

Barriers and Opportunities for Biochar Adoption: Perspectives from Agricultural Stakeholders in Belize

Gerardo Aldana¹
Elisa Lopez-Capel²
David Werner²

Abstract

Agriculture and ecosystem services are fundamental to livelihoods in Belize, underscoring the need to align agricultural productivity with environmental sustainability. This exploratory mixed-methods study examined stakeholder perspectives on biochar adoption using 28 semi-structured interviews and 41 online surveys conducted in 2017, followed by focus groups with 48 participants in 2018. Among the 69 interview and survey participants, farmers comprised 42%, extension officers 23%, educators/researchers 16%, government agents 10%, agricultural suppliers 4%, and other stakeholders 5%. Descriptive results showed that 44.9% reported general familiarity with biochar. In multiple-response items, 92.8% selected potential yield improvement and 66.7% selected environmental protection as motivations, whereas frequently selected barriers included biochar cost (78.3%), skepticism (75.4%), and transportation cost (69.6%). Focus-group participants emphasized education, local field research, and stakeholder collaboration. These findings document perceptions rather than measured agronomic or environmental effects. Although the data were collected in 2017–2018, they provide a baseline for assessing whether awareness, evidence, and institutional readiness have changed as attention to climate-smart agriculture and biochar has expanded.

Keywords: Biochar, climate change adaptation, agricultural sustainability, Belizean agriculture

¹ University of Belize

² New Castle University

Corresponding Author: Gerardo Aldana, Faculty of Science and Technology, University of Belize, Hummingbird Ave, Belmopan, Belize. email: galdana@ub.edu.bz

Introduction

Agriculture is a fundamental driver of Belize's economy. However, increasing demand places significant pressure on agricultural productivity, often leading to unsustainable management of vital natural resources, particularly soils (Chicas & Omine, 2015). Poor soil management negatively affects agricultural output and environmental health, contributing to deforestation, agrochemical contamination, and declining soil fertility (Avella et al., 2008; Kaiser, 2011; Chicas & Omine, 2015). Persistent slash-and-burn practices in Belize have exacerbated soil degradation and dependence on agrochemical inputs (Kaiser, 2011). Degraded soils increase susceptibility to agrochemical leaching, posing risks to environmental integrity and human health (Aldana et al., 2020).

Addressing these challenges requires adapting to sustainable soil management practices, including maintaining soil cover, improving soil structure, promoting biological diversity, applying nutrient amendments, increasing organic matter, incorporating recuperative periods, and limiting tillage (Sherwood & Uphoff, 2000). A promising strategy aligned with these practices is biochar—a carbon-rich material produced by pyrolyzing biomass under oxygen-limited conditions (Woolf et al., 2010). Biochar has been associated with improved soil fertility and reduced nutrient leaching (Aldana et al., 2020), as well as decreased agrochemical and heavy-metal contamination (Tang et al., 2013). Furthermore, biochar production may provide a way to convert suitable agricultural residues into an agricultural input. Successful implementation nevertheless depends on coordinated collaboration among stakeholders involved in education, research, policy, training, and extension (World Economic Forum, 2016). While several studies have evaluated farmers' acceptance of biochar, relatively few have examined broader stakeholder perspectives (Bjerregaard & Georg, 2011; Clare et al., 2014). Research specifically exploring stakeholder attitudes toward biochar implementation in Belize remains scarce despite growing global research on biochar (Zhang et al., 2016).

Belize's agricultural profile also points to several residue streams that could be assessed as biochar feedstocks. Sugarcane, citrus, and corn occupy substantial cultivated areas, and commercial timber production generates woody by-products (Statistical Institute of Belize, 2023). Candidate materials include sugarcane bagasse and field residues, citrus peels and processing residues, corn cobs and stover, and clean sawmill residues. Their technical potential does not establish practical availability: seasonal supply, existing uses, transport distance, moisture, contamination, and sustainable residue-removal rates would need to be quantified before production decisions are made.

Given this gap, understanding stakeholder roles, interactions, and perceptions within Belize's agricultural sector is important for evaluating whether biochar warrants further local research and development. Belize provides a relevant setting because agriculture and ecosystem services are economically important, soil degradation and agrochemical contamination remain concerns, and resource constraints can affect the adoption of unfamiliar technologies. This study therefore aimed to: (1) assess stakeholder familiarity with biochar and perceived relevance to Belizean agriculture; (2) examine stakeholder views on potential motivations and barriers; and (3) document opportunities proposed by participants for research, outreach, and collaboration.

