via

pyrolysis, biochar's physical and chemical properties, and how different biochars might interact with various soil properties and agricultural management practices. Variables like feedstock type, production method, biochar properties, soil properties, and crop type can interact in unpredictable ways that produce variable results. Understanding and defining the relative importance of these variables helps to identify scenarios that are compatible with the production and use of biochar within agroecosystems (Scholz et al. 2014).

1.1.4. Potential for Biochar Web-GIS Applications

Since 2006, an increasing number of individuals, non-governmental organizations (NGOs), government agencies, and research institutions have conducted research into experimental biochar applications and their differential effects on soil properties and crop yield. Significant research has been carried out in the United States, Europe, Australia, and China; with international development projects implemented in Central and South America, Southeast Asia, and Africa. Many biochar researchers and practitioners share their knowledge and project work through the International Biochar Initiative (<https://www.biochar-international.org/>), Yahoo's Biochar Group (<https://groups.yahoo.com/neo/groups/biochar/info>), and the Biochar Journal (<https://www.biochar-journal.org/en/home>). As a visitor to these sites, it can be difficult to keep track of member contributions, which could include their identity, organizational affiliation, geographic location, type of biochar project, and project details. Although discussion threads archived on the Yahoo Biochar Group website are searchable by author, subject, message, and date, they are not indexed by topic or georeferenced by location.

A web-GIS application that accepts volunteered geographic information (VGI)—and includes options for attaching photos, document files, and social media links—would provide a platform for learning the location and activities of individuals and institutions involved in

biochar research, experimentation, and practice. A web application focused on collecting and displaying biochar VGI should include the following: 1) a geodatabase (i.e., spatial database) containing information on biochar activities and site attributes, 2) a map service showing the location of formal biochar research and/or site-specific activities, and 3) user-generated content (i.e., VGI) that is searchable and exportable. The Biochar for Agriculture Mapping Tool (BfAMT), which is presented in Chapter 3, was designed to meet these three objectives.

Chapter 2 Related Work and Literature Review

With one recent exception (Salo et al. 2018), no web-GIS mapping applications have been developed to host information pertaining to biochar projects; be they focused on land restoration, waste management, climate change mitigation, or agriculture. Therefore, a discussion of related work will also focus on existing web-GIS applications that have design features and functionality that match the intended structure and objectives of the Biochar for Agriculture Mapping Tool (BfAMT). Biochar database and spatial analysis case examples will also be discussed.

2.1. Web 2.0 and Volunteered Geographic Information

Over the last 10 years, there has been a rapid and profound transformation in how geographic information is collected, stored, and disseminated. Several terms have been used to describe this phenomenon, including web 2.0, crowdsourcing, citizen science, and volunteered geographic information (Sui et al. 2013). Elwood et al. (2012) define volunteered geographic information (VGI) as geographic information that is voluntarily collected and shared with others to provide information about the geographic world, with novices, volunteers, and experts all playing a role. VGI systems have emerged as a complementary means of spatial data production; using the Internet and multiple computing devices and platforms (including desktop computers, cloud computing, global positioning system (GPS) devices, and smart phones) to create, share, visualize, and analyze geographic information (Sui et al. 2013). Sui et al. (2013) think geospatial data falls within the context of *big data*, or the ever-expanding universe of data that is being assembled, geographically referenced, and linked to digital networks.

Goodchild (2007) remarked that developments in VGI are contributing to the reversal of top-down approaches in how geographic data are gathered and distributed. For example, web applications like Wikimapia and OpenStreetMap have produced information on landmarks and

roads where none existed previously. Wikimapia and OpenStreetMaps are examples of VGI that serve to complement or augment *framework data* (e.g., landmarks, roads, and hydrography) commonly used for administrative programs, wayfinding, geopositioning, and geotagging (Elwood et al. 2012). *Non-framework data* include citizens' observations of conditions, events, activities and their locations. In some cases, VGI can be used to formulate research hypotheses and develop conceptual frameworks (Elwood et al. 2012).

Feick and Roche (2013) claim that engaging in VGI activities is a good way for individuals or groups of people to develop their spatial skills. They argue that the geosocial value of VGI is dependent on the data's intrinsic value and the socio-technical processes that go into producing and using it. Although VGI is mostly open-source and available to the public, inequalities exist regarding its global distribution and accessibility. These inequalities include different levels of Internet access and the affordability of electronic devices relative to earned income. VGI projects that target a global audience should be attentive to these issues and consider using multiple platforms for reaching out to those living and working in different socio-economic and socio-technical contexts.

As a data source, VGI's value has been challenged for lack of expert oversight, absence of professional standards, and spatial data uncertainty. Elwood et al. (2012) pointed out that VGI does not carry the same data quality assurances of conventional GI that was produced with authoritative products by trained experts. Goodchild (2012) discussed a general lack of quality assurance and expert oversight in VGI data and introduced three methods (i.e., *crowdsourcing*, *social*, and *geographic*) for accepting or rejecting volunteered contributions. Feick and Roche (2013) recognized that the quality of collaborative VGI datasets varied significantly among volunteered contributors and that it's complicated to assess data quality using standard measures

of accuracy and completeness. However, they argued that VGI is generally motivated by personal interests and local/experiential knowledge, which results in the creation of unique datasets that meet the needs and objectives of individuals and/or organizations. Thus, VGI can have the effect of building individual and community capacity (i.e., improved social networks) over short periods of time. Along these lines, Elwood et al. (2012) suggested that VGI data quality should be measured by the number of peers who have reviewed or edited its content.

Biochar proponents and practitioners cover a range of backgrounds and skill types that include: academic researchers, policy promoters, government agencies, non-profit/community organizations, humanitarian/aid organizations, farmers, and backyard enthusiasts. Those with an interest in reporting their biochar activities are typically professional and non-professional scientists. Many individuals and organizations involved in biochar research and practice would like to know: 1) what information is available on biochar projects, and 2) what activities are taking place in their area or region. Thus, a spatial database of biochar activities, site attributes, and documentation would help individuals and organizations search for projects that match their level of interest, expertise, and/or research needs.

2.2. Web Mapping Applications for Social and Environmental Monitoring

Web-GIS applications store and display georeferenced social and environmental data (collected by academics, professionals, citizen scientists, and volunteers) in an interactive mapping environment. Spatial data that is accessible through web-GIS apps can be viewed, edited and analyzed using open-source GIS software like QGIS and GRASS GIS, or proprietary software like Esri's ArcGIS Desktop and AGOL services.

2.2.1. Web-GIS Case Examples for Social and Environmental Monitoring

Hurliman et al. (2011) described a global database for mapping, control, and surveillance of neglected tropical diseases that involved the identification and authentication of geographic locations, prevalence study data, and literature relevant to a specific disease parasite, schistosomiasis. They reviewed multiple data sources for their ability to provide georeferenced, open-access information that can be queried to identify study locations, literary sources, and survey-specific attributes. The database and web-GIS app interface were designed so that administrators could: 1) enter and edit existing data, 2) mask confidential data as requested by authors, and 3) enable direct communication between researchers (Hurliman et al. 2011). Users can search records using different selection criteria (e.g., by country, document category, disease, and journal) and download records for research and monitoring purposes.

Another web-GIS app and database for mapping disease prevalence was developed by Wright (2017) as part of a global disease management strategy targeting the flea *Tunga penetrans*, which causes an epidermal parasitic skin disease called tungiasis. Wright's thesis titled "Web-GIS as a Disease Management Workspace: Enabling Advocacy at Multiple Scales Across Multiple Continents with the Case of Tungiasis" involved the development of two separate apps, the Chigoe Flea Eradication Project (CFEP) and the Tungiasis eLibrary. The overall objective of the web apps was to foster sharing of epidemiological data in support of international aid workers, non-governmental organizations (NGOs), and health professionals working to manage tungiasis on a global scale (Wright 2017).

The CFEP developed by Wright (2017) was designed to demonstrate the suitability of web-GIS as a collaborative workspace that uses VGI to monitor and control tungiasis, whereas the objective of the Tungiasis eLibrary was to create a general disease profile for tungiasis that could be used to define its spatial distribution and provide a World Health Organization policy

pathway for its classification as a neglected tropical disease. The Tungiasis eLibrary serves as a relational geodatabase for tungiasis-related journal articles that are displayed on a web map.

App users contribute georeferenced, peer-reviewed publications that they are asked to categorize by focus (e.g., epidemiology, public health, and medicine). Users contribute VGI in the form of their own, or others', published or unpublished work. Sources of unpublished literature include conference proceedings, government and NGO whitepapers, and spatial data. The CFEP allows community aid to track the provision of field surgeries, shoes, and medicine; record patient demographic data; and document the use of pesticides in sleeping shelters and communal areas. At a regional scale, aid groups involved in tungiasis prevention and education are invited to provide contact information and delineate their service boundary on a map using the CFEP web app interface (Wright 2017).

Web mapping tools have also been developed to display environmental data, including maps of soil-plant evapotranspiration and woodfuel resources. Masera et al. (2006) developed a spatially explicit method for assessing local wood energy supply and demand patterns using a variety of sources that include forestry, energy, and socio-economic information. The Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) application can display the spatial distribution of woodfuel consumption by fuel type, user category (e.g., household vs industrial) and type of demand. It can also be used to identify woodfuel priority areas—as a function of socio-cultural, technical, and environmental variables—where the demand/supply balance indicates an immediate or future deficit.

Baumann (2013) described GIS tools developed by eLEAF that use complex algorithms to calculate plant water requirements, soil moisture, and biomass production per pixel. The eLEAF model uses satellite imagery to calculate albedo, leaf area index, vegetation index, and

surface temperature. Model output is combined with meteorological data to create time-series maps of plant water use and biomass production. Combining these maps with land-use coverages can provide information about water and biomass availability by land-use class. ArcGIS Server and ArcGIS Online provide eLEAF data in multiple formats including Open Geospatial Consortium, Inc. (OGC), web services, and smartphone applications. In the future, output layers from WISDOM and eLEAF GIS tools could be integrated with the Biochar for Agriculture Mapping Tool (BfAMT) and biochar site suitability layers to help identify biochar priority areas.

Herrick et al. (2016) developed mobile applications for collecting spatio-temporal VGI that can be used to 1) monitor ecosystem health and land potential and 2) evaluate local trends in land degradation, resilience, and restoration. The Land Potential Knowledge System (i.e., Land PKS) suite of mobile apps were primarily developed to evaluate land production potential in Africa through the collection of local soil, vegetation, and landscape characteristics. Herrick et al. (2013) pointed out that recent advances in mobile phone and cloud computing technologies can help facilitate the integration of local and scientific knowledge when making land management decisions. According to Herrick et al. (2013), mobile apps can be used to record information about a site using drop-down menus, text-inputs, and picture matching.

Land PKS integrates simple, geo-tagged user inputs with data, information, and knowledge stored in the Cloud (Herrick et al. 2016). Locally-collected data can be integrated with global climate and soils databases and predictive models that can be used to generate point-specific estimates of land potential and make recommendations for food production and risk management. Users of Land PKS have different educational backgrounds (e.g., researchers, NGO workers, ag-extension agents, and farmers). Thus, some elements of Land PKS are language independent (i.e., icon- and video-based), while others require knowledge of plant

species and soil testing methods that are available through the app. Most Land PKS app elements require no special training thanks to picture-matching, drop-down menus, video explanations, and multiple-choice questions. User inputs are automatically uploaded from mobile phones to the Cloud when phones have access to data. According to Herrick et al. (2016), one of the most promising future applications of global Land PKS is the ability to rapidly share successful strategies with individuals managing land with similar potential.

2.2.2. Biochar and Spatial Analysis Case Example

Latawiec et al (2017) developed a multicriteria decision model (MCDM) to assess factors driving the successful application of biochar in temperate regions. Poland was used as a case study for overlaying spatial variables—specifically soil pH, organic matter, and texture, and trace metals (e.g., cadmium)—to identify potential areas for increasing agricultural productivity and mitigating soil contamination through the application of biochar. Soil acidity data was ranked and used to assign pH levels to soil polygons. The soil contamination layer (i.e. cadmium data layer) was derived using the Inverse Distance Weighted (IDW) interpolation method. A prioritization map was created by overlaying all soil layers in an ArcGIS environment and assigning ‘strong’ and ‘medium’ indicators to each soil variable. It should be noted that biomass availability was not included in the MCDM, although Latawiec et al (2017) stated a need to investigate whether Poland’s current biomass supply can meet future biochar production needs. Latawiec et al. (2017) concluded that their MCDM for identifying biochar site suitability represents a potential option for enhancing soil quality and agricultural productivity in Poland and could be applied to areas with similar physical and socio-economic conditions.

2.2.3. Biochar Database Case Example

An organized effort to characterize different biochars is being carried out at the University of California, Davis. The UC Davis Biochar Database website (<http://biochar.ucdavis.edu/>) states that there are many biochar suppliers producing unique biochars made from a variety of feedstock materials (UC Davis 2018). The purpose of the database is to generate knowledge about how biochar's chemical and physical properties impact its potential benefits. Major data types are classified into test categories (i.e., basic utility properties, toxic assessment, and advanced analysis of soil enhancement properties) based on the desired level of analysis. The open-access database allows registered users to enter biochar characterization data with options for selecting the biochar parameter, peer reviewed article type, and feedstock type, and plotting the results. Results are intended to aid end users when selecting biochars for specific applications. Although the data entry form includes a field for 'Geographic Region,' there is no field for geographic coordinates. A mapping application could help database users understand the socio-environmental context of individual biochar characterization efforts, and map feature symbology could be customized to help users visualize the types of biochar feedstock being tested locally and regionally.

2.2.4. Biochar Web-GIS Case Example

A web mapping application of biochar activities was recently published by the Finnish Biochar Association in Finland (Salo et al. 2018). The project website includes information about the five different categories used to symbolize the web map (i.e., *research organizations*, *biochar companies*, *finished projects*, *ongoing projects*, and *scientific research projects*). A web-based form (i.e., Google form) allows participants to report their biochar activities by defining their geographic location (i.e., city, neighborhood, and address), activity category, name/project

name, project description, area and amount of biochar applied, and additional information. Alternatively, participants can submit their information via e-mail. Presumably, a website administrator adds this information to the web map, which is continuously updated. Web page content states that there are biochar projects located in 30 different Finnish municipalities and cities and that the majority are related to biochar-based solutions for stormwater and runoff management, planting trees in urban areas, and improving the quality of water bodies through nutrient management. The web map, which runs on the Google maps platform, does not allow direct user input. However, it is possible to toggle (i.e., turn on and off) each activity category on the map because each category has its own layer. Also, each individual site is listed under its map layer category and zooming to individual sites is possible when the site name is clicked.

Chapter 3 Application Development

The Biochar for Agriculture Mapping Tool (BfAMT), which consists of a mobile data collection app integrated with a stand-alone web-GIS app, was designed to meet three major objectives: 1) enable users to document their biochar research and project activities using editable map feature services that are designed to represent the actors, projects, technologies, methods, and variables of the biochar community, 2) facilitate the visualization and exploration of VGI, and 3) promote coordination among biochar users to share information and identify best practices. The BfAMT name was chosen because biochar is primarily produced and applied as a soil amendment, with the purpose of reducing GHG emissions and improving soil fertility (IBI 2018).

Research institutions, government agencies, non-profit organizations, community organizations, international NGOs, and individual biochar enthusiasts were invited to upload and edit their biochar site information (i.e., spatial and non-spatial attributes) using two different applications: 1) Esri's Collector for ArcGIS mobile app, and 2) the BfAMT web-GIS app that was created with Esri's Web App Builder (WAB). Users of the BfAMT mobile and web apps were encouraged to upload their own photos, videos, literature and project data (published or unpublished). User-generated content (i.e., VGI) will support the development of a biochar-centric database that contains project information in the form of point feature attribute data, document files, and links to outside resources.

The BfAMT web-GIS app provides a shared workspace and template for biochar researchers and enthusiasts who want to contribute spatial data and project information to a central location (i.e., enterprise geodatabase). The spatial scale of the BfAMT is global and encompasses most temperate and tropical regions. Temporally, most biochar-related research and experimentation began circa 2006 with the study of *Terra Preta de Indio* soils, or *Amazonian*

Dark Earths (ADE), and continues into the present. ADE soils are classified as Pretic Anthrosols by the World Reference Base for Soil Resources (WRB) (2014). According to the WRB (2014, 147), Anthrosols have been heavily modified by human activities like the “addition of organic or mineral matter, charcoals or household wastes, or irrigation and cultivation”. According to the WRB (2014, 6, 13), a pretic horizon is a mineral surface horizon having the following characteristics: 1) dark in color, 2) high content of organic matter and phosphorous (P), 3) high content of exchangeable calcium (Ca) and magnesium (Mg) and 4) man-made charcoal residues and/or artefacts of human occupation like ceramics, lithics, and bone or shell tools. In the Amazon Basin, pretic soils are well-distributed and have persisted over several centuries despite high organic matter mineralization rates that are characteristic of tropical environments (World Reference Base for Soil Resources 2014).

Thus, the BfAMT database’s continued development will depend on VGI to expand the scope of biochar project information available for searching and visualization. Ultimately, the BfAMT’s web-based platform will help create a centralized body of information that promotes sharing, connectivity, and coordination within the biochar community. Such a platform could help define biochar’s ability to serve as a climate change mitigation and adaptation strategy for addressing the impacts of human-induced global warming.

3.1. Application Development Steps and Workflow

3.1.1. Application Development Steps

Application development of the BfAMT included several steps:

- Create an enterprise-level geodatabase using the ArcMap 10.6 ‘Create Enterprise Geodatabase’ tool to establish a connection with ArcGIS Server’s SQL Server platform. Spatial and non-spatial attribute data are stored within a relational database management

system (RDBMS) capable of: 1) maintaining entity relationships among attribute tables and 2) storing photo and file attachments.

- Create a point feature class with coded attribute domains and text fields in ArcMap 10.6. Publish a map feature service layer to AGOL to be used in connection with the Collector for ArcGIS mobile app and the BfAMT web-GIS app. Create an AGOL account called “Bio Char” to allow guest users to beta test the Collector for ArcGIS mobile app.
- Use Esri’s Web App Builder (WAB) to create a web-GIS application with help options, customized user interface, and out-of-box app functions (i.e., widgets) to aid users in navigating the interface, exploring the web map, uploading VGI, querying attribute data, and exporting site records as Excel comma separated value (CSV) files.
- Use HTML5, Javascript, and CSS programming languages—and Adobe Dreamweaver software (part of Adobe’s Create Cloud’s software-as-a-service)—to develop a basic web page with embedded links, help graphics, video tutorials, and the BfAMT web-GIS app itself. The BfAMT project website is hosted on the University of Southern California’s Spatial Sciences Institute Server.

3.1.2. Application Workflow

A flowchart for implementing the BfAMT web app and integrating it with the Collector for ArcGIS mobile app is presented in Figure 3 below.

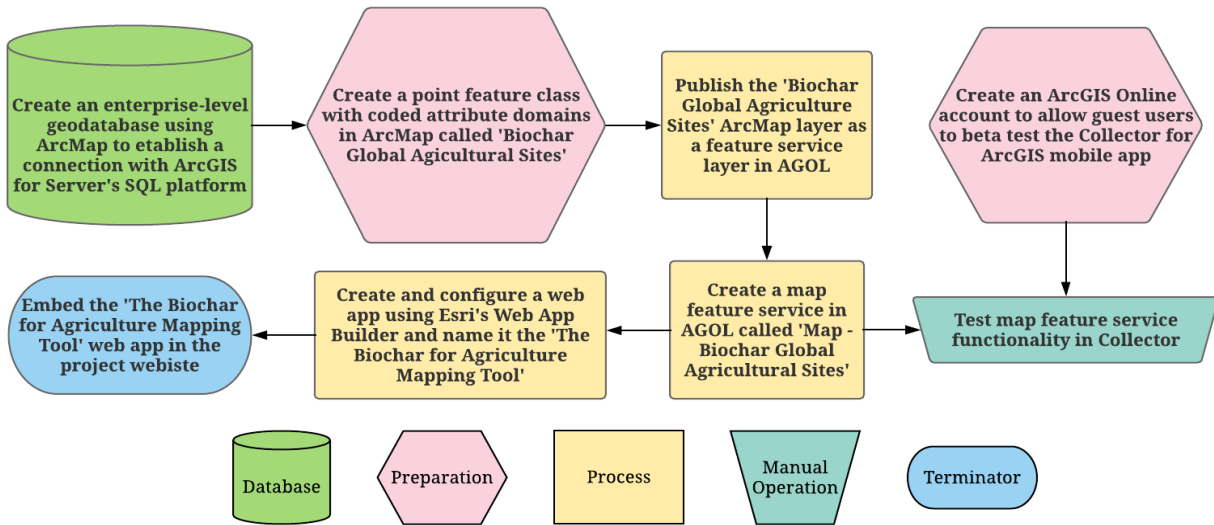


Figure 3. Workflow for implementing the BfAMT web app and integrating it with the Collector for ArcGIS mobile app

3.2. User Requirements

Targeted users of the BfAMT are academic researchers, agronomists, waste managers, environmental engineers, government agencies, international NGOs, biochar policy developers and promoters, commercial biochar producers, non-profit organizations, community organizations, farmers, and others biochar enthusiasts who are interested in research, experimentation, best practices, extension/outreach, policy development, and the advancement of biochar technology. Major areas of biochar research and experimentation include its 1) production and processing methods, 2) agricultural applications for food/fiber/fuel production, 3) waste/resource management applications for farms, forests, and urban environments, 4) potential for the remediation of toxic substances, wastewater treatment, stormwater management, etc., 5) economic and environmental viability as a soil amendment, renewable energy source, building/packaging material, etc., and 6) potential for carbon sequestration and climate change mitigation/adaptation.

Beta-testers were expected to possess intermediate computer and smart phone skills to help them navigate the BfAMT web and mobile apps. For users to access Esri's Collector for ArcGIS mobile app, they were required to have an authorized ArcGIS Online account. For this thesis project, a general use ArcGIS Online account was set up by the USC Spatial Science Institute (SSI) Server Administrator. The name for this account is "Bio Char". A login and password were created for the "Bio Char" account and distributed to those individuals who expressed interest in beta-testing the BfAMT. Beta-testers with iPhones (i.e., the iOS platform), who were familiar with downloading apps to their smart phones, were encouraged to download the Collector for ArcGIS mobile app using the Apple App Store, Google Play, Amazon App Store, or Microsoft Windows Apps and typing "Collector for ArcGIS" into the app store search window. Beta-testers with Android phones (i.e., the Android platform) were warned that the Collector mobile app might not work on their device (see Section 3.3. below).

3.3. Software

Esri's ArcMap version 10.6 is the proprietary GIS software used to create maps, register and implement an enterprise-level geodatabase, and establish a geodatabase connection to ArcGIS Server 10.4 using SQL Management Studio 2012. Although there are open-source GIS software options like GRASS GIS and QGIS, the author's knowledge of ArcGIS Desktop, its fundamental role in GIS, and the ease with which it can be used in conjunction with AGOL to publish and share map feature services were determining factors for choosing ArcGIS products and services to customize and implement the BfAMT mobile and web-GIS apps.

The software used to customize the BfAMT web-GIS app was Esri's Web App Builder (WAB); available through ArcGIS Online's software-as-a-service (SAAS). The current version of Esri's WAB is Kernel Version 2.10 in ArcGIS Online 6.3. Esri's WAB is a graphical

programming interface that allows users without code-writing skills to build 2D and 3D web apps that run on any device (Esri Web App Builder 2018). WAB's configurable themes and ready-to-use, out-of-the-box widgets make it easy for developers to customize the appearance and functionality of web-GIS apps. Esri's WAB was chosen over other open-source options such as Leaflet and Github's Customizable Map Viewer (CMV) because of its easy integration with Esri's ArcGIS Desktop and AGOL services.