Methodology

Strategy for assessing stakeholders' perceptions

This research adopted an inductive, exploratory approach aimed at gaining comprehensive insights into stakeholder circumstances, interactions, behaviors, attitudes, perceptions, and beliefs regarding biochar implementation (Srivastava & Thomson, 2009). A mixed-methods strategy was employed to effectively combine qualitative and quantitative data, thereby enhancing the depth and robustness of the analysis (Lieberman, 2005). Stakeholders were identified through purposive and snowball sampling techniques (Bryman, 2012), and triangulation was applied to ensure reliability and validity of the findings. Additionally, stakeholders were classified using a stakeholder matrix developed based on their influence and potential contributions toward biochar implementation in Belize. Following the analytical framework used by Sanye-Mengual et al. (2016), the matrix categorized stakeholders by their roles and involvement at various stages of biochar adoption. Table 1 outlines stakeholder categories along with their key contributions and the value derived from their collaboration (World Economic Forum, 2016).

Table 1. Key stakeholder contributions and value derived from collaboration. (Adapted from World Economic Forum, 2016)

Stakeholder Type	Key Contributions	Value Derived from Collaboration
Government	- Set national goals - Establish an enabling policy environment and invest infrastructure and other public goods and services - Create support for farmers and investors.	- Investment in agriculture, complementing public investment - Contributions to major initiatives
Research and Education/ Extension	- Create research that provides stakeholders with new knowledge - Promote partnership in spheres of influence	- The chance to contribute new ideas - Rich insights from “real world” applications
Farmers	- Influence policy and investment by sharing perspectives and recommendations - Identify needs for organization and training, and invest in implementing new practices	- Access to new technologies, information and markets - Increase yield and income
Agricultural Suppliers	- Invest in value chains, with a long-term view of investment that goes beyond short-term profit and considers the sustainability of the sector - Integrate a partnership approach into a long-term business strategy - Introduce new technologies, research or business models	- Establishment of business operations over the long term - Opportunity to innovate with new customers, technologies or business models - Alignment with strategic environmental, social or talent initiatives

Belize was selected for this stakeholder analysis based on several contextual considerations. Firstly, Belize's economy heavily relies on agriculture and natural ecosystem services, emphasizing the need for sustainable strategies that balance agricultural productivity and environmental protection. Secondly, there is an ongoing demand within Belize for effective soil management practices to address soil degradation. Thirdly, degraded tropical soils common in Belize are susceptible to agrochemical leaching, increasing risks of environmental contamination. Finally, given biochar's recognized benefits in enhancing soil health and mitigating contamination risks, Belize represents a particularly suitable context to explore the potential of biochar implementation in agriculture.

Semi-structured interviews and online surveys

Semi-structured interviews were employed to effectively engage stakeholders who had limited or no access to electronic communication, such as farmers residing in rural regions of Belize. These interviews facilitated an open and comfortable dialogue, encouraging participants to freely express their thoughts and perspectives (Srivastava & Thomson, 2009). A total of 28 stakeholders participated in the semi-structured interviews, conducted from March to April 2017. To complement this method, online surveys were administered to stakeholders who were inaccessible during the interview period, particularly government representatives. These online surveys, involving 41 participants, were distributed via the Bristol Online Survey platform from June to August 2017. Both data collection methods shared a consistent structure and thematic approach, encompassing three core areas: challenges in Belizean agriculture, stakeholder environmental awareness, and perspectives regarding biochar implementation. Additionally, the online surveys incorporated dichotomous multiple-choice and open-ended questions to capture diverse quantitative and qualitative responses (Bryman, 2012).

Focus groups

Focus group discussions were conducted in March 2018 to build on findings from the semi-structured interviews and online surveys completed the previous year. These three methods—focus groups, interviews, and surveys—formed the basis of methodological triangulation, enhancing the validity of the study and capturing diverse dimensions of stakeholder perspectives on biochar implementation. The focus groups included a broad range of participants, such as farmers and agents, agricultural suppliers, extension officers, educators, researchers, and government representatives. A total of 48 stakeholders participated in the focus groups, and shared their views on how best to capitalize on the opportunities that biochar presents, as well as how to address key barriers to its implementation in Belize. Additionally, the sessions facilitated the development of a stakeholder network aimed at fostering collaboration and outlining future steps toward the effective adoption of biochar in Belizean agriculture.

Data transcription and analysis

The transcription and analysis of textual and audio data were carried out at Newcastle University, UK. Recordings were transcribed and, where necessary, translated from Belizean Creole or Spanish into English; transcripts were checked against the recordings. Microsoft Excel 2013 and Word 2013 were used to organize the material, and NVivo 11 (QSR International) supported coding and framework analysis. Codes were grouped into recurring themes concerning agricultural challenges, environmental concerns, biochar familiarity, motivations, barriers, and proposed actions. Closed-ended survey items were summarized using frequencies and percentages in Excel 2013 and IBM SPSS Statistics 24. Some questions were dichotomous, whereas questions on agricultural challenges, motivations, and barriers allowed participants to select more than one response; consequently, percentages for those items do not sum to 100%. Unless otherwise stated, percentages use the 69 interview and survey participants as the denominator. Stakeholder-group patterns in Figure 1 are descriptive only. No inferential comparisons were conducted because the exploratory purposive sample produced small and unequal stakeholder subgroups. Focus-group recommendations were coded as multiple mentions; the percentages in Figure 3 describe the distribution of coded recommendations rather than the percentage of participants selecting each option.