Esri's Collector for ArcGIS mobile app, hereafter referred to as Collector, was integrated with the BfAMT web-GIS app to facilitate data collection in remote locations. The integration of Collector with the BfAMT web app necessitated the creation of an enterprise-level geodatabase because it is not possible to create a feature service from data residing in a file geodatabase (Esri Collector Discussion-1 2018). Collector was configured by creating a feature layer with coded attribute domains in ArcMap 10.6 and publishing it as a map feature service to AGOL.

The Collector mobile app can be used to upload point coordinates, site attributes, photos, and text files to the BfAMT web app, which is accessed in an Internet browser. The benefits of using Collector in conjunction with the BfAMT web app include: 1) uploading point features to the web app without a desktop computer, and 2) offline data collection capabilities in locations where cellular service is longer available, but where GPS services are still active. Data waypoints (i.e., point locations) collected offline with Collector can later be accessed and used to collect and upload attribute data when cellular service becomes available.

According to Esri's Collector website, these are the current requirements for mobile phones that can successfully implement the Collector app (Esri Collector Requirements 2018):

Android

- Android 4.2 (Jelly Bean) or later
- Processor: ARMv7 or later, or x86
- OpenGL ES 2.0 support
- Precise location (GPS and network-based) support

iOS

- iOS 8 or later
- iPhone, iPad, iPod touch

Windows 10 (tablet and PC)

- Version 1511 or later
- Long-Term Servicing Branch (LTSB) version 1607 or later

One current limitation to using Esri's Collector at local and global scales is that the latest versions of Collector require trusted certificates to access ArcGIS Server services in ArcGIS Online (ESRI Collector Discussion-2 2018). According to information posted on the Esri Collector Discussion website, this appears to have affected only Android smart phones, while iPhones and Windows devices (i.e., tablets) are unaffected. When connecting to Collector on an Android device with the pre-Android 6.0 operating system, the following message is displayed: "The server you are trying to connect to cannot be verified". This limitation is significant when considering that the Android operating system is estimated to own 88% of the global mobile operating system market share (Statista 2018). However, an announcement on October 29, 2018 claims that this issue (i.e., BUG – 000109667) has been fixed in Collector for ArcGIS (Android) 18.0.3. The announcement extends an invitation to beta-test Collector on the updated Android platform (Esri Collector Android 2018).

Adobe Dreamweaver, part of Adobe’s Creative Cloud suite of SAAS software, was used to design a web page to host the BfAMT web-GIS app. Dreamweaver was chosen over free web editors because it included help tutorials and file transfer protocol (FTP) client capability. Web page development involved the use of hypertext markup language (HTML), Javascript, and cascading style sheets (CSS) to format and juxtapose background information, links, photos, and videos; and embed the BfAMT web app.

3.4. Publishing Feature Services

Steps to publishing map and web feature services to the USC SSI ArcGIS Server:

- 1) Open an ArcMap 10.6 MXD file. Add a feature class layer to the map that is projected in the Web Mercator Auxiliary Sphere projection
- 2) Select File > Share As > Service > Publish a Service
- 3) Create an ArcGIS Server connection for hosting the feature service
- 4) Create an ArcGIS Server folder to publish the service
- 5) In the ‘Service Editor’ window, click the ‘Capabilities’ tab and check the ‘WMS’ and ‘WFS’ boxes to allow users to access the map via other applications and devices. Also select ‘Feature Access’ to allow web editing of map features. Under the ‘Mapping’ sub-tab, feature service operations for “Data”, “Map”, and “Query” are enabled by default. “Query” assures that map data can be downloaded even if attribute fields are turned off. In the ‘Feature Access’ sub-tab, feature service operations for “Create”, “Delete”, and “Update” are enabled by default. Disabling “Delete” would prevent the deletion of map features by users, although they could still edit features. This is a useful control for preventing the accidental or purposeful deletion of features services that are shared with

the public. Note: In WAB, the ‘Edit’ widget’s custom settings can be used to disable layer settings like “Add”, “Delete”, and “Update Geometry” to prevent public tampering.

- 6) Enter feature service information using the ‘Item Description’ tab
- 7) Click the ‘Share’ tab to specify who the feature service will be shared with
- 8) Click ‘Analyze’ to determine if any actions must be taken before the map document can be published. Resolve any errors that appear in the ‘Prepare’ window. Note: Feature layer basemaps cannot be published because basemap service is accessed through AGOL.
- 9) Once medium and/or high severity errors have been resolved, click ‘Publish’

3.5. Web Services

After a feature service is published to AGOL via the ArcGIS Server connection, representation state transfer (REST) service endpoints that use hypertext transfer protocol (HTTP) are called by the BfAMT web app when data is requested. REST services consist of browser-cached uniform resource identifiers (URIs) that link the web app to a network location where data is stored and delivered as web map services (WMS) or web feature services (WFS). WMS and WFS are Open Geospatial Consortium (OGC) interface standards that deliver maps and data in response to a user request (Jones and Purves 2008).

Usage limitations (i.e., credit usage) do not pertain to the BfAMT web app because web app data are hosted on the USC SSI Server and not AGOL. Thus, accessing data, using AGOL basemaps, exporting data, and searching for a single address do not consume credits. Although WAB geoprocessing functions—such as those available in the ‘Analysis’ widget—do consume credits, these were not included in the design and functionality of the BfAMT web app.

3.6. Platform

As previously mentioned, Esri's proprietary Collector mobile app (with configured feature service layer) integrated with a stand-alone web-GIS app (customized with Esri's WAB) was used as the platform for the BfAMT. The Collector mobile app was included as part of the BfAMT workflow to 1) allow those in the biochar community working in remote locations to upload and access their biochar site information, and 2) allow mobile app users to identify and access biochar site information generated by others around the world. The BfAMT mobile and web apps are intended for a global audience because biochar projects are being carried out across a wide range of climatic, environmental, socio-economic, and technological conditions.

3.7. User Input

The BfAMT geodatabase provides a centralized location for biochar-related projects, whether focused on waste/resource management, energy production, land remediation and restoration, climate change adaptation, or agricultural production. Input data for the BfAMT consists predominantly of VGI. App users are asked to 1) define their location as a point feature, 2) enter site attributes, and 3) upload supporting documentation such as photos, videos, and text files (e.g., spreadsheets, word processing documents, and PDF files).

Attribute fields and values for the database were chosen to encompass biochar projects with a land management or agricultural focus, although there are options for describing other types of biochar projects. These include: 1) descriptive text fields and 2) attachment capability for uploading documents. Both options serve to contextualize and enhance biochar site attributes that were collected using map-driven forms. Table 1 below lists the names of the coded attribute domains and text fields of the BfAMT. Tables of BfAMT attributes and their coded values are presented in Appendix A.

Table 1. BfAMT coded attribute domains and text fields

| Coded Attribute Domains | Text Fields | Length |
|--------------------------------------|--|---------------|
| Organization Type or Individual | Name of Individual or Organization (Optional) | 150 |
| Country Name | Contact Information (Optional) | 150 |
| Primary Biochar Project Type | Other Country (Optional) | 100 |
| Biochar Site Type | Other Biochar Project Type (Optional) | 150 |
| Primary Biochar Cropping System | Other Biochar Site Type (Optional) | 150 |
| Biochar Project Timeline | Primary Crop Species (Optional) | 150 |
| Type of Biochar Production Device | Specific Biochar Production Device (Optional) | 150 |
| Biochar Feedstock Source | Specific Feedstock Source (Optional) | 150 |
| Type of Biochar Feedstock | Specific Feedstock Type (Optional) | 150 |
| Method for Quenching Biochar | Specific Biochar Fertilization Method (Optional) | 150 |
| Method for Pulverizing Biochar | Specific Biochar Application Method (Optional) | 150 |
| Primary Biochar Quality Test | Other Research Trial Design (Optional) | 150 |
| Primary Biochar Fertilization Method | Additional Project Notes (Optional) | 255 |
| Biochar Soil Application Method | Soil pH Value (Optional) | 50 |
| Biochar Soil Application Rate | Biochar pH Value (Optional) | 50 |
| Biochar Research Trial Design | Percent Ash in Biochar (Optional) | 50 |
| Soil Properties Measured | Percent Volatile Carbon in Biochar (Optional) | 50 |
| Soil Texture Class | Percent Labile Carbon in Biochar (Optional) | 50 |
| Biochar Properties Measured | Percent Fixed Carbon in Biochar (Optional) | 50 |

The coded attribute domain values and text fields of the BfAMT are included in the entity-relationship diagram (ERD) in Figure 4 below. This E-R diagram represents the current BfAMT enterprise geodatabase design. Although the BfAMT enterprise geodatabase has RDBMS capability, there is currently only one feature class and attribute table. Because no entity (i.e. table/object) relationships are represented, the design is flat file. However, by enabling attachment capability for the geodatabase, a separate SQL table was generated. Thus, feature attachments constitute the sole entity relationship with the BfAMT attribute table. In Figure 4 below, coded domains are displayed as tables of coded values rather than entities. In contrast, the ‘BfAMT ATTACHMENT’ table is displayed as an entity.

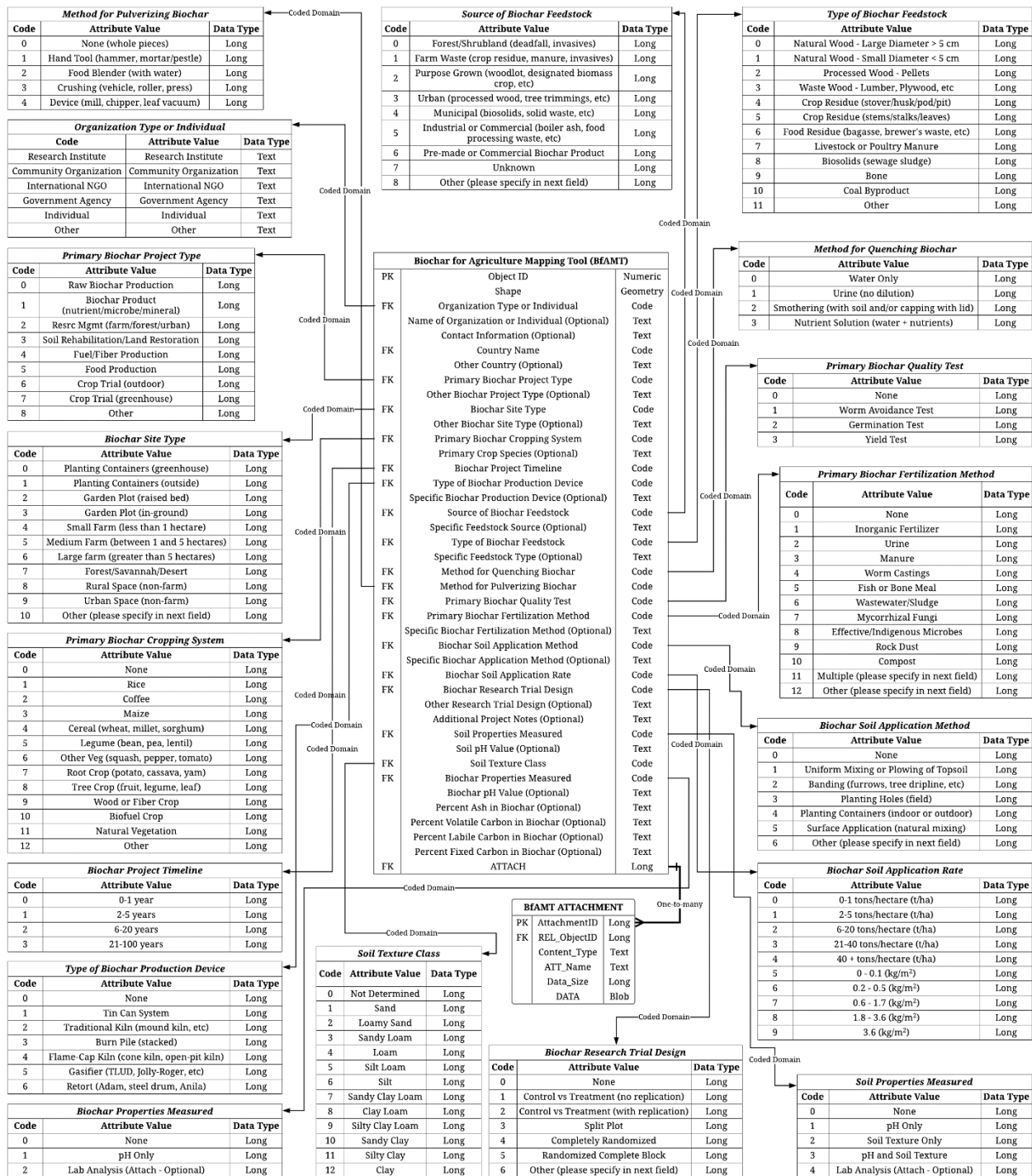


Figure 4. Entity-Relationship Diagram of the BfAMT enterprise geodatabase. Coded domains are displayed as tables of coded values rather than entities. In contrast, the 'BfAMT Attachment' table is displayed as an entity

3.8. Application Outputs

The BfAMT web-GIS app provides options for 1) selecting an area of interest, 2) querying map features, 3) summarizing and exploring query results, and 4) and exporting selected records as Microsoft Excel CSV files. Output records can be limited by the map extent, a selected area of interest drawn on the map, or a map filter or search query. BfAMT output examples are presented in Chapter 4 below.

Chapter 4 Results

Chapter 4 presents the content of the BfAMT website, which contains links and help resources for the Collector mobile application and BfAMT web-GIS application. Also included in Chapter 4 are user scenarios and output for the mobile and web apps.

Uniform resource locators (URLs), or web addresses, for the BfAMT web page and web-GIS application are presented in Table 2 below.

Table 2. BfAMT web app and web page URLs

| |
|--|
| BfAMT Web Page URL: https://tinyurl.com/y9maodr (Accessed Dec 27, 2018) |
| BfAMT Web-GIS Application URL: https://bit.ly/2QVDfk5 (Accessed Dec 27, 2018) |

4.1. Web Page for the BfAMT

The content of the BfAMT web page includes 1) a short summary of the tool's capability and intended audience, including a web app screenshot, 2) a link to the USC SSI URL in ArcGIS.com that hosts the web-GIS app, 3) a link to the Google survey questionnaire, 4) embedded video tutorials for using the Collector mobile app and BfAMT web app, 5) a help graphic for the BfAMT web app interface, 6) help instructions for using the BfAMT's web app interface and map tools (i.e., widgets), and 7) the embedded BfAMT web app itself. Figure 5 below shows the BfAMT web page heading, summary description, and web app screenshot, and Figure 6 below shows hyperlinks links to the BfAMT web app and online survey questionnaire, and the beginning of the video tutorial section.

Biochar for Agriculture Mapping Tool

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Summary

The Biochar for Agriculture Mapping Tool is a web mapping application that displays locational attributes (i.e. spatial data) and information for agricultural projects amended with biochar, or carbonized biomass. It relies on Geographic Information System (GIS) technology to maintain a connection between the Collector for ArcGIS mobile app, the interactive web map, and the server where the data is stored.

The Biochar for Agriculture Mapping Tool is designed as an editable map feature service that allows research institutions, government agencies, non-governmental organizations (NGOs), community organizations, and individuals (e.g., farmers, gardeners, and biochar enthusiasts) to upload and edit their biochar project information. The Biochar for Agriculture Mapping Tool web app enables 1) geographic visualization and identification of biochar experimental sites, 2) search and download options, and 3) sharing and connectivity within the biochar community.

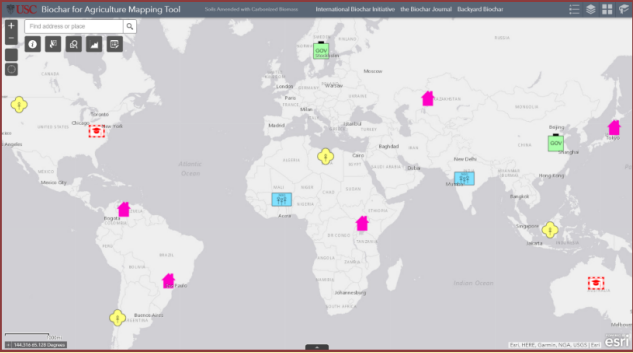


Figure 5. BfAMT web page showing heading, summary description, and web app screenshot

Link to the Biochar for Agriculture Mapping Tool

The link below will take you to the Biochar for Agriculture Mapping Tool web-GIS application. The web-GIS app is also embedded at the bottom of the current web page (scroll down past the video tutorials and help instructions graphics). **IMPORTANT** - Please return to this web page after you have tested mobile and web apps to complete the Google survey questionnaire. Your participation is crucial to the success of this research project.

[The Biochar for Agriculture Mapping Tool \(Web-GIS App\)](#)

Survey Questionnaire

After you have used the Collector for ArcGIS mobile app and/or the Biochar for Agriculture Mapping Tool web app to add your biochar site information and explore the web map, please complete this voluntary questionnaire. Your feedback is very important to improving the interface and functionality of the web app, so please take the time to respond to these short-answer questions. Thank you!

[Questionnaire - Biochar for Agriculture Mapping Tool](#)

Video Tutorials

Watch a 5-minute video tutorial for using Esri's ArcGIS Collector mobile app to collect and edit geographic information about your biochar agricultural site.

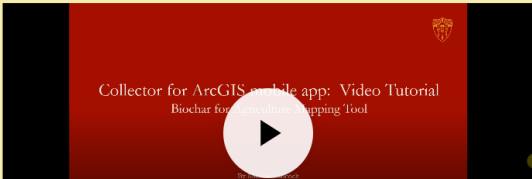


Figure 6. BfAMT web page showing hyperlinks to the BfAMT web app and online survey questionnaire, and the beginning of the video tutorial section

4.2. BfAMT Mobile and Web App User Scenarios

User scenarios for the Collector mobile app and BfAMT web app are presented in this section. Collector mobile app graphics demonstrate how to collect, edit, add photo attachments, and upload point features to the web map, while BfAMT web app graphics demonstrate widget functionality and how to export selected site records.

4.2.1. Esri's Collector for ArcGIS Mobile App

Figures 7-11 below are Collector screenshots for online data collection, editing, and submission. Additional Collector help graphics for navigating the mobile app interface and collecting data offline are presented in Appendix B. Figure 7 below shows automated feature point collection in Collector using the 'My Location' button.

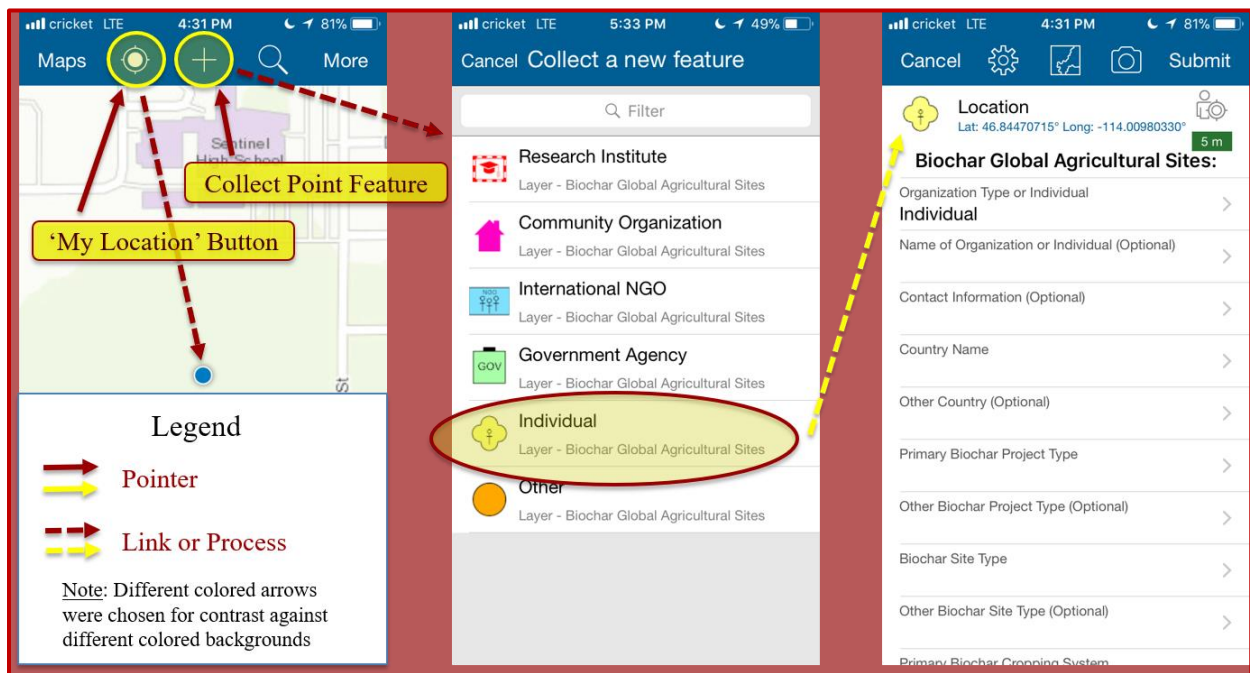


Figure 7. Automated point feature collection in Collector

Figure 8 below shows how to add a point feature manually in Collector using a smart phone touch screen, and Figure 9 below shows how to collect point feature attribute data.

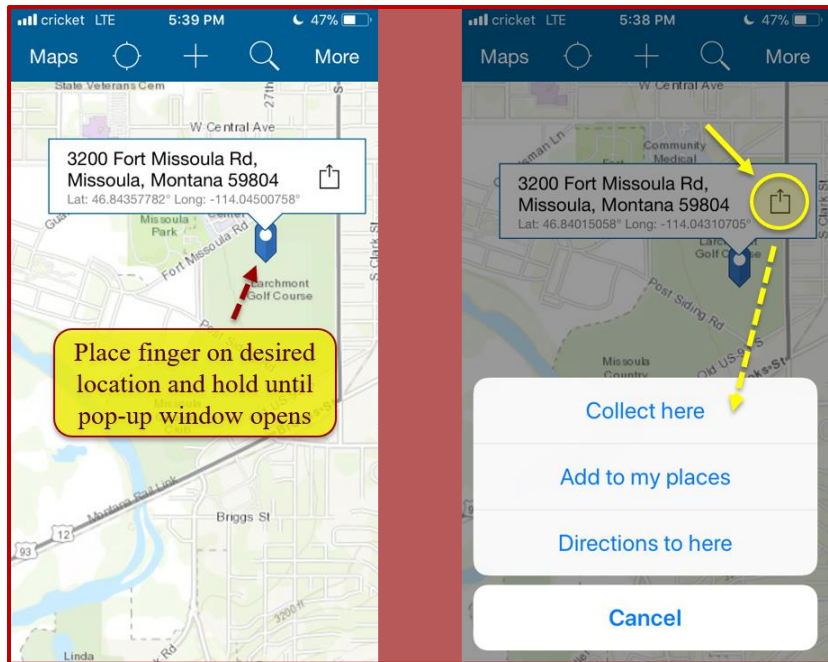


Figure 8. Manual point feature collection in Collector

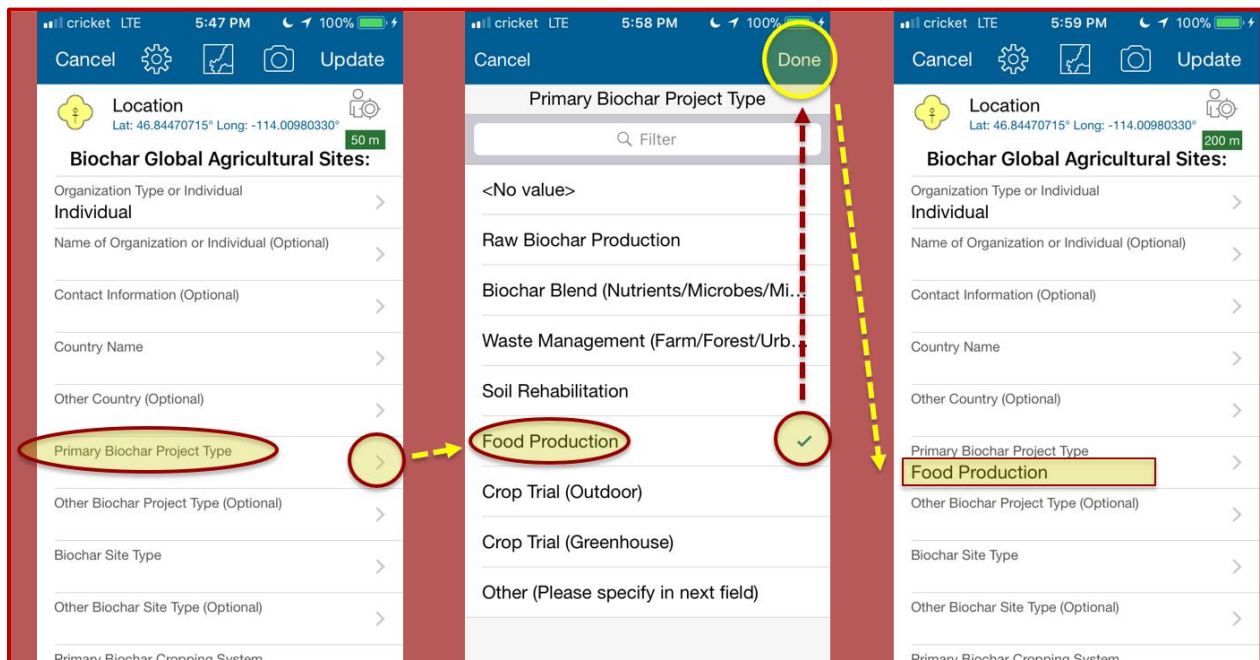


Figure 9. Collection of point feature attribute domain data in Collector

Figure 10 below shows how to use Collector to submit point feature attribute data and change the basemap.