Results

Stakeholder Categories and Representation

The study engaged 69 stakeholders through a combination of semi-structured interviews and online surveys. Of these participants, 42% were farmers, 23% were affiliated with extension services, and 16% represented the education and research sectors. Government agents accounted for 10%, agricultural suppliers made up 4%, and the remaining 5% were categorized as “other,” which included companies involved in agricultural media and communications.

Perceived Challenges in Belize’s Agricultural Sector

Stakeholders identified several challenges affecting agriculture in Belize (Figure 1). Because participants could identify more than one challenge, the frequencies are not mutually exclusive. Climate change was the most frequently cited concern and was described in terms of temperature variability, irregular rainfall, hurricanes, floods, and prolonged dry periods. Other recurring concerns included limited funding, restricted market access, inconsistent regulations, limited extension support, land access, production costs, pest management, contraband, low yields, and natural disasters. Apparent differences between farmers and other stakeholders are presented descriptively and were not tested statistically.

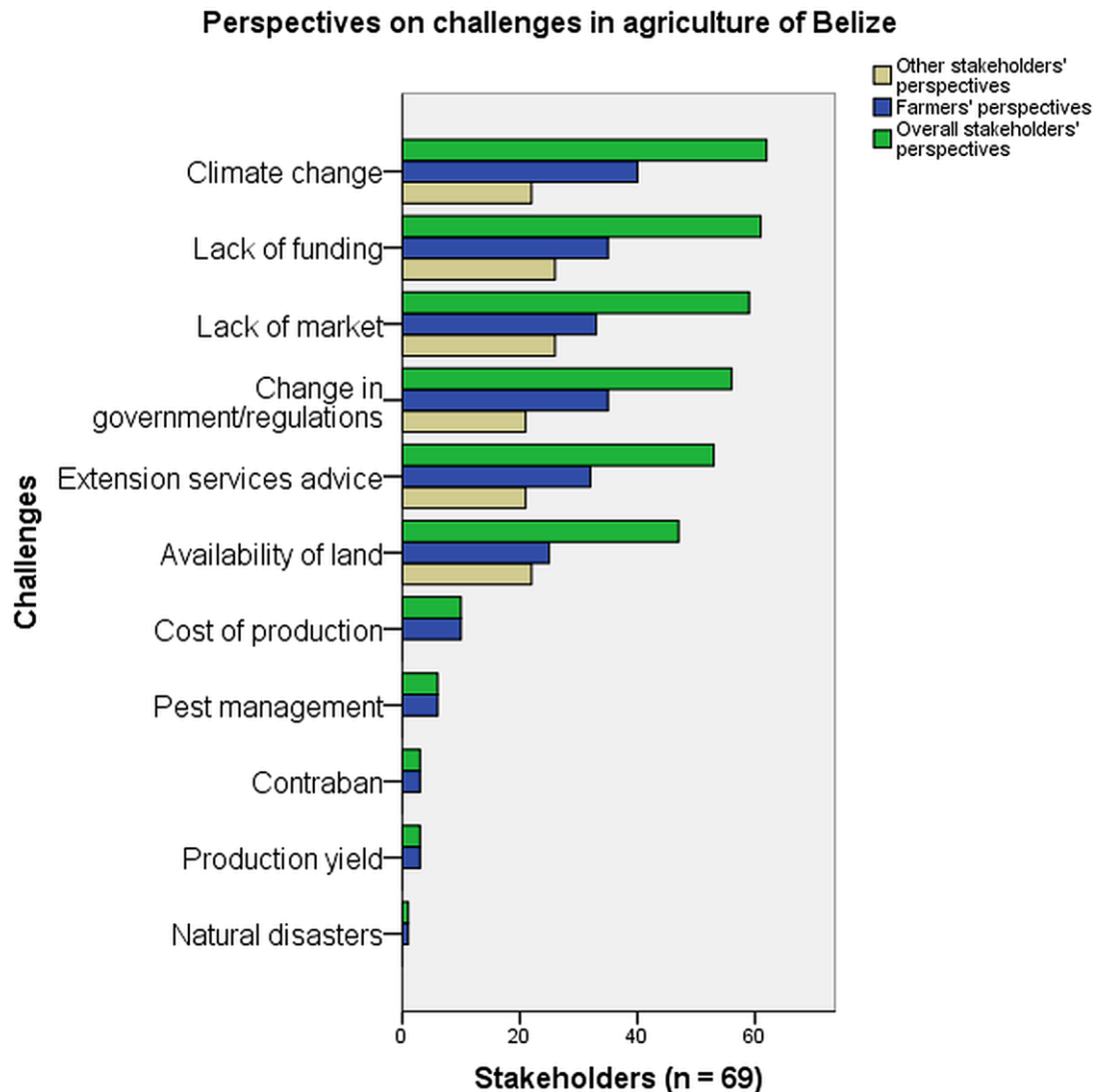


Figure 1. Agricultural challenges identified by stakeholders (n = 69). Multiple responses were permitted; stakeholder-group patterns are descriptive and were not tested inferentially.