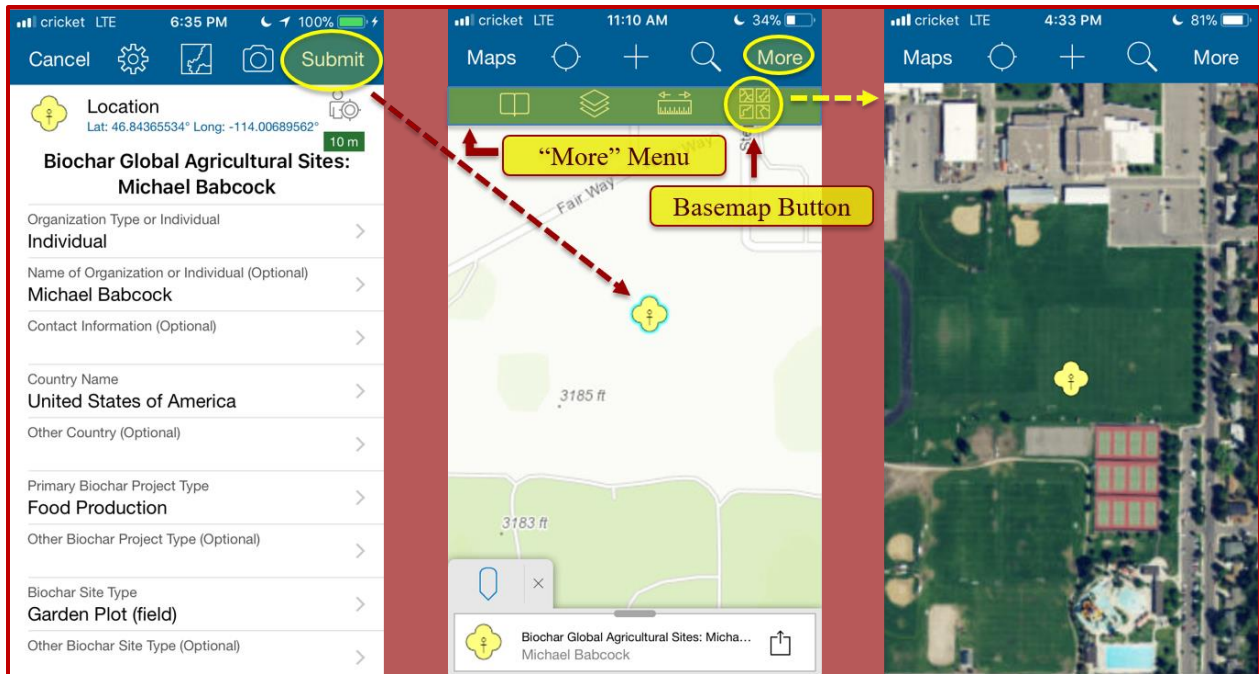


Figure 10. Point feature attribute data submission and basemap selection in Collector

Figure 11 below shows how to use Collector to edit point feature attributes and attach photos.

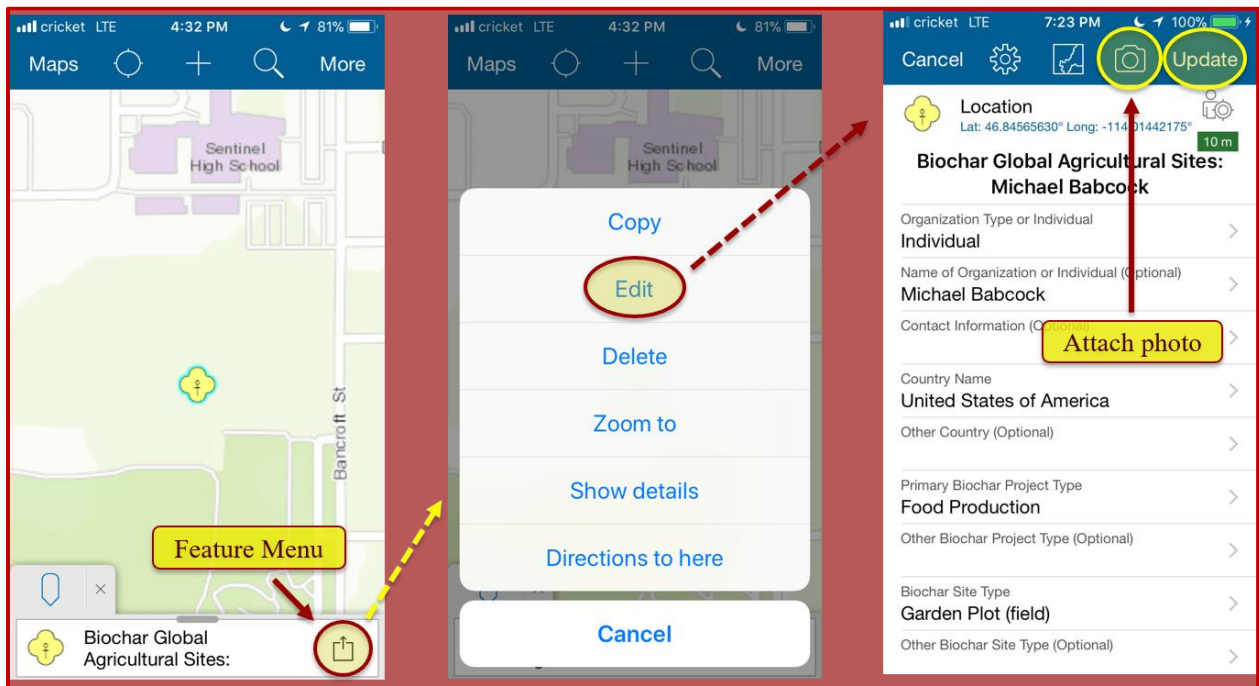


Figure 11. Editing point feature attributes and attaching photos in Collector

4.2.2. The Biochar for Agriculture Mapping Tool Web-GIS App

Figures 12-17 below are BfAMT web app help graphics for 1) navigating the user interface, 2) using WAB widgets to create point features and explore the web map's dataset, and 3) exporting site records using the 'Attribute Table'.

Figure 12 below displays the widgets and features of the BfAMT web app interface, which are labeled for easy identification.



Figure 12. BfAMT web app interface help graphic

The 'Foldable Theme' template in WAB was chosen for the BfAMT web app interface because of its clear layout and five space holders designated for widgets. The top of the map frame was configured with the USC logo (far left), a title (i.e., Biochar for Agriculture Mapping Tool), and web links to the *International Biochar Initiative*, the *Biochar Journal*, and *Backyard Biochar*. Widgets, or map tools, are in the top left of the screen under the address bar, and in the top right of the screen along the map frame's border. The five widgets in the top left are 'Help

Instructions’ (red), ‘Select Biochar Sites’ (light orange), ‘Search Biochar Sites’ (pink), ‘Chart Tool’ (green), and ‘Contribute Data’ (blue). The ‘Help Instructions’ widget contains detailed instructions about BfAMT web app features and widgets. Help instructions for the BfAMT web app can also be found in Appendix C. The four widgets located in the top right of the map frame are the ‘Legend’ (light pink), ‘Layer List’ (baby blue), ‘Basemap Gallery’ (yellow), and ‘Bookmark’ (light grey) widgets. The ‘Bookmark’ widget contains preset map regions for quick zooming. BfAMT web app widgets were chosen from the suite of widgets in WAB based on their relevance to basic web map functionality and to facilitate the visualization and exploration of attributes contained in the database of biochar agricultural sites. Some widgets were renamed (e.g., ‘Select’ widget renamed ‘Select Biochar Sites’, ‘Query’ widget renamed ‘Search Biochar Sites’, and ‘Edit’ widget renamed ‘Contribute Data’) for easier recognition by users of the BfAMT web app.

A graphic describing how to use the ‘Contribute Data’ widget to add point features to the web map is presented in Figure 13 below. Clicking on the ‘Contribute Data’ widget opens a pop-up window with a point feature template. The symbology of the template is also visible in the ‘Legend’ widget pop-up. The *Organization Type or Individual* coded attribute domain was chosen to symbolize point features because it serves to distinguish between different types of biochar users. Point marker symbols for *Organization Type or Individual* were selected from the available character marker symbols in ArcMap 10.6.

Once a point feature symbol has been selected and becomes highlighted in the ‘Contribute Data’ pop-up window, one can click on the map to add the point feature at its desired location (see Figure 13 below). To add a point feature to a precise location on the web map, one enters decimal degree coordinates (i.e., latitude decimal degree, longitude decimal degree) into

the 'Search' bar, located in the top left of the map frame, then clicks the search icon or hits enter on the keyboard.

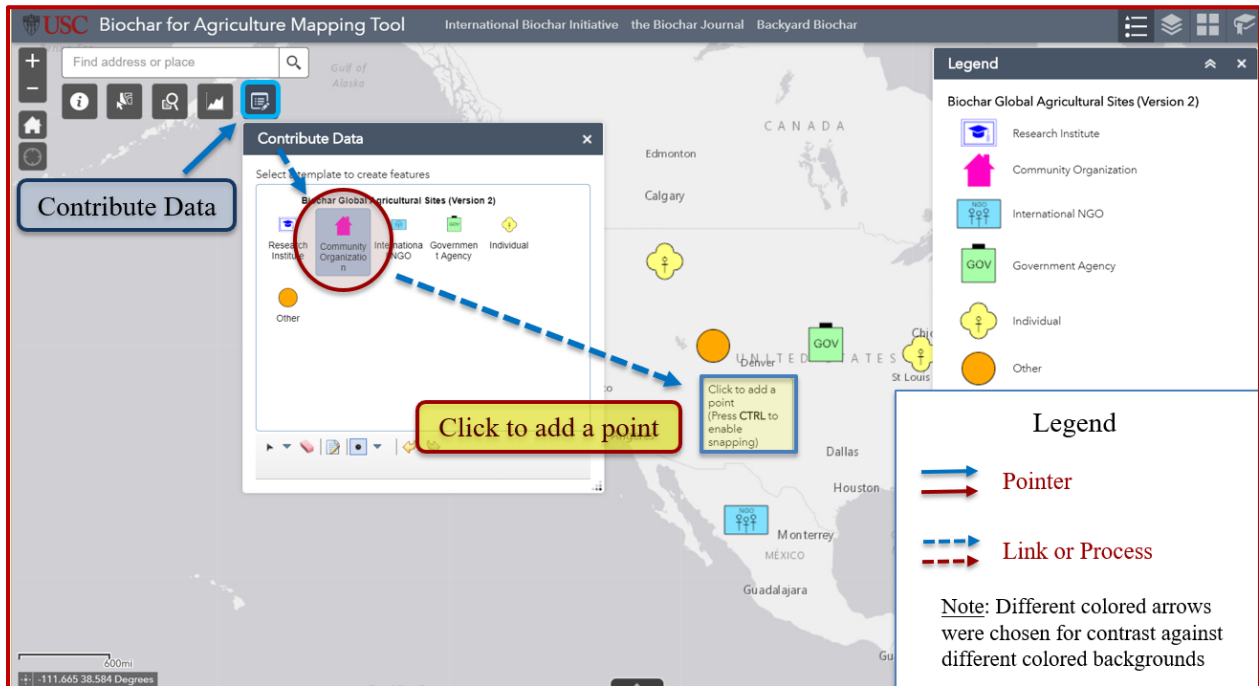


Figure 13. BfAMT 'Contribute Data' widget for adding point features

Once a point feature has been placed at its desired location on the map, a feature pop-up window will appear with attribute fields for data collection (see Figure 14 below). In Figure 14, the *Source of Biochar Feedstock* drop-down menu is active.

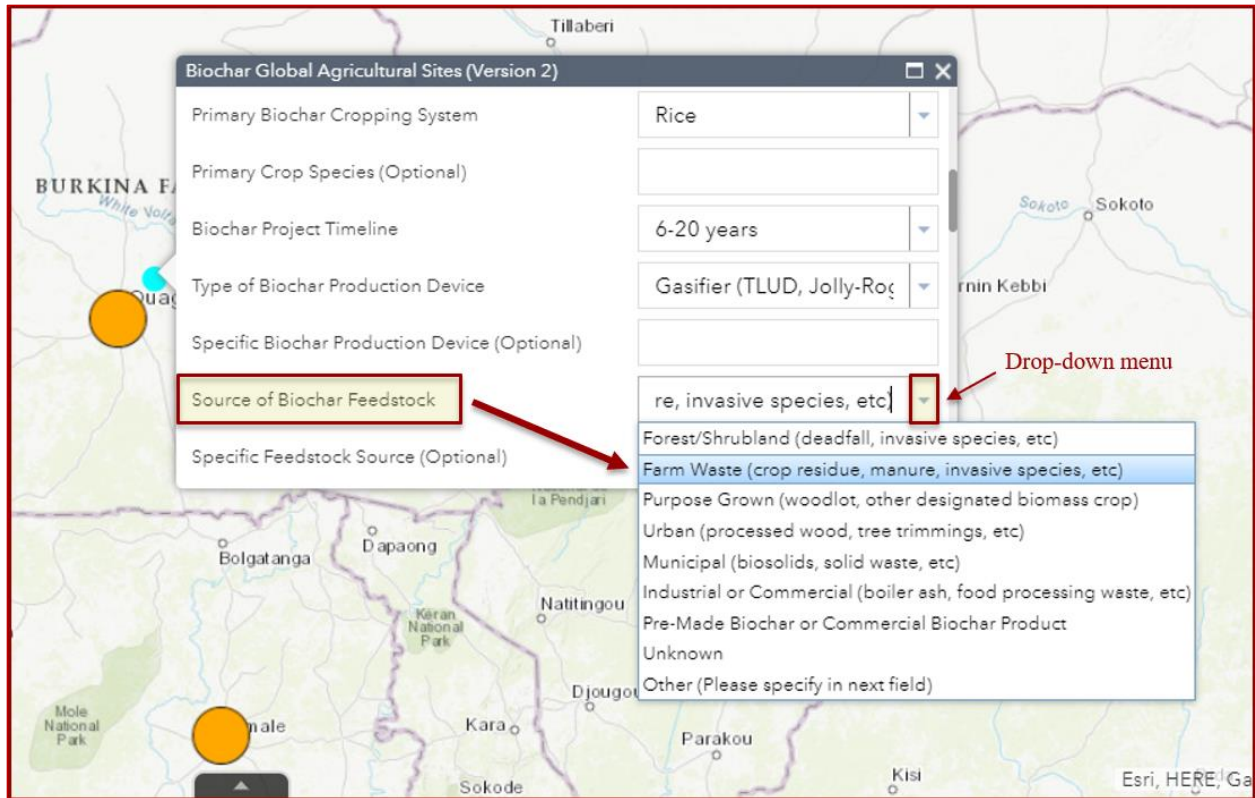


Figure 14. BfAMT feature pop-up window with attribute fields and active drop-down menu

The ‘Chart Tool’ widget (see Figure 15 below) has preset chart options for summarizing biochar site attributes. Upon opening the ‘Chart Tool’, there are three preset chart tasks for summarizing 1) *Biochar Project Type*, 2) *Biochar Cropping System*, and 3) *Biochar Production Device*. In Figure 15, the *Biochar Cropping System* chart task was selected. Pie chart results were generated based on the entire dataset (i.e., full map extent), although a spatial filter can be applied that will limit results to the current map extent, or an area defined by the drawing tool. The pie chart in Figure 15 displays the count total and percent for each attribute value as the cursor is moved over individual pie slices. Hovering over the ‘Coffee’ pie slice with the cursor highlights coffee production sites on the web map in a red square. Double-clicking the ‘Coffee’ pie slice zooms the map to the area encompassing coffee production sites.

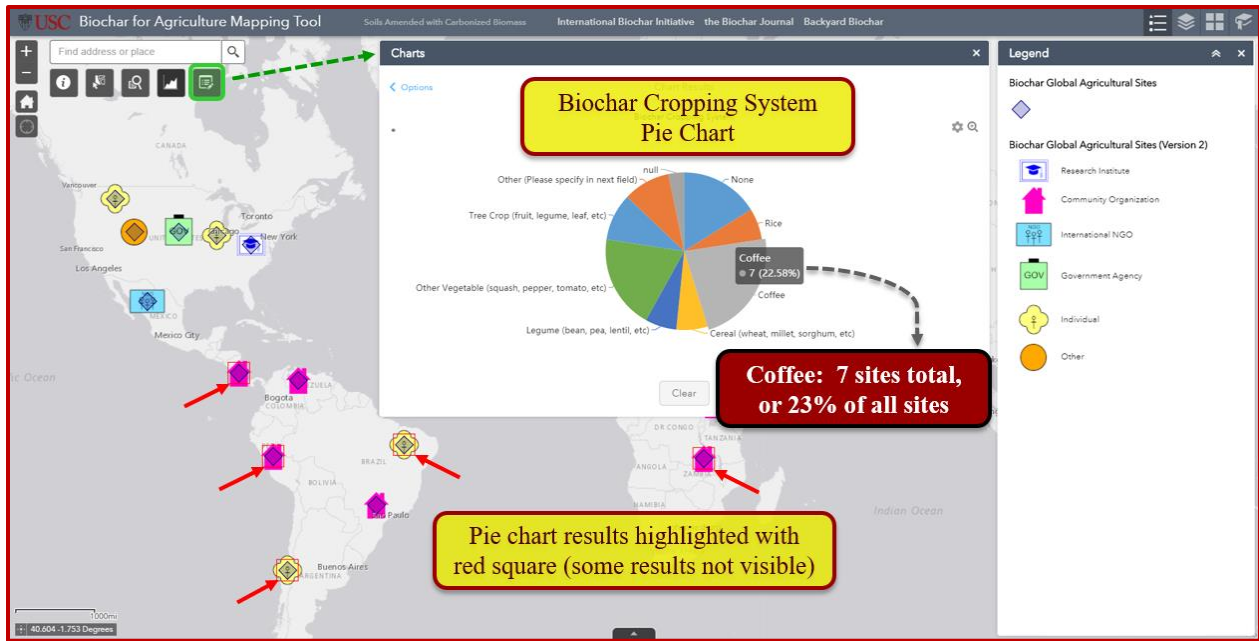


Figure 15. BfAMT ‘Chart Tool widget’ showing biochar cropping system pie chart results and coffee production sites

The ‘Search Biochar Sites’ widget contains three preset queries for displaying specific biochar site attributes. These preset queries are listed under the ‘Search’ tab and include queries for 1) *Coffee Growers* – to identify biochar sites with coffee as the primary cropping system, 2) *Resource Management (Farm/Forest/Urban)* – to identify biochar projects focused on resource management, and 3) *Biochar Feedstock (Crop Residue)* – to identify projects that use crop residue to make biochar. After clicking on a search task, results are highlighted with a pin marker. A customized pop-up window also appears with a list of results (see Figure 16 below).

Search results in Figure 16 below are generated based on the map’s current extent. Thus, to search a different area or region, zoom in (or out) and run the ‘Search Biochar Sites’ widget again. Results generated by running search tasks can be zoomed to, or viewed in the ‘Attribute Table,’ using the ‘three-dot-menu (...)’ of the ‘Search Biochar Sites’ pop-up window. Search results appear as a tab in the ‘Attribute Table’ and as a layer in the ‘Layer List’ widget until the tab is closed. The search results layer can be toggled on or off using the ‘Layer List.’ The process

of exporting search results as an Excel CSV file is explained below in the ‘Select Biochar Sites’ widget description and Figure 17 (next page).

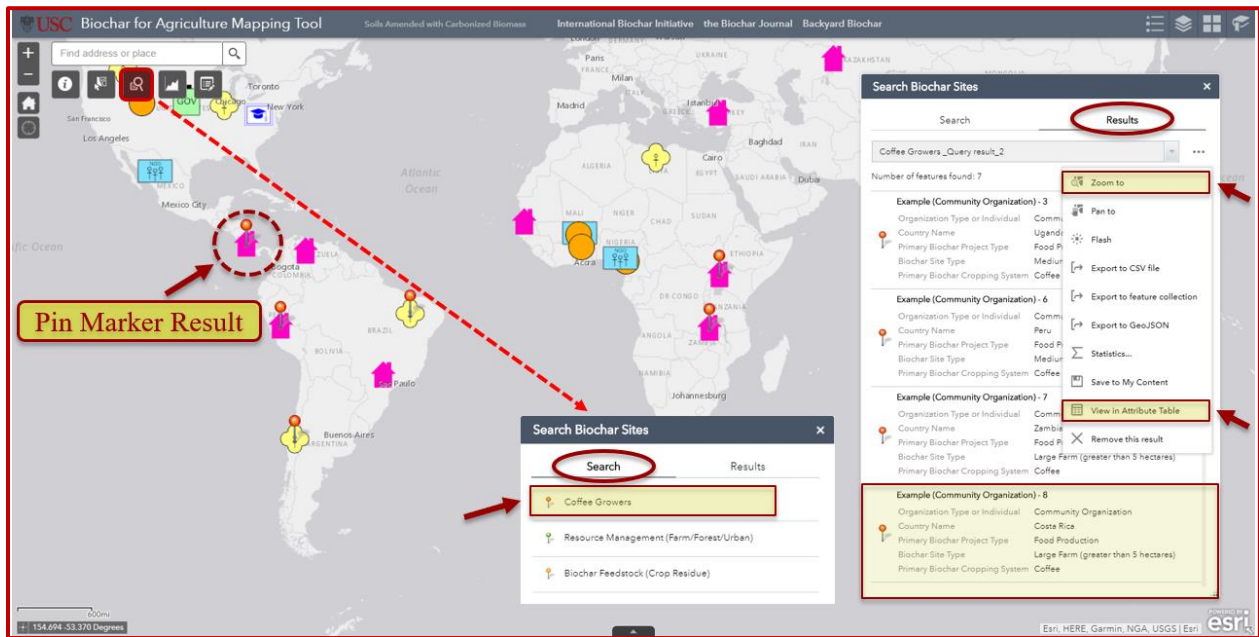


Figure 16. BfAMT ‘Search Biochar Sites’ widget showing the search tasks and search results windows for coffee growers

The ‘Select Biochar Sites’ widget (see Figure 17 below) allows users to select an area of interest on the map and view the results (i.e., site records). The ‘three-dot-menu (...)’ in the ‘Select Biochar Sites’ pop-up window contains options for zooming to selected records and viewing them in the ‘Attribute Table.’ Once the user has selected their features of interest, they can choose to export them as an Excel CSV file using the ‘Options Menu’ in the ‘Attribute Table’ (see Figure 17 below).

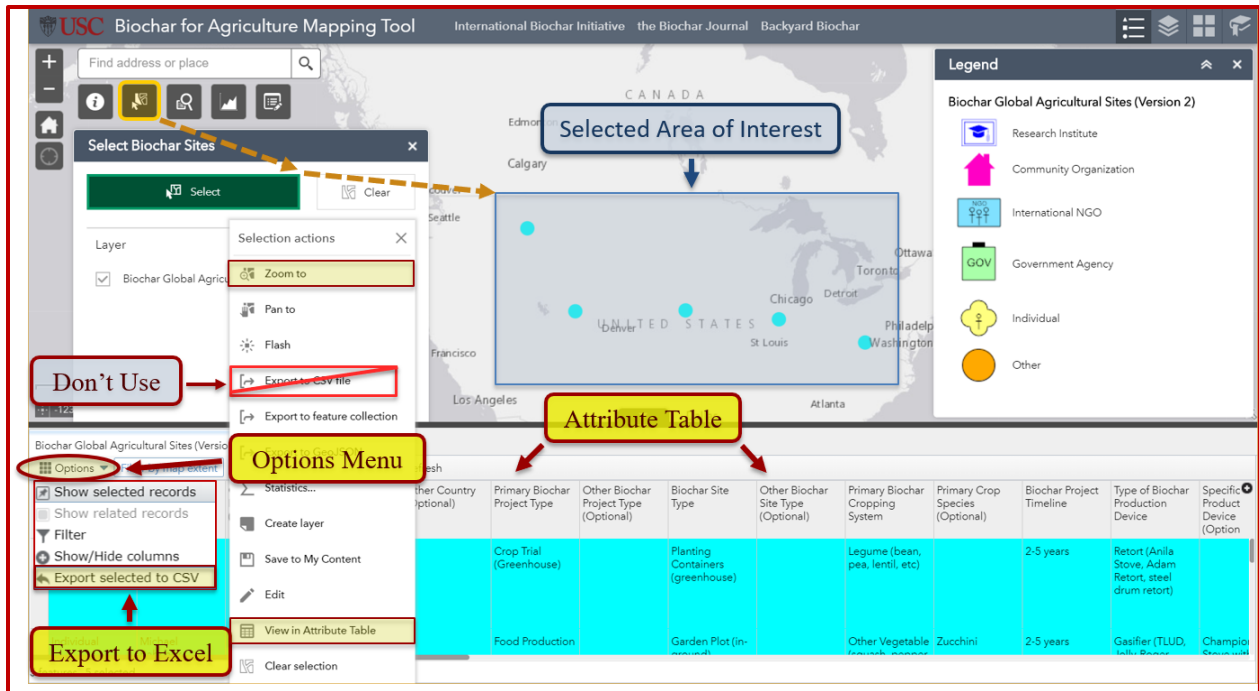


Figure 17. BfAMT ‘Select Biochar Sites’ widget showing the ‘Attribute Table’ and ‘Options Menu’ for exporting feature attributes as a Microsoft Excel CSV file

Caution should be mentioned when zooming to selected records or query results using the ‘Select Biochar Sites’ and ‘Search Biochar Sites’ widgets. If zooming to selected records obscures point feature symbols from the map frame’s view, those records will no longer be visible in the ‘Attribute Table.’ This same word of caution applies to manually opening the ‘Attribute Table’ and expanding its size by dragging it into the map frame. One can avoid this potential drawback by knowing the number of features that were originally selected using the ‘Select Biochar Sites’ widget, or the number of results that were originally generated by running the ‘Search Biochar Sites’ widget. The bottom left corner of the ‘Attribute Table’ shows the number of records contained in the table. It may be necessary to adjust the size of the ‘Attribute Table’, or the map frame using map controls (i.e., ‘Home’ button and ‘Zoom’ controls), so that all records are accounted for in the table.

After exporting selected biochar site records as an Excel CSV file, the output looks like the example output in Table 3 (see below). The Table 3 output (which consists exclusively of example point features created by the author) has been formatted for purposes of visual display, and only a select number of attribute fields are included. Example point features and their attribute values were created by the author and added to the BfAMT web map to provide 1) sample data for the customization of map widget tools, 2) background for help graphics, and 3) context for first-time BfAMT web app users.

Table 3. Selected point feature attributes (columns) from the BfAMT web app. Only example point features (rows) created by the author were included in the output

| Name of Organization | Country Name | Primary Biochar Project Type |
|---------------------------------------|--------------------------|--|
| Example (Community Organization) - 7 | Zambia | Food Production |
| Example (Research Institute) - 1 | United States of America | Crop Trial (Greenhouse) |
| Example (Community Organization) - 8 | Costa Rica | Food Production |
| Example (Community Organization) - 1 | Venezuela | Biochar Product (Nutrient/Microbe/Mineral) |
| Example (Community Organization) - 6 | Peru | Food Production |
| Example (Individual) - 1 | Chile | Crop Trial (Outdoor) |
| Example (Community Organization) - 2 | Brazil | Resrc Mgmt (Farm/Forest/Urban) |
| Example (Community Organization) - 10 | Senegal | Biochar Product (Nutrient/Microbe/Mineral) |
| Example (International NGO) - 1 | Burkina Faso | Food Production |
| Example (Individual) - 3 | Libya | Crop Trial (Outdoor) |
| Example (Individual) - 2 | Indonesia | Raw Biochar Production |
| Example (Community Organization) - 5 | Japan | Crop Trial (Greenhouse) |

| Biochar Site Type | Primary Biochar Cropping System | Primary Biochar Fertilization Method |
|--|---------------------------------------|---|
| Large Farm (greater than 5 hectares) | Coffee | Compost |
| Planting Containers (greenhouse) | Legume (bean, pea, lentil, etc) | Manure |
| Large Farm (greater than 5 hectares) | Coffee | Inorganic Fertilizer |
| Rural Space (non-farm) | None | Compost |
| Medium Farm (between 1 and 5 hectares) | Coffee | Manure |
| Garden Plot (in-ground) | Coffee | Urine |
| Large Farm (greater than 5 hectares) | Tree Crop (fruit, legume, leaf, etc) | Urine |
| Urban Space (non-farm) | None | Multiple (Please specify in next field) |
| Medium Farm (between 1 and 5 hectares) | Rice | Urine |
| Small Farm (less than 1 hectare) | Cereal (wheat, millet, etc) | Inorganic Fertilizer |
| Medium Farm (between 1 and 5 hectares) | Other Vegetable (squash, pepper, etc) | Fish or Bone Meal |
| Planting Containers (greenhouse) | Other Vegetable (squash, pepper, etc) | Effective/Indigenous Microbe Mix |

| Type of Biochar Production Device | Type of Biochar Feedstock | Biochar Soil Application Rate |
|---|--------------------------------------|---|
| Gasifier (TLUD, Jolly-Roger Oven, etc) | Crop Residue (Stems/Stalks/Leaves) | 0.6 - 1.7 kilograms/square meter (kg/m ²) |
| Retort (Adam retort, steel drum, etc) | Crop Residue (Stover/Husk/Pod/Pit) | 0.6 - 1.7 kilograms/square meter (kg/m ²) |
| Burn Pile (stacked) | Natural Wood - Small Diameter < 5 cm | 0.6 - 1.7 kilograms/square meter (kg/m ²) |
| Gasifier (TLUD, Jolly-Roger Oven, etc) | Waste Wood - Lumber, Plywood, etc | 1.8 - 3.6 kilograms/square meter (kg/m ²) |
| Flame-Cap Kiln (cone kiln, open-pit kiln) | Crop Residue (Stover/Husk/Pod/Pit) | 2-5 tons/hectare (t/ha) |
| Gasifier (TLUD, Jolly-Roger Oven, etc) | Natural Wood - Small Diameter < 5 cm | 6-20 tons/hectare (t/ha) |
| Burn Pile (stacked) | Natural Wood - Large Diameter > 5 cm | 6-20 tons/hectare (t/ha) |
| Flame-Cap Kiln (cone kiln, open-pit kiln) | Natural Wood - Small Diameter < 5 cm | 21 - 40 tons/hectare (t/ha) |
| Gasifier (TLUD, Jolly-Roger Oven, etc) | Crop Residue (Stover/Husk/Pod/Pit) | 2-5 tons/hectare (t/ha) |
| Tin Can System | Crop Residue (Stems/Stalks/Leaves) | 0 - 0.1 kilograms/square meter (kg/m ²) |
| Traditional Kiln (mound kiln, etc) | Crop Residue (Stover/Husk/Pod/Pit) | 0.2 - 0.5 kilograms/square meter (kg/m ²) |
| Flame-Cap Kiln (cone kiln, open-pit kiln) | Natural Wood - Large Diameter > 5 cm | 21 - 40 tons/hectare (t/ha) |

Figure 18 below shows global biochar sites symbolized by *Organization Type or Individual*, and Figure 19 below shows global biochar sites symbolized by *Primary Biochar Project Type*. Example biochar sites created by the author, and actual biochar sites contributed by users, are included in Figures 18 and 19.

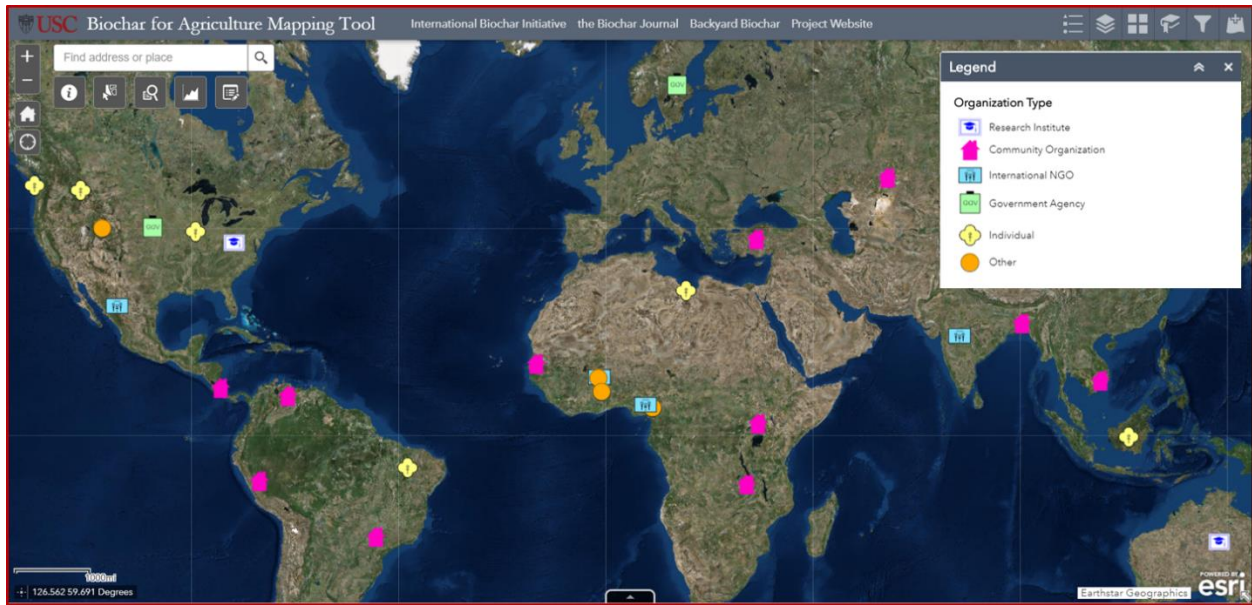


Figure 18. Biochar sites symbolized by *Organization Type or Individual*

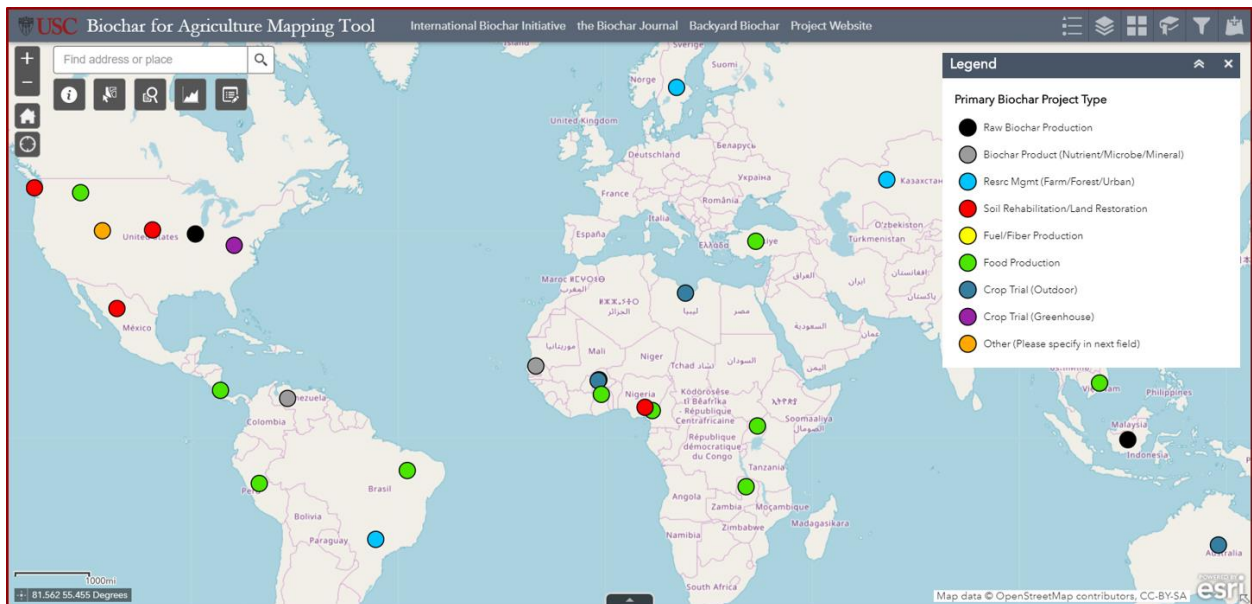


Figure 19. Biochar sites symbolized by *Primary Biochar Project Type*

4.3. BfAMT User-Generated Content

There were eleven VGI point features uploaded to the BfAMT web map. These eleven sites were contributed by three individuals and five organizations. One of these organizations uploaded three sites in Africa that they symbolized with the ‘Other’ point marker symbol (see

Figure 20 below). Selected attributes for the eleven user-generated biochar sites are presented in Table 4 below. Text fields (outlined in red) include *Primary Crop Species*, *Specific Feedstock Type*, and *Specific Production Device*. These fields were included in the BfAMT design to allow users the option of specifying important characteristics of their biochar projects that were not captured using attribute drop-down menus. The inclusion of text fields attempted to address a limitation of Collector that does not allow for selecting multiple values per field. Unfortunately, text field responses are not easily searchable using SQL functions because the text string in the search expression must exactly match that of the text field (i.e., spelling, wording, length, etc.). For this reason, it is preferable to have users to enter data using drop-down menus.

Table 4. BfAMT user-generated content or VGI

| Organization Type or Individual | Country Name | Primary Biochar Project Type |
|---------------------------------|--------------------------|--|
| Community Organization | Bangladesh | Resrc Mgmt (Farm/Forest/Urban) |
| Other | Burkina Faso | Crop Trial (Outdoor) |
| Other | Ghana | Food Production |
| Other | Cameroon | Food Production |
| International NGO | Cameroon | Soil Rehabilitation/Land Restoration |
| Government Agency | United States of America | Soil Rehabilitation/Land Restoration |
| Individual | United States of America | Raw Biochar Production |
| Other | United States of America | Other (Please specify in next field) |
| Individual | United States of America | Food Production |
| Individual | United States of America | Soil Rehabilitation/Land Restoration |
| Research Institute | United States of America | Biochar Product (Nutrient/Microbe/Mineral) |

| Biochar Site Type | Primary Biochar Cropping System | Primary Crop Species (Optional) |
|--------------------------------------|--------------------------------------|---------------------------------|
| Other (Please specify in next field) | Other (Please specify in next field) | Garden and field crops |
| Garden Plot (in-ground) | Other Veg (squash, pepper, tomato) | |
| Garden Plot (in-ground) | Other Veg (squash, pepper, tomato) | |
| Garden Plot (in-ground) | Other Veg (squash, pepper, tomato) | |
| Large Farm (greater than 5 hectares) | Tree Crop (fruit, legume, leaf, etc) | Banana |
| Urban Space (non-farm) | Other (Please specify in next field) | Trees |
| Other (Please specify in next field) | Other (Please specify in next field) | All |
| Garden Plot (in-ground) | Other Veg (squash, pepper, tomato) | Zucchini |
| Small Farm (less than 1 hectare) | Other Veg (squash, pepper, tomato) | |
| Other (Please specify in next field) | Coffee | |

| Type of Biochar Feedstock | Specific Feedstock Type (Optional) | Source of Biochar Feedstock |
|--------------------------------------|---------------------------------------|--|
| Natural Wood - Small Diameter < 5 cm | various woods, cowdung+biomass | Other (Please specify in next field) |
| Crop Residue (Stover/Husk/Pod/Pit) | | Farm Waste (crop residue, manure, invasives) |
| Crop Residue (Stems/Stalks/Leaves) | rice husks | Farm Waste (crop residue, manure, invasives) |
| Crop Residue (Stems/Stalks/Leaves) | | Farm Waste (crop residue, manure, invasives) |
| Crop Residue (Stover/Husk/Pod/Pit) | Empty fruit bunches | Farm Waste (crop residue, manure, invasives) |
| Natural Wood - Small Diameter < 5 cm | | Pre-Made or Commercial Biochar Product |
| Natural Wood - Small Diameter < 5 cm | | Urban (processed wood, tree trimmings, etc) |
| Other (Please specify in next field) | All | Other (Please specify in next field) |
| Processed Wood - Pellets | Douglas fir wood pellets (40 lb. bag) | Urban (processed wood, tree trimmings, etc) |
| Other (Please specify in next field) | Red Alder wood chips for mulch | Urban (processed wood, tree trimmings, etc) |
| Crop Residue (Stover/Husk/Pod/Pit) | Stems, stalks, leaves | Farm Waste (crop residue, manure, invasives) |

| Biochar Production Device (Optional) | Biochar Research Trial Design | Biochar Soil Application Method |
|--------------------------------------|---|--------------------------------------|
| Akha TLUD cookstove | Other (Please specify in next field) | Other (Please specify in next field) |
| | Randomized Complete Block | Uniform Mixing or Plowing of Topsoil |
| | Randomized Complete Block | Uniform Mixing or Plowing of Topsoil |
| | Randomized Complete Block | Uniform Mixing or Plowing of Topsoil |
| Kon-Tiki | Control vs Treatment (no replication) | Planting Holes (field) |
| | None | Surface Application (natural mixing) |
| also flame cap | None | None |
| All can be considered | | |
| Champion TLUD Stove | None | Planting Holes (field) |
| TLUD design and function | Control vs Treatment (with replication) | Surface Application (natural mixing) |
| | Control vs Treatment (with replication) | Uniform Mixing or Plowing of Topsoil |

Figure 20 below shows the location of the eleven VGI sites from Table 4 above. Two users (representing four sites total) chose to represent their biochar sites using the ‘Other’ point marker symbol for the *Organization Type or Individual* attribute. This suggests that it may be necessary to include more options for *Organization Type or Individual* to describe other types of organizations involved in biochar activities. In Figure 20, three ‘Individual’, one ‘Government Agency’, one ‘Community Organization’, one ‘Research Institute’, and four sites labeled ‘Other’ are visible across North America (5), Africa (4), Central America (1), and Asia (1).

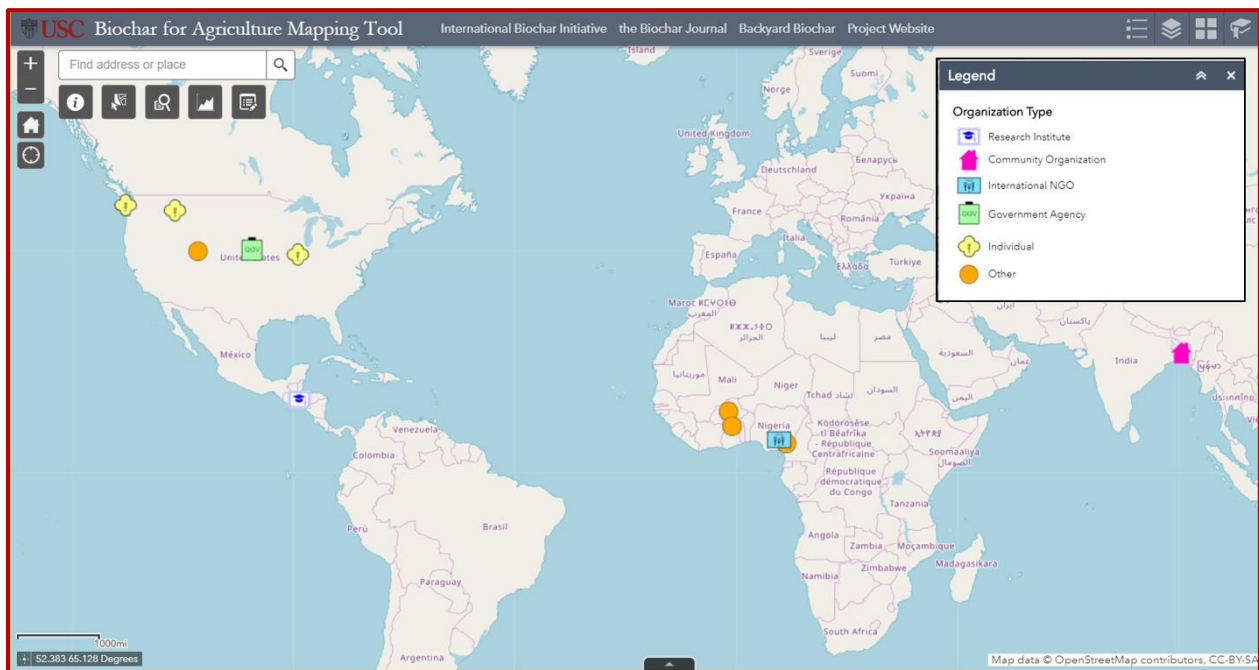


Figure 20. Biochar VGI sites (11 total)

4.4. The BfAMT Web App Mobile Phone Interface

Launching the BfAMT web-GIS app on the author’s iPhone 5s smart phone resulted in a cluttered interface because the size of point feature icons relative to the map frame increased considerably compared to the desktop interface. Also, use of the ‘Attribute Table’ was very difficult because only one site record was visible, and the number of visible fields in the table was limited. Furthermore, it was difficult to access the point feature pop-up window’s ‘three-dot-

menu (...)’ to perform editing tasks, etc. On an iPhone 5s, the ‘three-dot-menu (...)’ was hidden off-screen at the bottom of the interface. It was necessary to use one finger to lift the touch screen and use another finger to tap the ‘three-dot-menu (...)’ so it stayed visible. It was only by performing this task that ‘three-dot-menu (...)’ could be opened. Thus, it is not recommended to use the BfAMT web app on an iPhone 5s (and perhaps other mobile devices). However, despite its apparent drawbacks, loading the BfAMT web app on a mobile phone presents a no-cost alternative that avoids the need for an AGOL user account to access the Collector mobile app on a smart phone device. It should be pointed out, however, that the BfAMT web app will not work offline when opened a mobile device.

4.5. Managing Coded Domains and Feature Class Fields in ArcMap 10.6

Adding coded values to attribute domains using the ‘Database Properties’ ‘Domains’ tab in ArcMap 10.6 went smoothly when adding a new coded value to existing coded values. However, when reordering or reassigning coded values, the changes applied did not appear in numeric order when the ‘Database Connection’ was refreshed. The ‘Sort Coded Value Domains’ geoprocessing tool can be used to reorder coded values, but this tool apparently does not work when updating the order of coded values for active coded domains (i.e., those that are linked to feature service layers published in AGOL). This issue was circumvented by creating a new coded domain and re-entering coded values in the desired order. However, to assign the new domain to the same attribute field required the creation of a new feature class, for reasons given in the following paragraph.

Publishing a feature service layer to AGOL had the effect of locking feature class properties under the ‘Fields’ tab in ArcMap 10.6, which prevented editing operations (e.g., adding a new field, changing the field name and data type, and assigning a different domain to

the field). For a newly created feature class, it is possible to edit all field properties. Thus, an existing feature class, which was locked in ArcMap 10.6 because it had been published to AGOL, was exported to the same database and renamed. It was then possible to edit fields for the newly created feature class. This process was repeated each time a new feature class field need to be added, or when a feature class field required updating. However, when adding a field, the only option was to add it as the last field in the list. It was not possible insert or reorder fields. After researching the issue, a workaround was implemented by downloading an extension for ArcCatalog called *X-Ray for Geodatabases* and using its ‘Reorder Fields’ tool. Using this tool required the author to create an ordered list of attribute field names in Excel that could be pasted into the *X-Ray* tool. Although this proved to be a successful workaround, it was later realized that attribute fields could be reordered in AGOL using the ‘Configure Pop-up’ tool.

4.6. Help Resources

A complete series of help graphics for using the Collector mobile app is found in Appendix B. There is also a five-minute Collector video tutorial (created and narrated by the author) that is posted on the BfAMT web page. Complete help instructions for using the BfAMT web-GIS app can be found in the web app’s ‘Help Instructions’ widget, in Appendix C of this document, and in a twelve-minute video tutorial (created and narrated by the author) on the BfAMT web page.

4.7. App Evaluation / Testing

4.7.1. Subjects

The recruitment of human subjects for beta testing of the BfAMT mobile and web apps was carried out via e-mail and through an open invitation announcement posted to a biochar listserv (i.e., Yahoo Groups - Biochar). Personal acquaintances of the author, as well as contact

referrals who are members, or affiliates, of the International Biochar Initiative (IBI), were sent e-mail invitations with an attached information/consent form that could be openly distributed to others via e-mail. In total, 10 IBI members and 10 IBI affiliates—who provided input on their biochar projects for a 2018 white paper entitled “The Potential for Biochar to Improve Sustainability in Coffee Cultivation and Processing”—received the e-mail invitation to beta-test the BfAMT. An invitation announcement was also posted on the Yahoo Biochar Group listserv (<https://groups.yahoo.com/neo/groups/biochar/info>) that has an estimated 300-400 active members. In the body of the e-mail and listserv announcements, participants were provided with hyperlinks to the BfAMT web page, web-GIS app, and Google survey questionnaire. Participants interested in beta-testing the Collector mobile app were asked to contact the author and request the login credentials needed to access Collector on their mobile devices.

After beta-testing, users were asked to fill out an online survey questionnaire that was created using Google forms. Because beta-testing the BfAMT and completing the online survey involved human subjects in research, approval by USC’s Institutional Review Board (IRB) was required. The study entitled “Beta Testing for Biochar Web-GIS Application” (UP-18-00696) was approved by USC-IRB on October 30, 2018.

4.7.2. Design of User Survey

As previously mentioned, a survey questionnaire for beta-testers of the BfAMT mobile and web apps was designed using Google Forms, which is part of the Google Drive office suite. Screenshots of the online Google survey questionnaire are presented in Appendix D. Google Forms is an information collection tool that allows the creation of customized surveys. Survey customization includes options for 1) choosing the question format (e.g., multiple choice, checkboxes, dropdown, short answer, and paragraph), 2) requiring responses to individual

questions, 3) limiting responses to once per person, 4) allowing users to return to the survey and edit their responses, and 5) applying custom themes, such as adding custom images or logos to the header and page background. A Google survey spreadsheet is automatically populated with user responses and can be downloaded as an Excel CSV file. Additionally, pie chart results are generated for each survey question, making it easy to visualize user responses.

4.7.3. Timeframe for Beta-Testing

The first beta-testing invitation was sent via e-mail on November 7, 2018. A Biochar Yahoo Group listserv announcement was posted on November 9, and a second listserv announcement was posted on Nov 18. Subsequent e-mail invitations and reminders were sent on Nov 9, 17, and 25, 2018.

4.7.4. Evaluation of the BfAMT Web-GIS and Mobile Apps

The BfAMT mobile and web-GIS app components were beta-tested by a group of biochar users who are members, or affiliates of, the International Biochar Initiative; an international NGO based in the United States dedicated to promoting worldwide biochar research, production, and use; and other biochar users who subscribe to the free Yahoo Groups-Biochar listserv.

Preliminary testing of the Collector mobile app and BfAMT web-GIS app by the author found that the apps performed well in meeting project objectives. Issues encountered in Collector included 1) compatibility with Android devices and 2) a complicated workflow for collecting point features offline (see Appendix B). Issues encountered with BfAMT web app included 1) point features not being included in the 'Attribute Table' when the 'Attribute Table' obscures point features in the map frame, 2) customized map scale zoom levels that would not display the

basemap, and 3) exporting site records to an Excel CSV file using a widget pop-up's 'three-dot-menu (...)' that resulted in Excel CSV files populated with codes instead of text descriptions.

As of Dec 27, 2018, five people had responded to the BfAMT survey questionnaire. Tables 5-9 below contain user responses to the questionnaire. Responses to Questions 1-11 are contained in Table 5 (see below). Three people were able to use the Collector mobile app to contribute data (see Q1 in Table 5 below). All five were able to use the web app to contribute data (see Q4 in Table 5 below). None of the respondents tried exporting data from the 'Attribute Table' (see Q6 in Table 5 below), with reasons given being "not needed" and "lack of time." Two people said they would make changes to the BfAMT web app interface (see Q9 in Table 5 below). One person said that their input did not reflect the type of work they were doing. Another said they would change the formatting by reducing the size of point marker icons and wanted the ability to place an icon in the exact location of their project. Using the web app to place a point in one's exact location is possible by typing decimal degree coordinates (separated by a comma) into the address bar. This feature is described in the BfAMT 'Help Instructions' widget. However, the process of adding decimal degree coordinates to the 'Search Bar' window is not included in the BfAMT web app video tutorial posted on the project web page. Lastly, there was a comment that users will need time to become comfortable with app features.

Table 5. User responses to Questions 1-11 of the BfAMT survey questionnaire

| | Yes | No | Maybe | |
|--|---|------|-------|--|
| Q1. Were you able to use the Collector for ArcGIS mobile app to enter your biochar site information? | 3 | 2 | None | |
| Q2. If you answered 'No' to Q1, what was the main problem? | P3: I do not use any apps P4: Could not download the app | | | |
| Q3. Can you explain your response to Q2? | P3: I do not use apps | | | |
| Q4. Were you able to use the Biochar for Agriculture Mapping Tool (web app) to add your data point and edit your biochar site's attributes? | 5 | None | None | |
| Q5. If you answered 'No' to Q4, what was the main problem? | No Responses | | | |
| Q6. Did you try exporting data from the Attribute Table as an Excel CSV file? | None | 5 | None | |
| Q7. If you answered 'Yes' to Q6, were you successful? | No Responses | | | |
| Q8. If you answered 'No' to Q7, what was the main issue? | P1: Not needed P3: My personal lack of time at this time P5: I did not need to do so | | | |
| Q9. Would you change anything about the Biochar for Agriculture Mapping Tool's web app interface (i.e. visual display) or website content? | 2 | 3 | None | |
| Q10. If you answered 'Yes' to Q9, what would you change? | P2: The formatting P4: Several things need development for more detail | | | |
| Q11. Can you explain your response to Q10? | P2: Smaller icons, the ability to put the icon in the exact location of the project P3: Users will need some time to get into the use of the program P4: My input does not reflect what I am actually doing P5: I like the layout as is. Simple to use | | | |

User responses to Questions 12-17 are contained in Table 6 below. As for BfAMT attribute categories and their associated drop-down menu options (see Q12 in Table 6 below), two people would like to add an option for choosing multiple responses, especially for users who are applying biochar in field trials and conducting multiple types of projects. Not having the option to make multiple selections for drop-down attribute values is one of the biggest limitations of the BfAMT feature service layer and map-driven form. In contrast, Esri's Survey 123's form-centric interface has multiple selection capability and can possibly be integrated with Collector (see Chapter 5 – Conclusion).

Table 6. User responses to Questions 12-17 of the BfAMT survey questionnaire

| | Yes | No | Maybe | |
|--|--|----|-------|--|
| Q12. Would you change anything about the biochar site attribute categories and drop-down menu options that are collected via the ArcGIS Collector mobile app? | 2 | 3 | None | |
| Q13. If you answered 'Yes' to Q12, what would you change? | <p>P2: Add, modify, or delete drop-down menu options for specific biochar attribute categories</p> <p>P5: I would like to have a 'select all that apply' for the Biochar Project Type, because my projects fits in at least 4 categories</p> | | | |
| Q14. Can you explain your response to Q13? | <p>P2: Allow multiple responses especially for those who are using biochar in field trials</p> <p>P3: A great start does not need to be changing things from the first moment.</p> <p>P5: We are producing biochar to eliminate a byproduct of coffee production, we will mix it with soil to restore fertility and conduct field research trials</p> | | | |
| Q15. Would you change anything about the Biochar for Agriculture Mapping Tool's functionality? | 2 | 3 | None | |
| Q16. If you answered 'Yes' to Q15, what would you change? | <p>P2: Improve pop-ups by including more or less information, etc</p> <p>P4: Add contextual map layers (e.g., soil class, land use, land cover, and climate)</p> | | | |
| Q17. Can you explain your answer to Q16? | <p>P2: Some info in the pop-ups is redundant. Including a project overview would be nice as well - including whether the project is a replicated study, demonstration site, or simply a site that uses biochar as part of their bmps</p> <p>P3: See previous comments about the need for some time.</p> <p>P5: It was easy to use and worked well</p> | | | |

One option for storing multiple selections for individual questions is to add duplicate questions labeled as *primary*, *secondary*, and *tertiary* (e.g., *Secondary Biochar Project Type*). Alternatively, text fields can be used for including additional selections. Text fields were added as a follow-up to BfAMT coded attribute fields where multiple selections were warranted.

Regarding BfAMT functionality (see Q15 in Table 6 above), one person would like to reduce “redundancy” in feature pop-up windows and include a field for a project overview that would allow users to describe whether a project is a replicated study, demonstration site, or a test site that uses biochar as a best management practice (BMP). A drop-down option for specifying whether a project is simply an implementation of a BMP (and not part of a project research design) could be added to the *Primary Biochar Project Type* category. Currently, adding a project overview is possible using the *Additional Notes* text field, although only 255 characters are available. Originally, a *Project Summary* text field was one of the first attribute fields listed in the ‘Contribute Data’ widget pop-up window. However, the *Project Summary* field was moved down the list of attribute fields and renamed *Additional Notes* to capture any project details that were not adequately addressed by other attribute fields.

User responses to Questions 18-20 are contained in Table 7 below. Three people described the BfAMT app as “neither difficult or easy”, one as “somewhat easy” and one as “very easy” (see Q18 in Table 7 below). The ability of the BfAMT to facilitate visualization and exploration of biochar sites included four responses for “very well” and one response for “average” (see Q19 in Table 7). As to how well the BfAMT will facilitate communication between individuals and organizations involved in biochar research and experimentation, three people said, “very well”, one said “somewhat well”, and one said “somewhat poorly.”

Table 7. User responses to Questions 18-20 of the BfAMT survey questionnaire

| | Neither Difficult nor Easy | Somewhat Easy | Very Easy |
|--|---|--------------------------|------------------|
| Q18. How easy or difficult was it to use ArcGIS Collector (mobile app) to document your agricultural work with biochar? | 3 | 1 | 1 |

| | Very Well | Average |
|---|------------------|----------------|
| Q19. How well do you think the Biochar for Agriculture Mapping Tool (web app) facilitates the visualization and exploration of biochar agricultural sites? | 4 | 1 |

| | Very Well | Somewhat Well | Somewhat Poorly |
|--|------------------|--------------------------|----------------------------|
| Q20. How well do you think the Biochar for Agriculture Mapping Tool (web app) will facilitate communication between individuals and organizations involved with biochar research and experimentation? | 3 | 1 | 1 |

User responses to Questions 21-27 are contained in Table 8 below. The three people who used the Collector mobile app to contribute data said they would continue to use it (see Q21 in Table 8 below). Four people said they would continue to use the BfAMT web app and a fifth person said that future use would depend on whether more “real” data points (as opposed to the example points that currently constitute the majority of point features) were added to the web map (see Q23 in Table 8 below). All respondents said they would recommend the BfAMT web app to others in the biochar community (see Q25 in Table 8 below). Regarding the BfAMT in general (see Q27 in Table 8 below), one person said “It seems to fill an important niche. It will take time to build up its critical mass of users.”

Table 8. User responses to Questions 21-27 of the BfAMT survey questionnaire

| | Yes | No | Maybe | |
|---|---|------|-------|--|
| Q21. Will you continue to use Collector for ArcGIS (mobile app) to update your biochar site's attributes? | 3 | 1 | 1 | |
| Q22. If you answered "No" or "Maybe" to Q21, can you explain? | <p>P3: I do not use mobile apps</p> <p>P4: Our interest in biochar is democratization. We are developing a new TLUD, investigating urine as a source of nitrogen, and have a large experiment to define the contribution of biochar to an organic garden (on a comparative basis), new protocols for BC incorporation, the use of chickens for nutrient enhancement in soil as well as several smaller experiments top document more specific soil questions.</p> | | | |
| Q23. Will you continue to use the Biochar for Agriculture Mapping Tool (web app) to search for information about other biochar research sites? | 4 | None | 1 | |
| Q24. If you answered 'No' or 'Maybe' to Q23 can you explain? | P3: Will be 'Yes' when there are more real data points | | | |
| Q25. Will you recommend the Biochar for Agriculture Mapping Tool (web app) to others in the biochar community? | 5 | None | None | |
| Q26. If you answered 'No' or 'Maybe' to Q25, can you explain? | No responses | | | |
| Q27. Any additional comments? | <p>P1: Perhaps give an option early to simply jump right in.</p> <p>P3: It seems to fill an important niche. It will take time to build up to its "critical mass" of users.</p> <p>P4: If I can help, call me</p> <p>P5: No, thank you for creating this tool</p> | | | |

User responses to Questions 28-31 (i.e., demographics) are contained in Table 9 below.

In the pool of survey respondents, there was one female 25-34 years of age, one male 45-54, and three males over 64. One person had a Master/JD degree and four had PhDs (see Table 9 below).

Table 9. User responses to Questions 28-31 of the BfAMT survey questionnaire

| | 25-34 | 45-54 | 64+ |
|-------------------------------|--------------|--------------|------------|
| Q28. What is your age? | 1 | 1 | 3 |

| | Male | Female |
|----------------------------------|-------------|---------------|
| Q29. What is your gender? | 4 | 1 |

| | White |
|--|--------------|
| Q30. What is your race/ethnicity (select all that apply)? | 5 |

| | Master/JD | PhD |
|--|------------------|------------|
| Q31. What is your highest level of education? | 1 | 4 |

Chapter 5 Conclusions and Future Work

Chapter 5 includes a summary description (Section 5.1.), application development challenges (Section 5.2.), strengths (Section 5.3.), limitations (Section 5.4.), promotion and extension (Section 5.5.), future work (Section 5.6.), and broader impact (Section 5.7.) of the BfAMT.

5.1. Summary Description of the BfAMT

The BfAMT was primarily designed as a platform for sharing biochar activities related to land rehabilitation, resource management, and agriculture. The integration of the Collector mobile app with the BfAMT web app empowers users in remote locations, and those in low-income areas of the world who have limited computer/Internet resources, to use mobile devices to 1) document their on-site biochar research and activities, 2) visualize and explore user-generated content, 3) coordinate multi-site biochar projects, and 4) share information about best practices. The BfAMT web-GIS app serves as a browser-based workspace for managing, exploring, and exporting biochar site information using Esri WAB features and widgets. Either the Collector mobile app or BfAMT web app can be used to create point features, record site attributes, upload photos and videos, download and save photos and videos, and view text file attachments (e.g., Excel spreadsheets, Word documents, and PDF files). However, only the BfAMT web app can be used to 1) upload text file attachments, 2) download and save text file attachments, and 3) query and export geodatabase site records.

5.2. Challenges in BfAMT App Development

In general, BfAMT app development challenges included: 1) working with coded attribute domains and feature class fields in ArcMap 10.6, 2) updating and customizing feature services in AGOL, and 3) working with symbology in ArcMap 10.6 and AGOL.

Issues encountered when working with coded attribute domains and feature class fields in ArcMap 10.6 are described in Section 4.5. above. Loss of BfAMT web app configurations (i.e., widget settings) in WAB was experienced when updating feature service layers in AGOL and reassigning data sources within the BfAMT web app. Also, in WAB, customizing map scale zoom levels resulted in loss of the basemap. Map scale customization may only be possible using Esri's Developer Edition to work directly with WAB Javascript Object Notation (JSON) files or the ArcGIS programming interface (API) for Javascript.

Other issues were encountered when working with map symbology in ArcMap 10.6, Collector, and WAB. To get symbology text descriptions to appear within the symbology template that is used to identify and select the appropriate point feature symbol to add to the map in ArcMap and AGOL, it was necessary to assign a data type of 'Text' to the coded domain(s) used to symbolize the map (e.g., *Organization Type or Individual* and *Primary Biochar Project Type*). It was also necessary to write codes and values using identical text (see the coded domain table for *Organization Type or Individual* in Figure 4 above). Although this method worked for a single coded domain (i.e., *Organization Type or Individual*), the author was unable to create a second coded domain with a 'Text' data type (i.e., *Primary Biochar Project Type*) and use it to assign text descriptions to map symbology (as described in the next paragraph).

As described previously in Section 4.5., changing a coded domain's data type after its feature class has been published to AGOL required exporting the feature class to the same geodatabase and renaming it so that coded domains and feature class fields could be edited. However, after 1) creating a new coded domain with data type 'Text', 2) assigning the new domain to its corresponding attribute field (i.e., *Primary Biochar Project Type*) and 3) adding the new feature class layer to the map in ArcMap 10.6, point features disappeared during the process

of assigning unique symbology to the layer. Interestingly, even though point features were no longer visible in the map frame, they could still be selected using the ‘Select Features’ tool. However, because point features were not displayed in ArcMap 10.6, they were also not displayed when the published feature service layer was opened in AGOL’s Map Viewer. It may be necessary to create an empty feature class to assign one, or multiple, attribute domains as coded text before publishing to AGOL. This will be investigated.

Originally, a difference in map symbology size between the Collector mobile app and the BfAMT web app was experienced. Specifically, the size of map feature symbols in Collector appeared much smaller than they did in the BfAMT web app. To correct this issue, web maps with different size symbology were created from the same feature class layer. A web map with larger symbols was assigned to Collector and a web map with smaller symbols was assigned to the BfAMT web app. Functionally, edits made to either web map were reflected in both.

5.3. Strengths of the BfAMT

Based on user feedback, the BfAMT is succeeding in its objectives to facilitate the visualization and exploration of biochar sites, with generally favorable reviews regarding its ability to facilitate communication between individuals and organizations involved in biochar activities. Users who beta-tested the BfAMT said they would continue to use the apps and recommend them to others in the biochar community. Lastly, users seemed mostly satisfied with the attribute categories and drop-down menu options for describing biochar (agricultural) sites. However, recommended improvements included the integration of options for 1) selecting multiple values per attribute domain and 2) describing different types of biochar field studies.

The BfAMT was compared to other biochar databases and web-GIS applications, and the comparative limitations and advantages of each are discussed: The UC Davis Biochar Database

is a well-constructed website with web-based data entry forms aimed at collecting data on different biochars' physical and chemical characteristics. Although the data entry form includes a text field for *Geography*, there is no field for entering geographic coordinates. There is also no mapping application linked to the database for visualizing locations where people are conducting biochar characterization research. However, a web mapping application is not necessarily a useful extension of the UC Davis Biochar Database unless map users value an ability to search for biochar characterization data on feedstocks that are available within their own geographic or socio-environmental context. The UC Davis Biochar Database does offer analysis and visualization of biochar characteristics with options for plotting different biochar variable combinations on x and y-axes. However, no other database search options are available. Instead, users have the option to download the entire dataset as an Excel CSV file.

The sole biochar web-GIS application that the author found is produced by the Finnish Biochar Association in Finland. The app, called "Map of biochar activities in Finland", is effective in its simplicity and its inclusion of all biochar-related activities. Data collection is form-centric, designed using Google forms. Users are asked to answer a short list of questions about their biochar activity and submit a form to the Finnish Biochar Association. Attribute information is subsequently entered into the database and displayed on the map. Perhaps the best feature of the web map is a layer list that displays all major biochar activity categories, with individual sites listed below each category. When clicked, individual sites are displayed in the map's center. Limitations of this web-GIS app include no ability to download the data and no search options for finding and displaying locations with specific biochar activity attributes.

5.4. Limitations of the BfAMT

Possible limitations that came up during and after BfAMT implementation were: 1) the need to expand the app's appeal to reach a broader base and include users involved in biochar projects outside the realm of agriculture, 2) the effectiveness of the BfAMT mobile and web apps to connect those in the biochar community, 3) the need to develop more targeted methods for reaching out to biochar researchers and project managers (in an effort to build the database), and 4) the need for additional feedback to help improve the mobile and web apps.

Follow-up questions that could be used to address limitations of the BfAMT include: 1) Do BfAMT users consider the dataset to be trustworthy, informative, and/or robust enough for identifying and learning about biochar research and activities? 2) Will users of the BfAMT mobile/web app platform use it to reach out directly to other researchers and biochar practitioners? 3) Do map-driven forms provide attribute categories and values that reflect user needs for comparing different biochar sites? and 4) Will the BfAMT be able to retain active users and recruit new users over time?

5.5. Promotion and Extension of the BfAMT

The BfAMT will continue to be promoted by International Biochar Initiative staff, who have offered to spread the word via e-mail and include an announcement in their monthly newsletter as soon as the post-beta-testing version of the app is ready. The updated BfAMT will also be shared on the Yahoo Biochar Group listserv. Future promotional tools will include targeted e-mails to researchers, organizations, and individuals who have recently published biochar research, or are actively studying or using biochar. In general, an effort will be made to populate the BfAMT web app with as many biochar user profiles and site activities as possible to increase the likelihood that the International Biochar Initiative will commit to continuing the

map feature service as part of their organization's global outreach campaign for promoting the production and use of biochar. This may involve secondary means of recruiting volunteer participation. For example, Google forms and e-mail attachments could be used to collect information about biochar activities from those who are not necessarily interested in taking the time to use the BfAMT to contribute data themselves, but who would like to have their project information added to the database. Under this scenario, a BfAMT app administrator would use VGI to create map features, enter attribute data, and add attachments.

An alternative to using the Esri's Collector for ArcGIS map-centric mobile app to collect spatial data is Esri's Survey 123 form-centric mobile app. The capabilities and benefits of Survey 123 compared to Collector are available on Esri's Survey 123 blog site (Esri Survey 123 Blog 2018). Survey 123 incorporates a user-friendly survey form that is configurable using a Microsoft Excel CSV spreadsheet that contains app-specific language for defining data collection field types. To create a geoint, a small interactive map frame (embedded in the survey form) is used to place a pin marker at a desired location. Survey 123 offers two major advantages over Collector: 1) a more aesthetic data collection form (i.e., smart form) with an option to select multiple values for a single question, and 2) anonymous access with no AGOL account sign-in required. However, Survey 123 layers can only be hosted in AGOL and are therefore more subject to Esri credit usage. Furthermore, Survey 123 only supports the collection of point features and photo attachments.

The author chose to use Collector as the mobile data collection app to pair with the BfAMT web-GIS app because it can 1) be integrated with ArcGIS Server and Microsoft's SQL Server to support multiple document type attachments (e.g., photos, PDFs, and Microsoft Word and Excel files) in a RDBMS, and 2) supports data collection of points, lines, and polygons.

Although photo attachments can be uploaded with Collector, text files cannot. However, text files attached through the BfAMT web app can be downloaded and viewed with Collector. Neither line nor polygon feature services were published as part of the original BfAMT, but the option to create these feature classes for delineating biochar research plots or activity areas could be implemented in future versions. Ultimately, the ability to 1) upload point, line, and polygon feature class data to the USC SSI ArcGIS Server and 2) give mobile app users the option to view text attachments (e.g., article PDFs, lab spreadsheets, and word processing files) were the main criteria for choosing Collector over Survey 123.

Esri recently offered a new course called “Field Data Collection and Management Using ArcGIS” that teaches best practices for 1) configuring and implementing the suite of ArcGIS field productivity apps, which includes Collector for ArcGIS and Survey 123, and 2) configuring these apps to work together. The author will explore the possibility of integrating Collector and Survey 123 as part of future BfAMT app development and deployment.

The BfAMT is focused on biochar projects that have a land restoration, resource management, or agricultural focus. However, for the BfAMT to be used by other biochar interest groups, feature class subtypes with their own set of coded attribute domains may need to be developed to accommodate users who are interested in 1) biochar carbon capture and storage (CCS), 2) biochar production byproducts like hydrogen gas and bio-oil that can be used to produce electricity, and 3) commercial biochar production and distribution. The creation of feature class subtypes for the enhanced visualization and data exploration of different biochar activities represents a feasible next step for building a more inclusive biochar activities database and increasing the outreach of the BfAMT.

5.6. Future Work

In an effort to be more inclusive of other types of biochar projects and activities outside the realm of agriculture, future iterations of the BfAMT will include the creation of database subtypes and/or an expansion of attribute categories and values for describing projects related to biochar's use in 1) stormwater management, 2) wastewater treatment, 3) environmental remediation, 4) building construction, 5) energy production, 6) commercial products and services, and 7) promotion and policy as it relates to climate change mitigation. Additionally, a feature class subtype could be created for biochar events (e.g., trainings, workshops, promotional events, volunteer projects, and meet-ups).

The addition of contextual map layers is another consideration for future iterations of the BfAMT. Experimental agriculture has an inherent spatial component that can be correlated with in-situ environmental variables; like soil properties, climatic variables, and biomass availability; and socio-economic variables like population density, land use, distance to transportation networks, and economic metrics. Individually or collectively, these environmental and socio-economic variables could be used to analyze and define site suitability for biochar production and cropping systems.

More generally, the addition of map layers to the BfAMT would provide a contextual background for biochar users who are interested in assessing how different factors might affect the sustainability of their biochar system(s). For this thesis project, contextual map layers were considered optional or unnecessary from a utility perspective. Also, the global scale of the BfAMT would require large datasets that could affect app performance. Nonetheless, contextual map layers could be added to the BfAMT where detailed local or regional datasets are available, or where legitimate research or management needs are identified.

A possible addition to the BfAMT web page is an advanced video tutorial that teaches users how to apply filters and/or add expressions to map widgets. Learning this skill would enable users to search the database for specific attributes without relying on preset functions. The project web page might also be redesigned to include a header, side panels, and/or tabs with supplementary help resources and information about biochar. Web page formatting might also be changed to improve aesthetics and ease-of-use. Lastly, the addition of a blog section could be useful for those wishing to 1) make an announcement, 2) share links and information, or 3) start a dialogue with other biochar users.

5.7. Broader Impact

Once user feedback and other recommended modifications are incorporated into a revised version of the BfAMT, it will be promoted and shared with a larger segment of the biochar community. This will involve new recruitment methods that target recent contributors to the field of biochar research and practice (e.g., academic and research institutions, NGOs, government agencies, and self-proclaimed biochar associations).

The future research, networking, and policy value of the BfAMT will depend on user contributions (i.e., VGI) to build a critical mass of biochar research and activity sites that encourage continued and expanded the use of the tool. Over time, the BfAMT has the potential to develop into an internationally recognized web-GIS application for the sharing, visualization, investigation, and promotion of global biochar activities.

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Appendix A: BfAMT Text Fields and Coded Attribute Domains with Values

Table 1A. BfAMT attribute categories Page 1 (text fields and coded values)

| Attribute Category | Data Type | Code | Code Description |
|--|--------------|------|---|
| Organization Type or Individual | Long Integer | 0 | Research Institute |
| | | 1 | Community Organization |
| | | 2 | International NGO |
| | | 3 | Government Agency |
| | | 4 | Individual |
| | | 5 | Other |
| Name of Individual or Organization (Optional) | Text | | |
| Contact Information (Optional) | Text | | |
| Country Name | Text | Text | Three letter Country ID |
| Other Country (Optional) | Text | | |
| Primary Biochar Project Type | Long Integer | 0 | Raw Biochar Production |
| | | 1 | Biochar Product (Nutrient/Microbe/Mineral) |
| | | 2 | Resrc Mgmt (Farm/Forest/Urban) |
| | | 3 | Soil Rehabilitation/Land Restoration |
| | | 4 | Fuel/Fiber Production |
| | | 5 | Food Production |
| | | 6 | Crop Trial (Outdoor) |
| | | 7 | Crop Trial (Greenhouse) |
| | | 8 | Other (Please specify in next field) |
| Other Biochar Project Type (Optional) | Text | | |
| Biochar Site Type | Long Integer | 0 | Planting Containers (greenhouse) |
| | | 1 | Planting Containers (outside) |
| | | 2 | Garden Plot (raised bed) |
| | | 3 | Garden Plot (in-ground) |
| | | 4 | Small Farm (less than 1 hectare) |
| | | 5 | Medium Farm (between 1 and 5 hectares) |
| | | 6 | Large Farm (greater than 5 hectares) |
| | | 7 | Forest/Savannah/Desert |
| | | 8 | Rural Space (non farm) |
| | | 9 | Urban Space (non farm) |
| | | 10 | Other (Please specify in next field) |
| Other Biochar Site Type (Optional) | Text | | |
| Primary Biochar Cropping System | Long Integer | 0 | None |
| | | 1 | Rice |
| | | 2 | Coffee |
| | | 3 | Maize |
| | | 4 | Cereal (wheat, millet, sorghum, etc) |
| | | 5 | Legume (bean, pea, lentil, etc) |
| | | 6 | Other Vegetable (squash, pepper, tomato, etc) |
| | | 7 | Root Crop (potato, cassava, yam, etc) |
| | | 8 | Tree Crop (fruit, legume, leaf, etc) |
| | | 9 | Wood or Fiber Crop |
| | | 10 | Biofuel Crop |
| | | 11 | Natural Vegetation |
| | | 12 | Other (Please specify in next field) |
| Primary Crop Species (Optional) | Text | | |

Table 2A. BfAMT attribute categories Page 2 (text fields and coded values)

| Attribute Category | Data Type | Code | Code Description |
|--|--------------|------|---|
| Biochar Project Timeline | Long Integer | 0 | 0-1 year |
| | | 1 | 2-5 years |
| | | 2 | 6-20 years |
| | | 3 | 21 - 100 years |
| Type of Biochar Production Device | Long Integer | 0 | None |
| | | 1 | Tin Can System |
| | | 2 | Traditional Kiln (mound kiln, beehive kiln, etc) |
| | | 3 | Burn Pile (stacked) |
| | | 4 | Flame-Cap or Open-Air Kiln (cone kiln, pyramid kiln, open-pit kiln) |
| | | 5 | Gasifier (TLUD, Jolly-Roger Oven, etc) |
| | | 6 | Retort (Anila Stove, Adam Retort, steel drum retort) |
| | | 7 | Industrial or Commercial-Size Reactor (Gasifier or Pyrolyzer) |
| Specific Biochar Production Device (Optional) | Text | | |
| Biochar Feedstock Source | Long Integer | 0 | Forest/Shrubland (deadfall, invasive species, etc) |
| | | 1 | Farm Waste (crop residue, manure, invasive species, etc) |
| | | 2 | Purpose Grown (woodlot, other designated biomass crop) |
| | | 3 | Urban (processed wood, tree trimmings) |
| | | 4 | Municipal (biosolids, solid waste, etc) |
| | | 5 | Industrial or Commercial (boiler ash, food processing waste, etc) |
| | | 6 | Pre-Made Biochar or Commercial Biochar Product |
| | | 7 | Unknown |
| | | 8 | Other (Please specify in next field) |
| Specific Feedstock Source (Optional) | Text | | |
| Type of Biochar Feedstock | Long Integer | 0 | Natural Wood - Small Diameter < 5 cm |
| | | 1 | Natural Wood - Large Diameter > 5 cm |
| | | 2 | Waste Wood - Lumber, Plywood, etc |
| | | 3 | Processed Wood - Pellets |
| | | 4 | Crop Residue (Stems/Stalks/Leaves) |
| | | 5 | Crop Residue (Stover/Husk/Pod/Pit) |
| | | 6 | Food Residue (Bagasse/Brewer's Waste) |
| | | 7 | Livestock or Poultry Manure |
| | | 8 | Biosolids (Sewage Sludge) |
| | | 9 | Bone |
| | | 10 | Coal Byproduct |
| | | 11 | Unknown |
| | | 12 | Other (Please specify in next field) |
| Specific Feedstock Type (Optional) | Text | | |
| Method for Quenching Biochar | Long Integer | 0 | Water Only |
| | | 1 | Urine (no dilution) |
| | | 2 | Smothering (with soil and/or capping with lid) |
| | | 3 | Nutrient Solution (water + nutrients) |
| Method for Pulverizing Biochar | Long Integer | 0 | None (whole pieces) |
| | | 1 | Hand Tool (hammer, mortar and pestle, etc) |
| | | 2 | Food Blender (with water) |
| | | 3 | Crushing (vehicle, roller, press, etc) |
| | | 4 | Device (mill, chipper, leaf vacuum, etc) |
| Primary Biochar Quality Test | Long Integer | 0 | None |
| | | 1 | Worm Avoidance Test |
| | | 2 | Germination Test |
| | | 3 | Yield Test |

Table 3A. BfAMT attribute categories Page 3 (text fields and coded values)

| Attribute Category | Data Type | Code | Code Description |
|---|--------------|------|---|
| Primary Biochar Fertilization Method | Long Integer | 0 | None |
| | | 1 | Inorganic Fertilizer |
| | | 2 | Urine |
| | | 3 | Manure |
| | | 4 | Worm Castings |
| | | 5 | Fish or Bone Meal |
| | | 6 | Wastewater/Sludge |
| | | 7 | Mycorrhizal Fungi |
| | | 8 | Effective/Indigenous Microbe Mix |
| | | 9 | Rock Dust |
| | | 10 | Compost |
| | | 11 | Multiple (Please specify in next field) |
| | | 12 | Other (Please specify in next field) |
| Specific Biochar Fertilization Method (Optional) | Text | | |
| Biochar Soil Application Method | Long Integer | 0 | None |
| | | 1 | Uniform Mixing or Plowing of Topsoil |
| | | 2 | Banding (furrows, tree dripline, etc) |
| | | 3 | Planting Holes (field) |
| | | 4 | Planting Containers (indoor or outdoor) |
| | | 5 | Surface Application (natural mixing) |
| | | 6 | Other (Please specify in next field) |
| Specific Biochar Application Method (Optional) | Text | | |
| Biochar Soil Application Rate | Long Integer | 0 | 0-1 tons/hectare (t/ha) |
| | | 1 | 2-5 tons/hectare (t/ha) |
| | | 2 | 6-20 tons/hectare (t/ha) |
| | | 3 | 21 - 40 tons/hectare (t/ha) |
| | | 4 | 40 + tons/hectare (t/ha) |
| | | 5 | 0 - 0.1 kilograms/square meter (kg/m ²) |
| | | 6 | 0.2 - 0.5 kilograms/square meter (kg/m ²) |
| | | 7 | 0.5 - 1.7 kilograms/square meter (kg/m ²) |
| | | 8 | 1.8 - 3.6 kilograms/square meter (kg/m ²) |
| | | 9 | 3.6 + kilograms/square meter (kg/m ²) |
| Biochar Research Trial Design | Long Integer | 0 | Control vs Treatment (no replication) |
| | | 1 | Control vs Treatment (with replication) |
| | | 2 | Split Plot |
| | | 3 | Completely Randomized |
| | | 4 | Randomized Complete Block |
| | | 5 | Other (Please specify in next field) |
| Other Research Trial Design (Optional) | Text | | |
| Additional Project Notes (Optional) | Text | | |

Table 4A. BfAMT attribute categories Page 4 (text fields and coded values)

| Attribute Category | Data Type | Code | Code Description |
|--|--------------|------|----------------------------------|
| Soil Properties Measured | Long Integer | 0 | None |
| | | 1 | pH Only |
| | | 2 | Soil Texture Only |
| | | 3 | pH and Soil Texture |
| | | 4 | Lab Analysis (Attach - Optional) |
| Soil pH Value (Optional) | Text | | |
| Soil Texture Class | Long Integer | 0 | Not Determined |
| | | 1 | Sand |
| | | 2 | Loamy Sand |
| | | 3 | Sandy Loam |
| | | 4 | Loam |
| | | 5 | Silt Loam |
| | | 6 | Silt |
| | | 7 | Sandy Clay Loam |
| | | 8 | Clay Loam |
| | | 9 | Silty Clay Loam |
| | | 10 | Sandy Clay |
| | | 11 | Silty Clay |
| | | 12 | Clay |
| Biochar Properties Measured | Long Integer | 0 | None |
| | | 1 | pH Only |
| | | 2 | Lab Analysis (Attach - Optional) |
| Biochar pH Value (Optional) | Text | | |
| Percent Ash in Biochar (Optional) | Text | | |
| Percent Volatile Carbon in Biochar (Optional) | Text | | |
| Percent Labile Carbon in Biochar (Optional) | Text | | |
| Percent Fixed Carbon in Biochar (Optional) | Text | | |
| ATTACHMENT | Blob | | |
| SHAPE | Geometry | | |

Appendix B: BfAMT Collector Mobile App Screenshots and Workflow

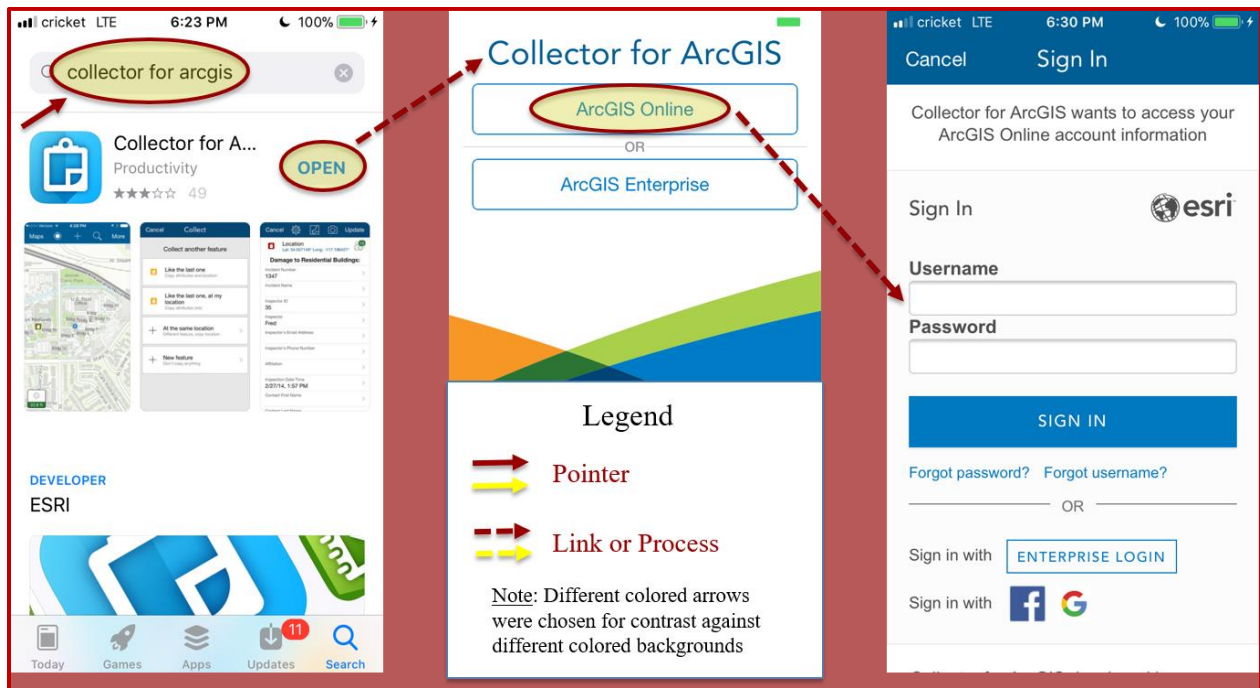


Figure 1B. Collector for ArcGIS app download on iPhone 5S, and ArcGIS Online login screen

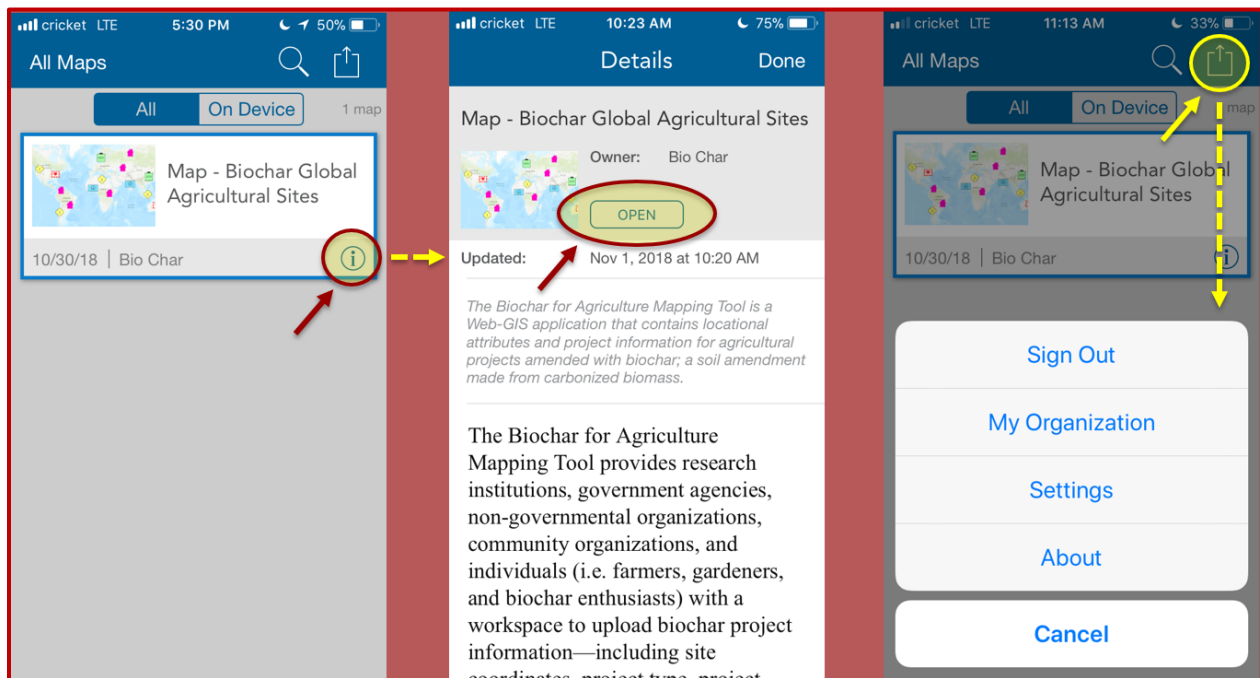


Figure 2B. Home screen, information details screen, and options menu screen in Collector

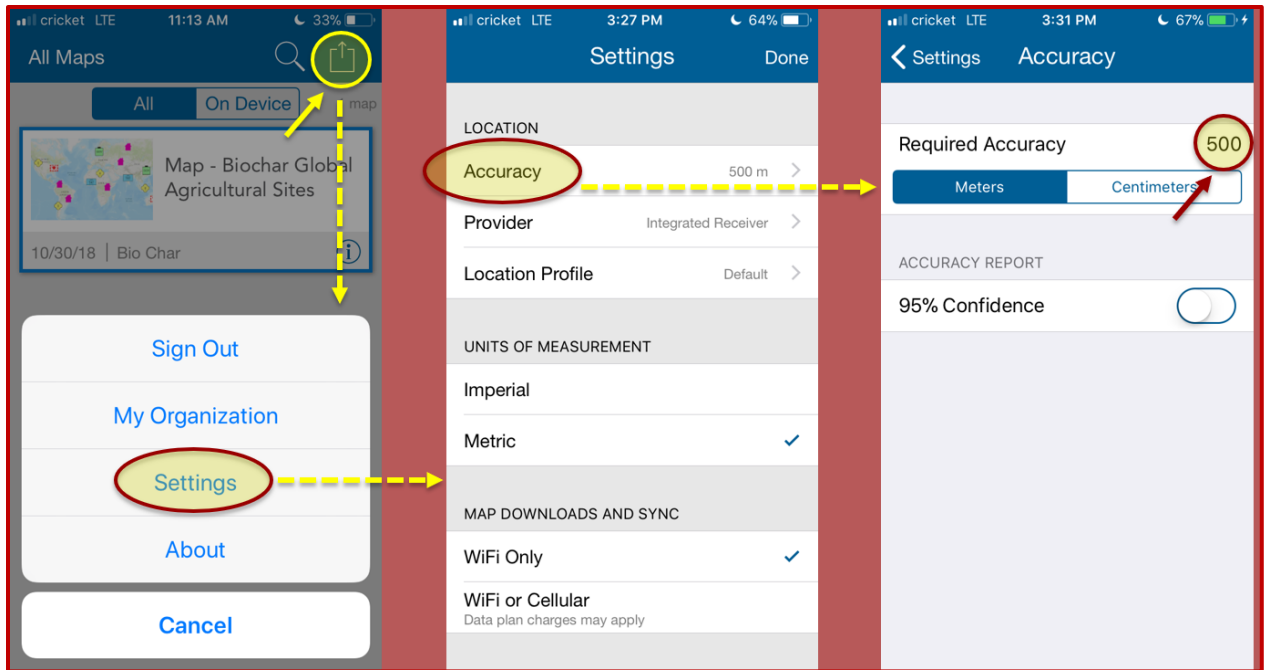


Figure 3B. Options menu, settings menu, and accuracy menu

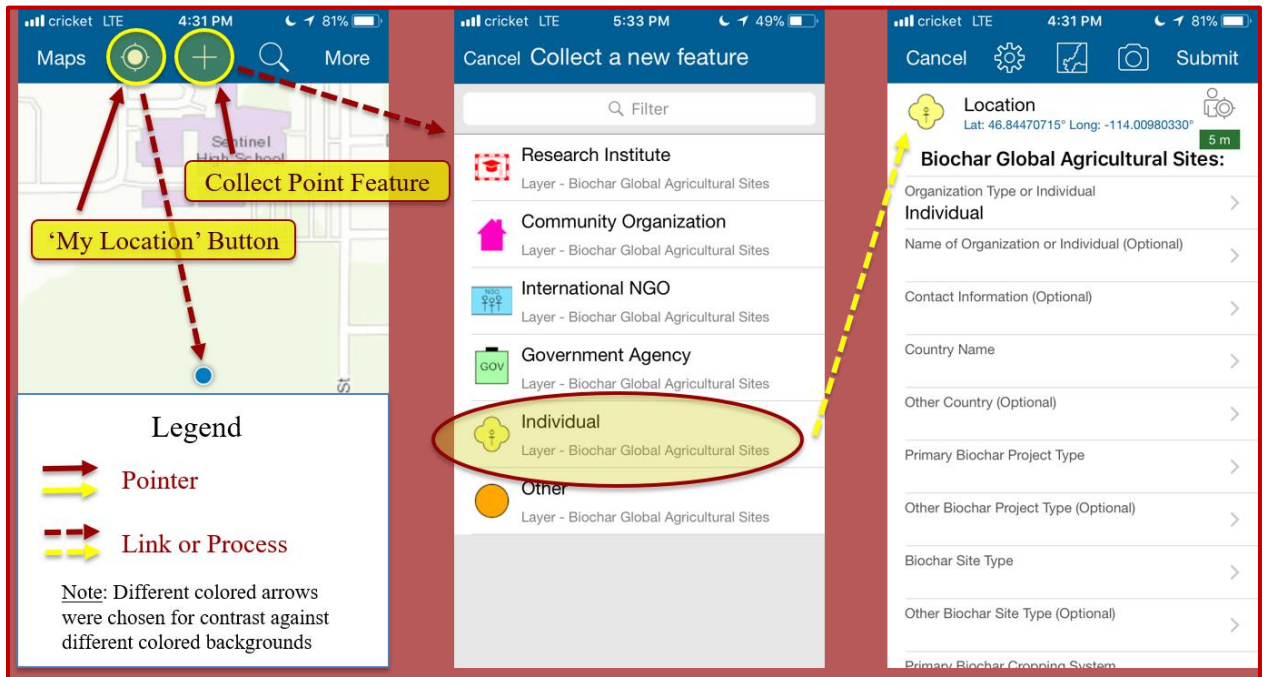


Figure 4B. Automated point feature collection in Collector

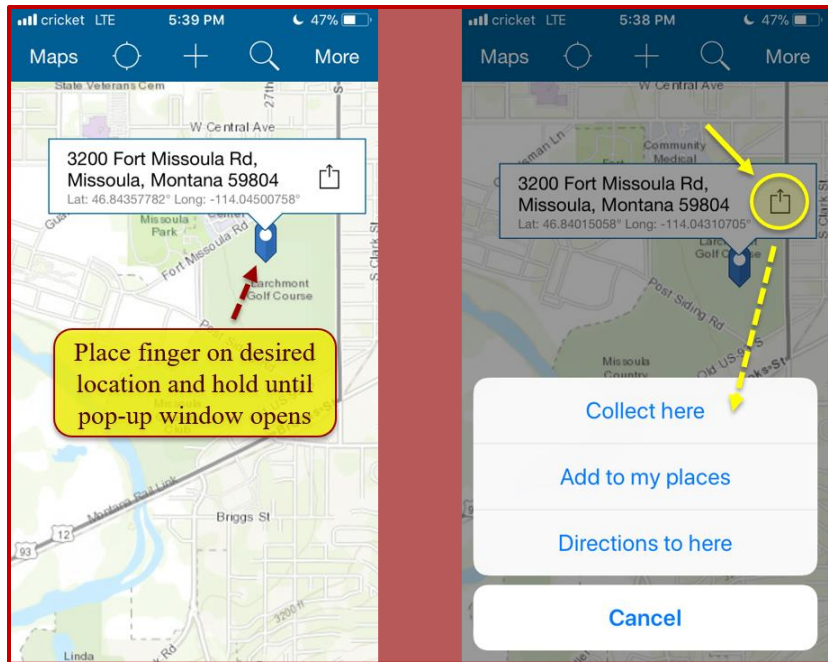


Figure 5B. Manual point feature collection in Collector

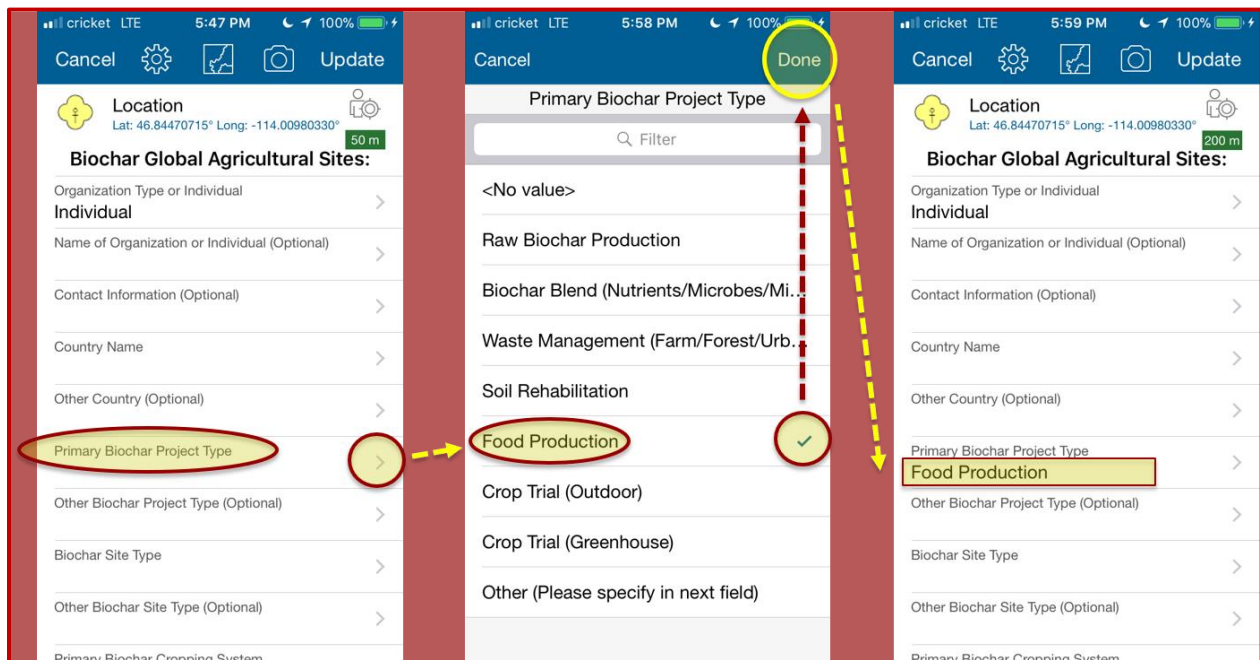


Figure 6B. Collection of point feature attribute domain data in Collector

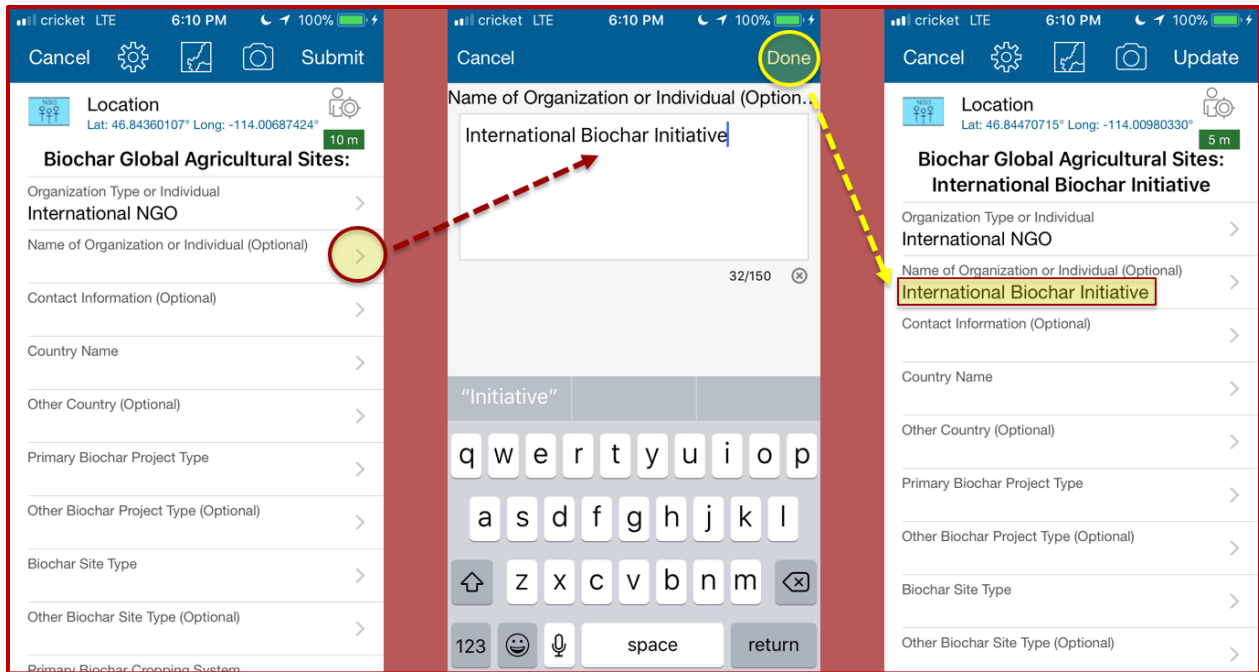


Figure 7B. Collection of point feature text field data in Collector

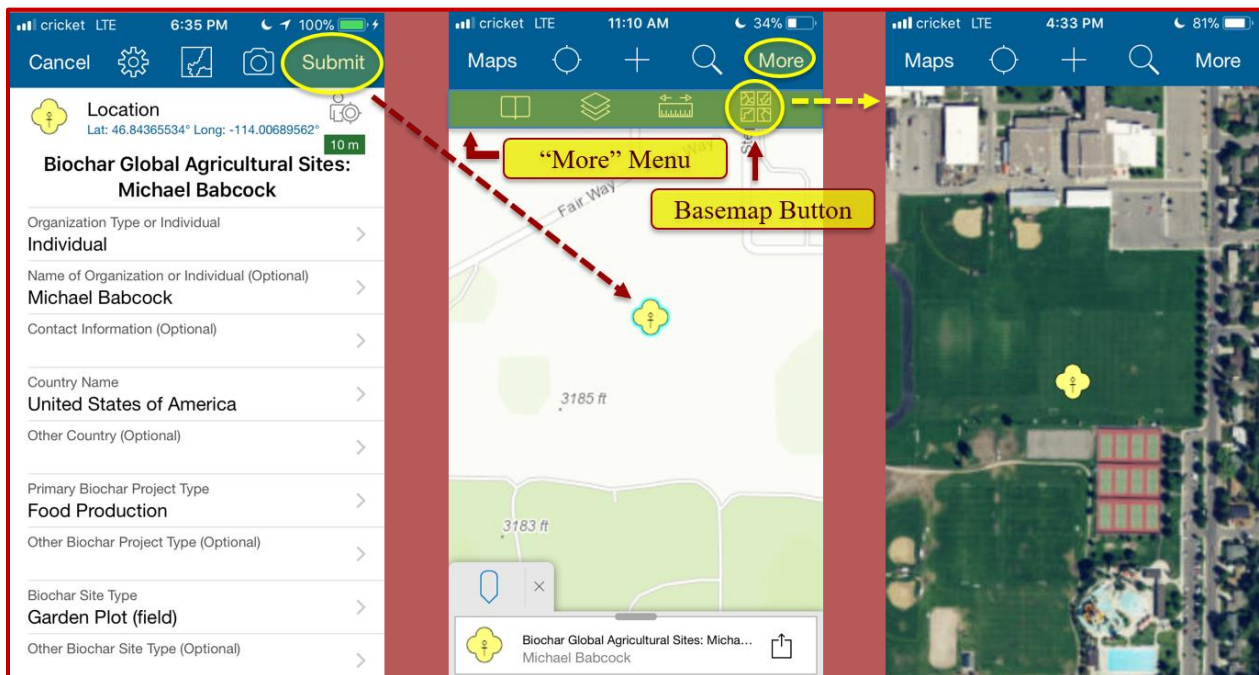


Figure 8B. Point feature attribute data submission and basemap selection in Collector

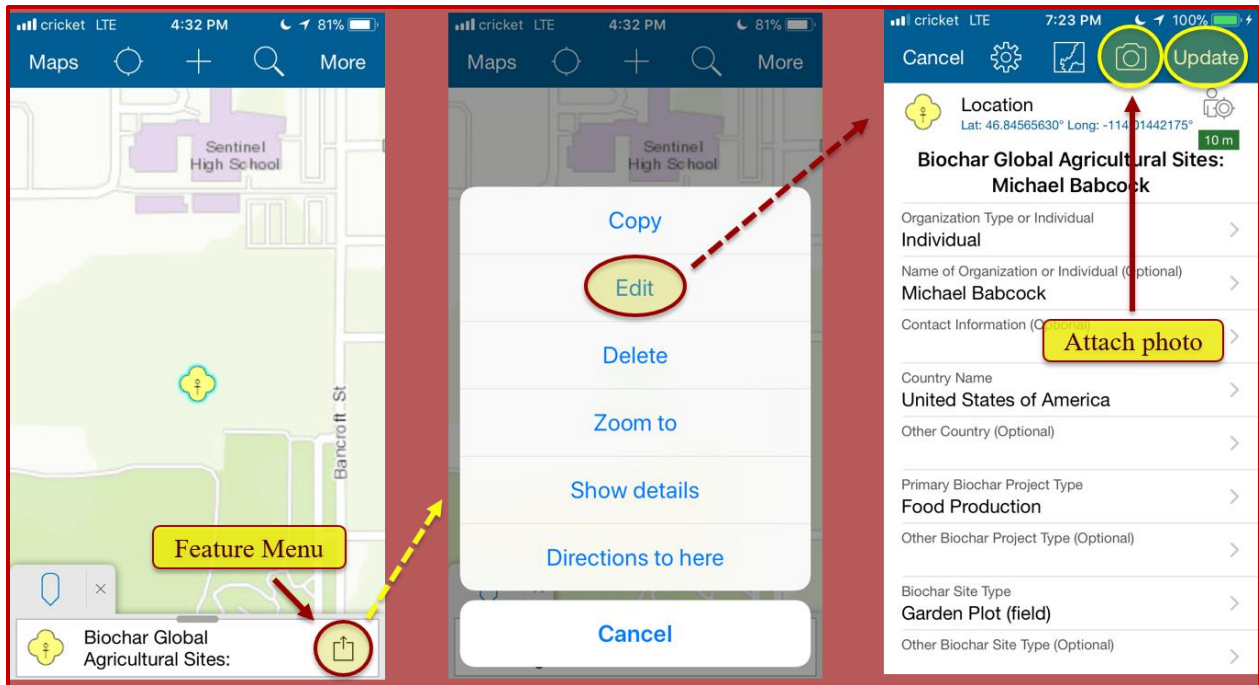


Figure 9B. Editing point feature attributes and attaching photos in Collector

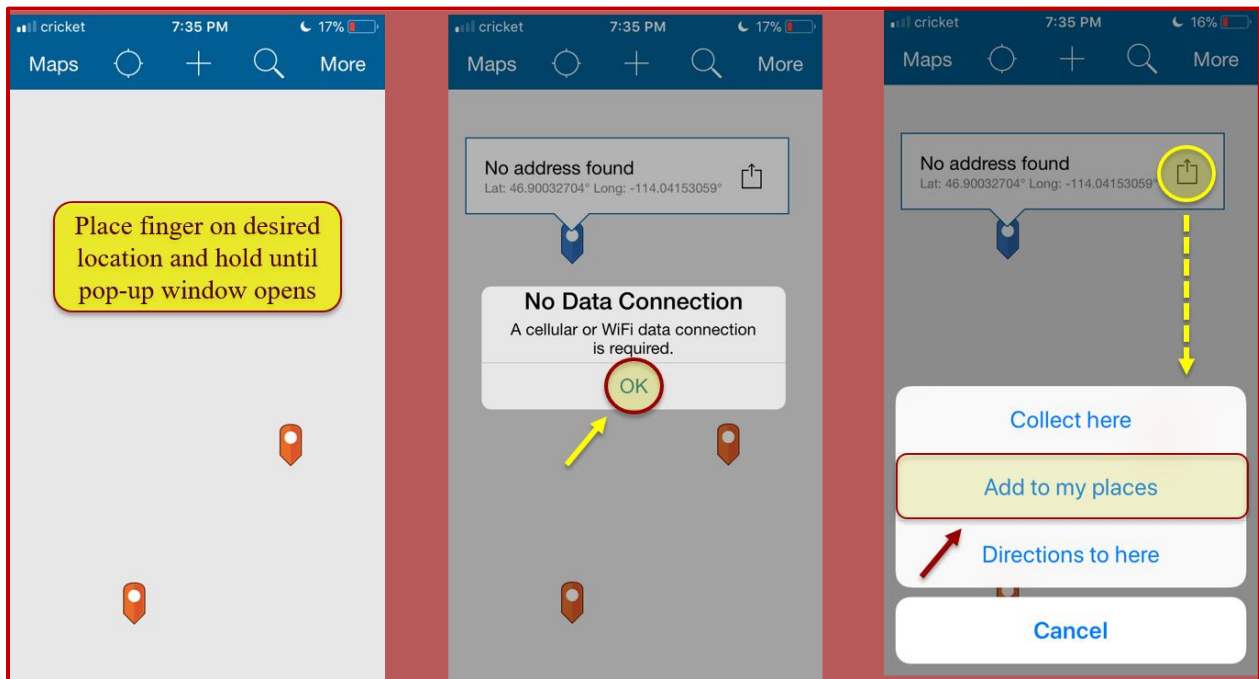


Figure 10B. Offline point feature collection with Collector (Adding Waypoints – Slide 1)

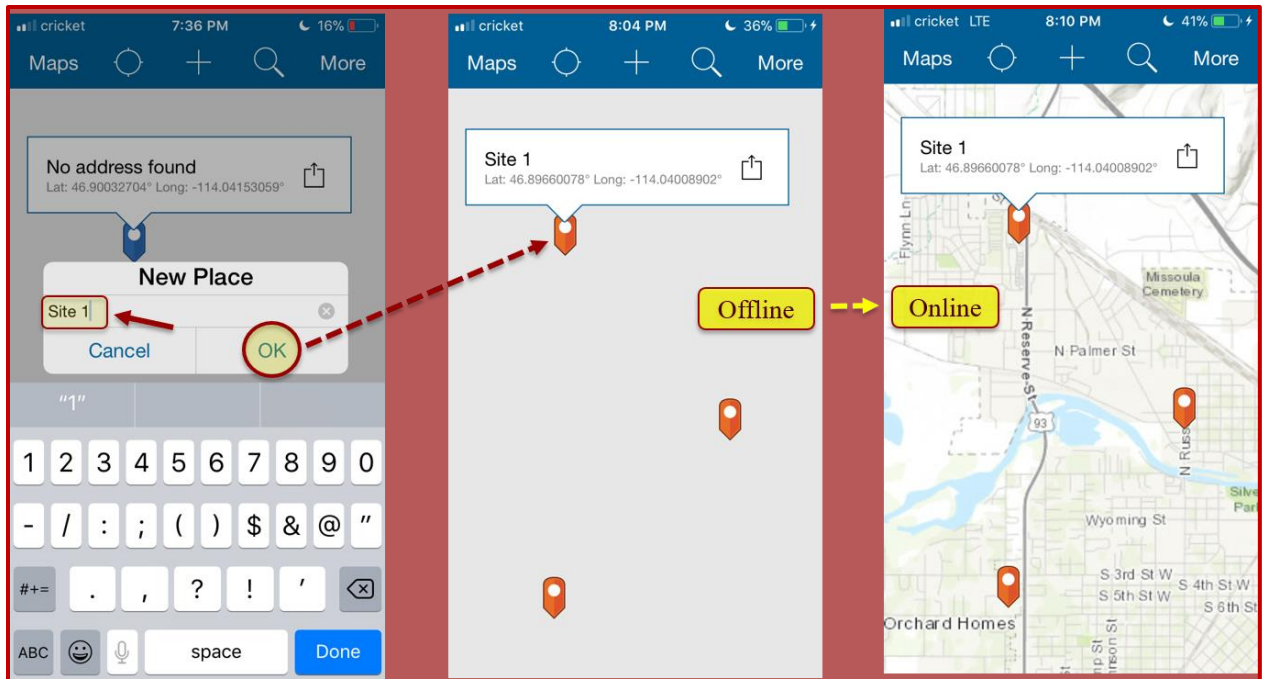


Figure 11B. Offline point feature collection with Collector (Adding waypoints – Slide 2)

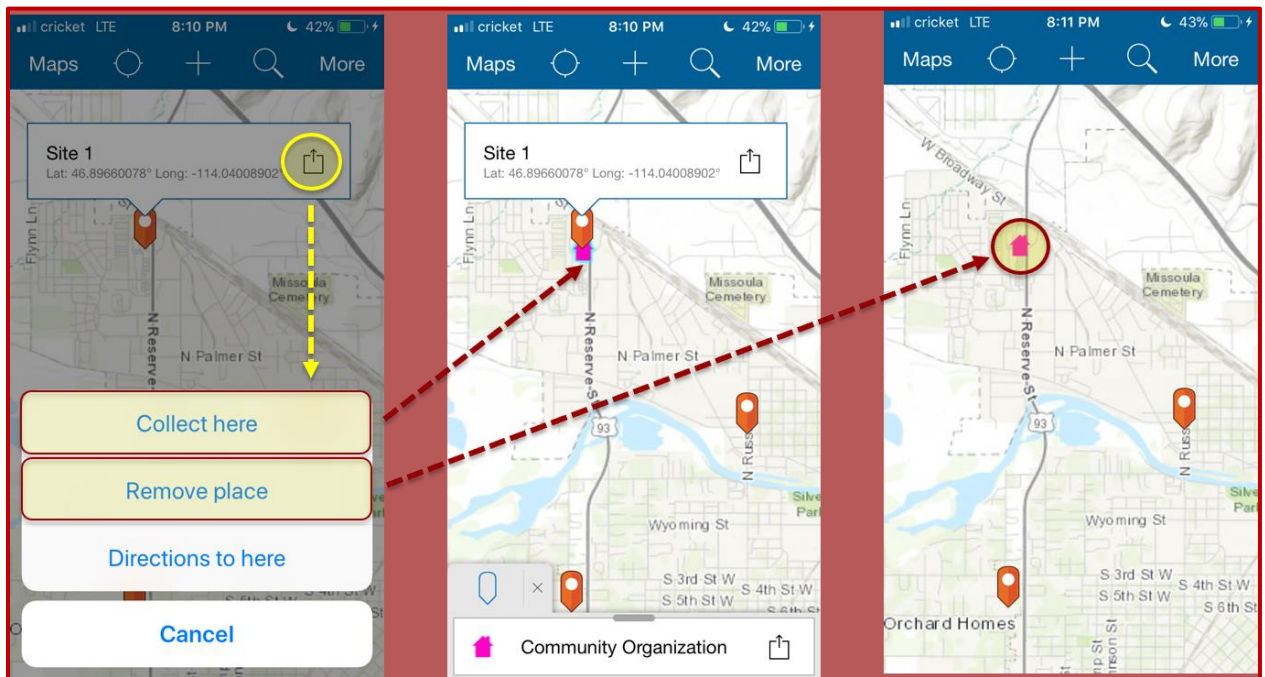



Figure 12B. Online data collection in Collector using waypoints





Appendix C: BfAMT Web-GIS App Help Instructions

THE BIOCHAR for AGRICULTURE MAPPING TOOL

Basic Map Controls are in the upper left corner of the map:


- **Zoom** in and out using the **+/-** buttons or the scroll wheel on your mouse
- Use the **Home**  button to return to the map's full extent
- The **Search** bar allows you to input place names, addresses, and decimal degree coordinates








Widgets, or map tools, are in the upper left corner of the map below the search bar, and in the upper right corner of the map along the top border. Hover over a **Widget's** icon with your cursor to reveal its title. Map **Widgets** from left to right are as follows:



- The **Help Instructions** widget (this widget!) contains instructions for using The Biochar for Agriculture Mapping Tool (BfAMT).
- The **Select Biochar Sites** widget allows you to select an area of the map and view the results in the **Attribute Table** . After clicking the **Select Biochar Sites** tool, you can define an area of interest by clicking and dragging the pointer on the surface of the map. If necessary, move the **Select Biochar Sites** pop-up window to reveal your area of interest. To view the **Attribute Table**  return to the **Select Biochar Sites** pop-up window and click the **'three-dot-menu (...)**'. This will give you the option to **'View in Attribute Table'** that will display an **Attribute Table**  containing all biochar sites within your area of interest. **ALWAYS!** clear your results with the **'Clear'** button in the **Select Biochar Sites** pop-up window, otherwise the biochar sites you selected will remain highlighted in a baby blue color.
- The **Search Biochar Sites** widget contains **preset queries** for searching different biochar site attributes. These **preset queries** are listed under the **'Tasks'** tab. Simply click on a task (i.e., query) and the results are highlighted on the map. A pop-up window appears with the query results. In the pop-up window, you can scroll through your results site by site. These results are limited to the current map extent (i.e., what you see is what you get!).
Therefore, if you want to search the entire database, please hit the **Home** 

button to view the map's full extent. If you want to search a defined area or region, **Zoom** in using the **+/-** buttons and run the task (i.e., query) again.

- The **Chart Tool** widget has **preset chart options** for summarizing biochar site attributes. Simply click on a chart task and choose **'Apply'** to see the results displayed. You have the option to apply a **'spatial filter'** to your results. By checking the **'spatial filter'** box, you can limit your results to the map's extent or an area you defined by you using a drawing tool.
- Click the **Contribute Data** widget to add another biochar project site to the map. Simply click on one of the icon choices to highlight it, then choose your location on the map by using the **Zoom +/-** buttons to specify where exactly you want to place your point. Next, click on the map to place your point. To maintain privacy, you may choose to place a point in the general vicinity of your project area (e.g., same neighborhood, county, or province).
- The **Legend** widget, located in upper right corner of the map along the top border, displays the **LEGEND** for each map layer.
- The **Layer List** widget displays all map layers. If a layer's check box is checked, it should be visible on the map. By unchecking a layer's check box, its features will no longer be visible on the map. To view each map layer's symbology, simply click the small **DOWN** arrow next to the map layer's name.
- The **Basemap Gallery** widget presents a gallery of basemaps and allows you to select one as the basemap for The Biochar for Agriculture Mapping Tool. It is easy to switch basemaps using this widget. Try it out! I like to use the **'Light Grey Canvas'** basemap for clarity. Each time you open the web app it will default to the **'Topographic'** basemap, so you will need to change it to your preferred basemap each time.
- The **Bookmark** widget allows you to add bookmarks for preferred locations on the map. I have already created some regional bookmarks you can use. You are welcome add your own bookmarks. First, zoom to the area you would like to bookmark. Then click the **'Add'** button and name your bookmark. You have the option to **'Edit'** or **'Delete'** your bookmark.

There are several options for viewing, searching, and exporting data from the [Attribute Table](#) :

- To view the entire dataset, you can click the small UP arrow that is centered at the bottom of the map (**Attention:** it's small and hard to see). This will bring up the first few rows of the [Attribute Table](#) . (**Note:** To view more table rows, you will have to use the table's scroll bar, located on the right side of the table. Or, to increase the size of the table, hover over the table's top border with your cursor (until you see a two-way arrow symbol like this one ), then click and drag upward. However, if the expanded table obscures any of the points on the map, you will no longer see these points in the table. So, you'll need to adjust the map view (by zooming out) so that all points are still visible in the map frame. To export data from the [Attribute Table](#)  as an Excel CSV file, you will need to click the arrow next to the **'Options'** tab, located in the upper left corner of the [Attribute Table](#) . You can export the entire table, or you can select which rows you want to export by holding down the **'Control'** button on your keyboard and clicking in the left margin of the rows you want to export. If done correctly, the rows you choose should be highlighted in a baby blue color. Under the **'Options'** menu, you will see an option for **'Export Selected to CSV'**. Once clicked, your Excel CSV table (.csv file) should download to your computer.
- Another way to search biochar site attributes is to use the **'Options'** menu of the [Attribute Table](#) . Click **'Options'** and choose **'Filter'**. Next, click **'Add Expression'** and choose from the drop-down menu options to create your own search expression. The results will be displayed on the map. They can then be exported as an Excel CSV file. **REMEMBER!** to use the **'Filter'** window pop-up to delete your expression, otherwise the map will continue to show only the results from your search (which might be 0!). So, click the **'X'** next to your expression to delete it and allow the map to repopulate with the full range of biochar sites.
- You can also view the entire [Attribute Table](#)  using the [Layer List](#) widget. After clicking the [Layer List](#) icon, you can view a map layer's [Attribute Table](#)  by selecting the **'three-dot-menu (...)'** to the right of the layer name.
- The [Select Biochar Sites](#) tool provides another way to select map data and export it to an Excel CSV file. Open the [Select Biochar Sites](#) tool and use it to select an area of interest (e.g., the continent of Africa). Only those biochar


sites that were selected will show up highlighted in a baby blue color in the [Attribute Table](#) . As described above, use the **'Options'** tab located in the upper left corner of the [Attribute Table](#)  to export the selected records as an Excel .CSV file. (Warning: If you click on the **'three-dot-menu (...)**' in the [Select Biochar Sites](#) pop-up window, you will see an option to **'Export to CSV file'**. However, the cell values in the exported table will show up as coded values instead of text descriptions).

To edit or update your **biochar site's attribute data**, simply click on the icon of the map feature point you created. This brings up a pop-up window with your biochar site's attributes. At the bottom right corner of the pop-up window you will see a **'three-dot-menu (...)**'. Click the **'three-dot-menu (...)**' and choose **'Edit'** from the drop-down list. Now, you can start editing your biochar site's attributes. When finished, simply close the pop-up window and your changes are saved. Using the **'Edit'** feature allows you to add photo and file attachments (e.g., Microsoft Word and PDF files) to your biochar site. Adding document attachments is a unique feature of the **BfAMT web app** that is not possible when using the **Collector for ArcGIS mobile app**, although **Collector** does allow you to upload photos.

I welcome feedback and suggestions for improving The Biochar for Agriculture Mapping Tool (mebabcoc@usc.edu).

Web Author: Michael Babcock, M.S. Candidate, University of Southern California
Product Version: ArcGIS Online 6.3 – October 2018
Kernel Version: 2.10

Appendix D: BfAMT Online Google Survey Questionnaire



Biochar for Agriculture Mapping Tool

My name is Michael Babcock, a Master of Science Candidate in Geographic Information Science & Technology at the University of Southern California's Spatial Sciences Institute (Los Angeles, California). I've developed a web application called the 'Biochar for Agriculture Mapping Tool' that allows users to contribute volunteered geographic information about land restoration, resource management, and agricultural projects amended with biochar.

I welcome and value your feedback on the utility and performance of the mobile and web apps that comprise the 'Biochar for Agriculture Mapping Tool'. This information and consent form provides information about the mobile and web apps and requests that you fill out an online questionnaire at the conclusion of beta testing. Answer only as many questions as you feel comfortable answering.

Your involvement in this study is critical to the development and outreach of the 'Biochar for Agriculture Mapping Tool'. Continue reading for more detailed information about the tool and questionnaire. You can change your mind about participating in this study at any time. Thank you!

The 'Biochar for Agriculture Mapping Tool' web app allows academic researchers, government agencies, non-profit organizations, international non-governmental organizations, community organizations, and individual farmers, gardeners, and biochar enthusiasts to upload their biochar project information—including geographic coordinates, site attributes, photos, and documents—to a map feature service connected to a secure server and database. The web app provides a platform that 1) enables geographic visualization and identification of biochar agricultural sites 2) provides search options for biochar site attributes, and 3) promotes sharing and connectivity within the biochar community.

Beta testing the Biochar for Agriculture Mapping Tool (web app) involves use of the 'Collector for ArcGIS' mobile application for uploading geographic coordinates, site attributes, and photos for your biochar site. Your experience using the 'Collector for ArcGIS' mobile app and the 'Biochar for Agriculture Mapping Tool' web app will be assessed using an Internet-based questionnaire (Google Forms). The questionnaire asks a series of questions about your experience using the mobile and web apps, in addition to some basic demographic questions.

Benefits and Risks: There is no cost, and little risk, to you participating in this voluntary research project. However, if you are ever uncomfortable answering the questions, you can stop and withdraw at any time. The immediate benefit of your participation in this research project is that you will help the developer (Michael Babcock) understand user preferences regarding: 1) the 'Collector for ArcGIS' mobile app, 2) the 'Biochar for Agriculture Mapping Tool' web app, 3) the quality and quantity of user-generated content, and 4) app functionality. The ultimate benefit of your participation in this study is the promotion of information sharing and connectivity within the biochar community.

Confidentiality and Privacy: During the research project, we will keep all data from the survey in a secure location. Study staff—which includes myself (Michael Babcock), my faculty advisor, and two additional USC faculty members who serve on my thesis committee—will have access to the data, although legally authorized agencies, including the University of Southern California Office for the Protection of Research Subjects, have the right to review research records. In the data set, your responses will be anonymized.

Any feedback you provide to help improve the mobile and web apps will be greatly appreciated. Thank you.

Questions: If you have any questions about this project, please contact me at (406) 218-1235 or e-mail (mebabcoc@usc.edu). If you have any questions about your rights as a research participant in this project you can contact the University of Southern California Office for the Protection of Research Subjects by phone at (213) 821-1154 or by e-mail at opr@usc.edu.

Figure 1D. Information section of the BfAMT survey questionnaire Information and Consent Form

Form): The questionnaire asks a series of questions about your experience using the mobile and web apps, in addition to some basic demographic questions.

Benefits and Risks: There is no cost, and little risk, to you participating in this voluntary research project. However, if you are ever uncomfortable answering the questions, you can stop and withdraw at any time. The immediate benefit of your participation in this research project is that you will help the developer (Michael Babcock) understand user preferences regarding: 1) the 'Collector for ArcGIS' mobile app, 2) the 'Biochar for Agriculture Mapping Tool' web app, 3) the quality and quantity of user-generated content, and 4) app functionality. The ultimate benefit of your participation in this study is the promotion of information sharing and connectivity within the biochar community.

Confidentiality and Privacy: During the research project, we will keep all data from the survey in a secure location. Study staff—which includes myself (Michael Babcock), my faculty advisor, and two additional USC faculty members who serve on my thesis committee—will have access to the data, although legally authorized agencies, including the University of Southern California Office for the Protection of Research Subjects, have the right to review research records. In the data set, your responses will be anonymized.

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Questions: If you have any questions about this project, please contact me at (406) 218-1235 or e-mail (mababcc@usc.edu). If you have any questions about your rights as a research participant in this project you can contact the University of Southern California Office for the Protection of Research Subjects by phone at (213) 821-1154 or by e-mail at opr@usc.edu.

* Required

I attest that I am 18 years of age or older. I agree to participate in the research project entitled "Beta Testing the Biochar for Agriculture Mapping Tool". I understand that I can change my mind about participating in this project at any time. (If you agree to participate, PLEASE TYPE YOUR NAME IN THE SPACE BELOW. Your typed signature will serve as your written signature.) *

Mike _____

If you've chosen to participate in the study, please provide your e-mail address, which will be kept confidential in a secure location. Please understand that providing your e-mail address is optional.

Your answer _____

NEXT

Never submit passwords through Google Forms.

This form was created inside of University of Southern California. Report Abuse - Terms of Service

Google Forms

Figure 2D. Consent section of the BfAMT survey questionnaire Information and Consent Form

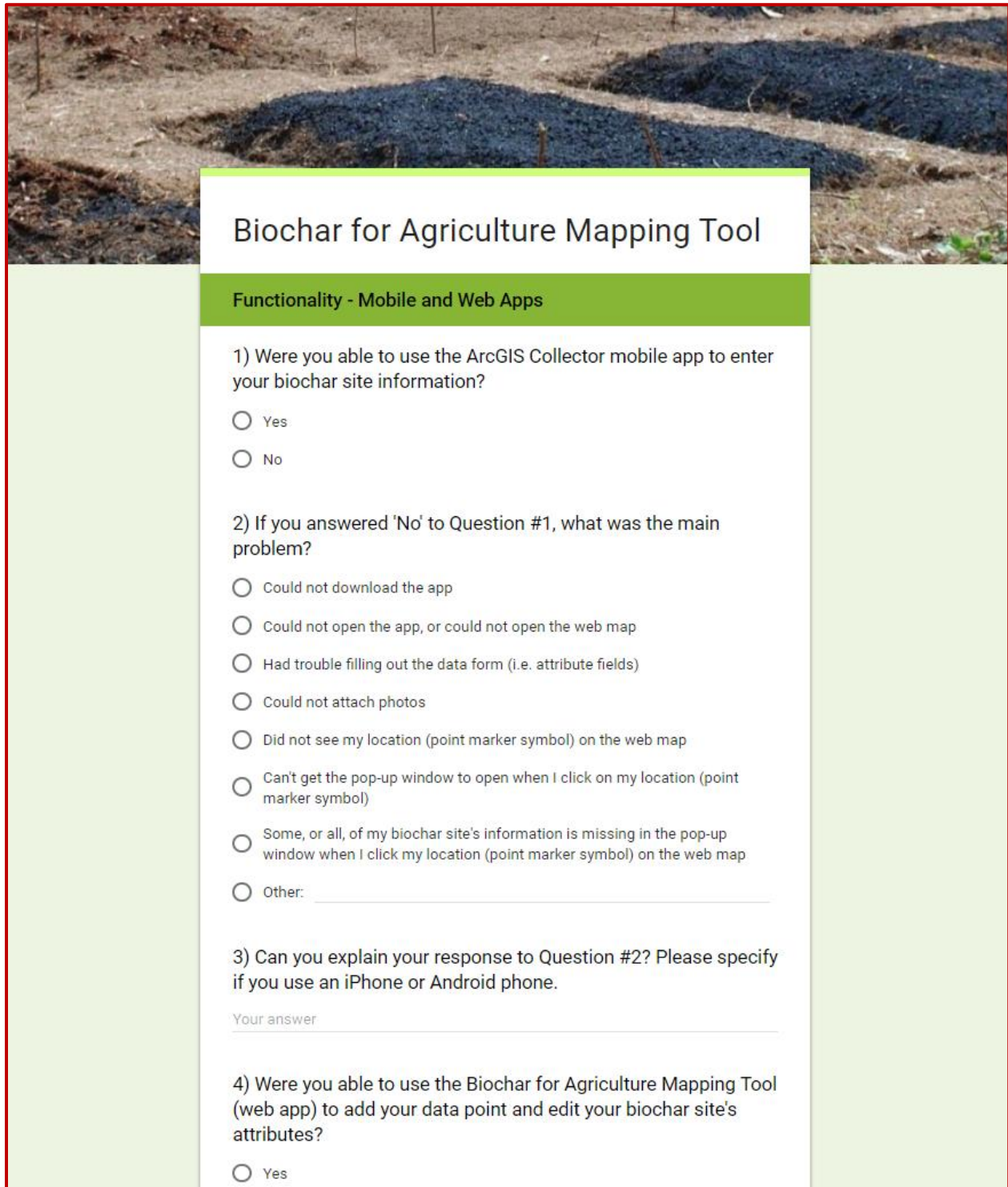


Figure 3D. Functionality section (partial screenshot) of the BfAMT survey questionnaire

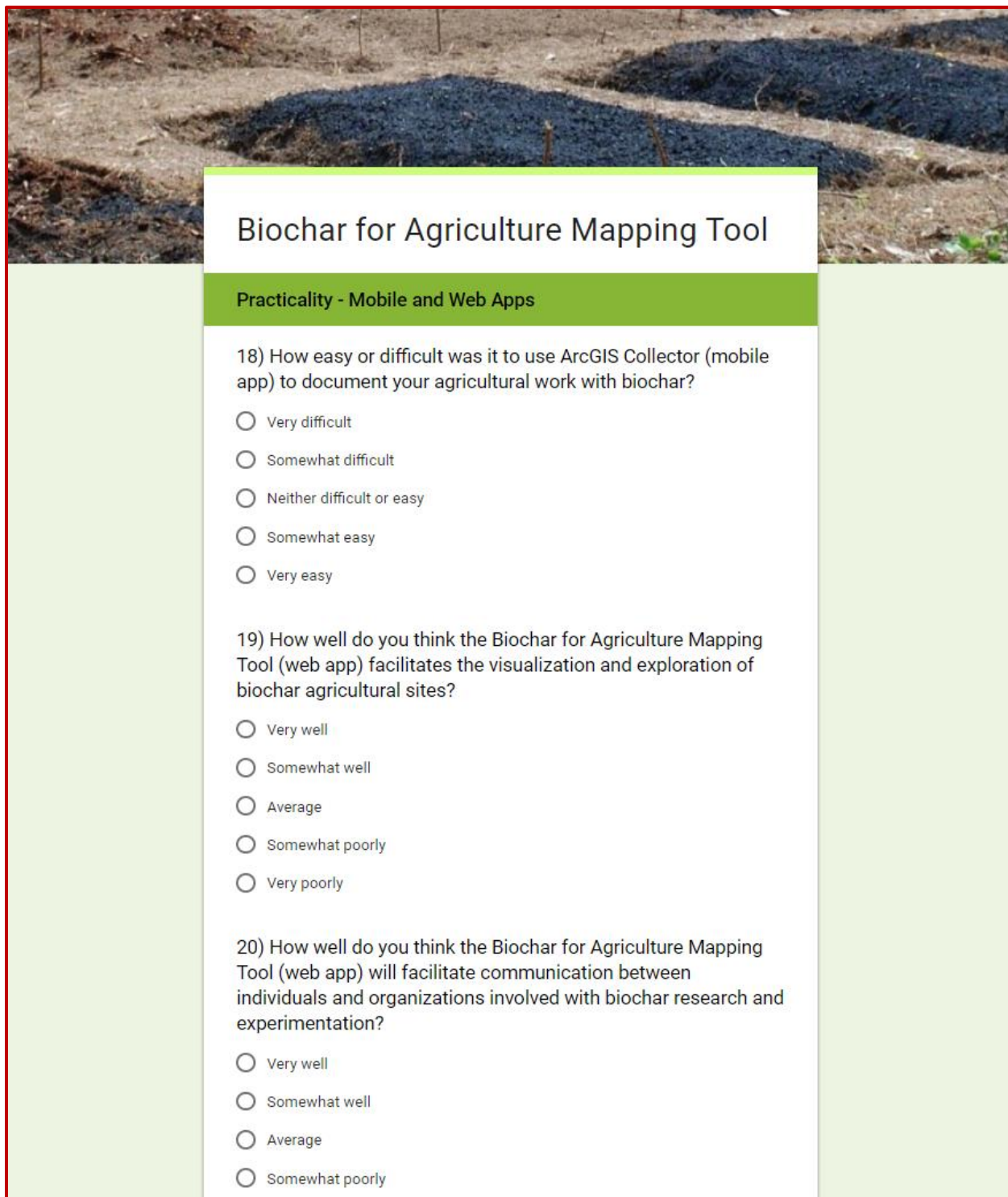


Figure 4D. Practicality section (partial screenshot) of the BfAMT survey questionnaire

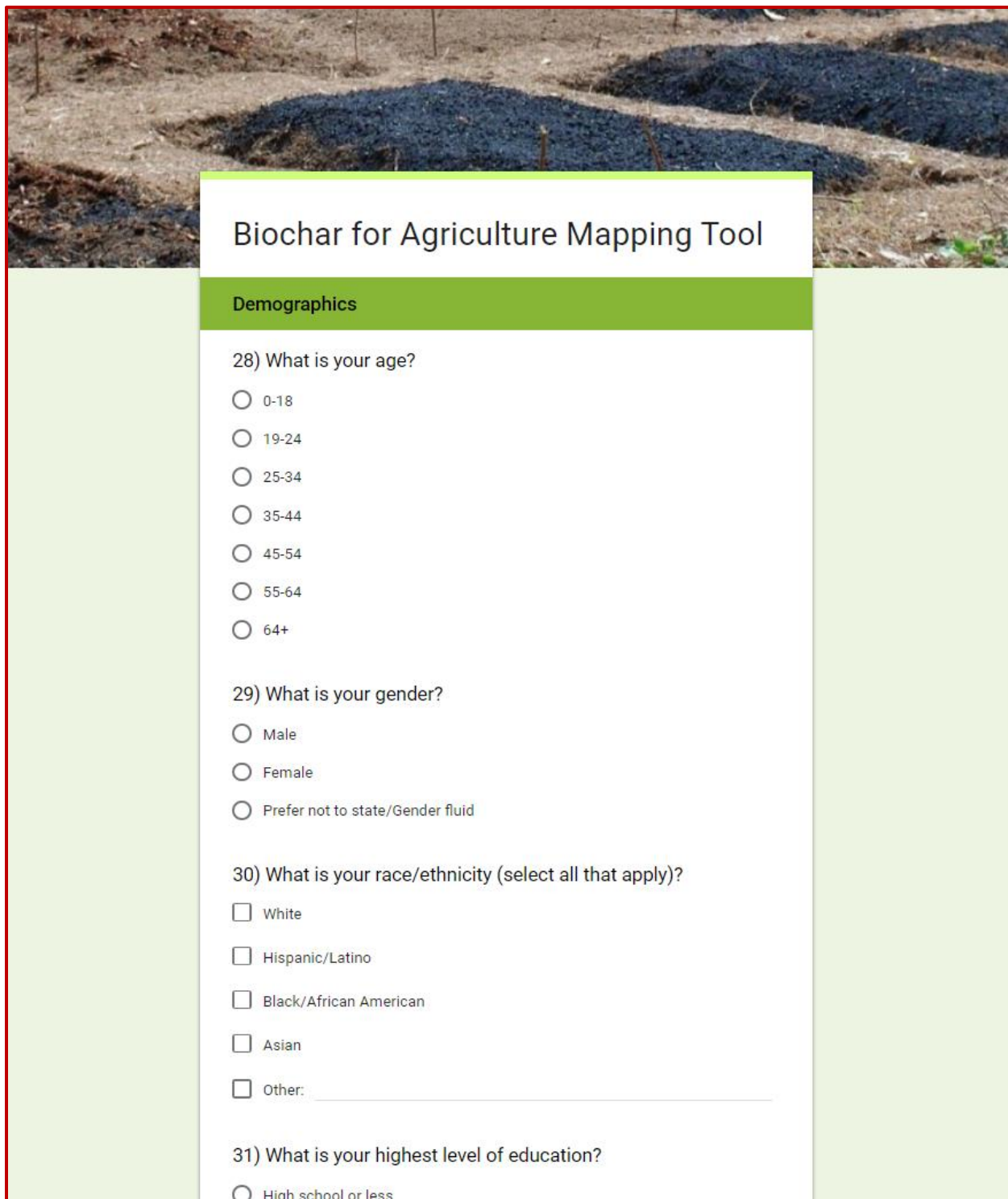


Figure 5D. Demographics section (partial screenshot) of the BfAMT survey questionnaire