Stakeholders' Environmental Awareness and Concerns

To determine the likelihood of biochar being accepted as a strategy for environmental protection, the study assessed the environmental awareness of stakeholders, as seen in Table 2 below. The results showed that 89.9% of the 69 stakeholders considered protecting the natural environment to be important. However, the semi-structured interviews revealed variations in perspectives across different stakeholder categories. Stakeholders' responses indicated that beliefs, traditions, and cultural values influenced their attitudes toward the environment. For example, a subsistence farmer stated, "The natives have always believed that they have to live in harmony with nature." An extension officer from the Belize Agriculture and Health Authority noted that, "Some farmers consider their environment. The more orthodox are concerned about pests being used. Their belief allows them to use minimal pests and fertilizers." A researcher from the Belize Sugar Industry Research and Development Institute remarked, "Farmers are mainly concerned about yield. Most farmers are still in the milpa (slash-and-burn) system. They practice rotational farming. Even though rotational farming is a tradition, it is not good for the environment since eventually the soil will be used up and not fertile." Meanwhile, a

government agent from the Ministry of Agriculture stated, “Farmers know that farming practices affect the environment. The awareness is there, but it is not adequately monitored or evaluated.”

Table 2. Perspectives of different stakeholders on environmental awareness.

Stakeholder category	Organization	Perspective
Farmer	Subsistence farmer	“The natives have always believed that they have to live in harmony with nature.”
Extension officer	Belize Agriculture and Health Authority	“Some farmers consider their environment. The more orthodox are concerned about pests being used. Their belief allows them to use minimal pests and fertilizers.”
Researcher	Belize Sugar Industry Research and Development Institute	“Farmers are mainly concerned about yield. Most farmers are still in the milpa (slash-and-burn) system. They practice rotational farming. Even though rotational farming is a tradition, it is not good for the environment since eventually the soil will be used up and not fertile.”
Government agent	Ministry of Agriculture	“Farmers know that farming practices affect the environment. The awareness is there, but it is not adequately monitored or evaluated.”

The study also assessed perceptions of pesticide pollution to contextualize interest in biochar as a possible agrochemical-attenuation strategy. One participant commented, “Yes, it is a concern, but it is not being dealt with.” Of the 69 stakeholders, 52 (75.4%) regarded pesticide pollution as a problem in Belize and 53 (76.8%) supported safety measures to prevent it (Table 3a). These responses indicate perceived concern; they do not measure pesticide exposure or demonstrate that biochar would reduce contamination under field conditions.

Table 3a. Environmental awareness and pesticide-related concerns among interview and survey participants (n = 69).

Awareness	n	%
Protecting the environment is important	62	89.9
Pesticide pollution is a problem in Belize	52	75.4
Minimizing effects on other citizens is important	59	85.5
Safety measures are needed to prevent pesticide pollution	53	76.8

Note. Items were analyzed as separate dichotomous responses; percentages use n = 69.

In addition to recognizing the problem, stakeholders proposed several solutions, such as increasing awareness about pesticide risks, reinforcing sustainable pesticide practices, and possibly introducing a pesticide pollution tax. Other recommendations included distributing appropriate pesticide disposal containers, offering land tax incentives for low-contamination farming, banning harmful pesticides, and promoting biological pest control methods.

Awareness and Perceived Benefits of Biochar

Biochar research in Belize was initiated in 2011 by the Maya Mountain Research Farm. Of the 69 participants, 31 (44.9%) reported general familiarity with biochar and 14 (20.3%) knew of its use in Belize; nine (13.0%)

indicated that adequate information was available. In a multiple-response item, potential higher yield was selected by 64 participants (92.8%), improved plant health by 56 (81.2%), improved soil health by 55 (79.7%), environmental protection by 46 (66.7%), and ease of handling and application by 40 (58.0%) (Table 3b; Figure 2). These percentages represent anticipated benefits that could motivate use, not measured outcomes of biochar application.

Table 3b. Biochar familiarity and motivations among interview and survey participants (n = 69).

Familiarity and Motivations	n	%
Adequate information reported	9	13.0
General familiarity with biochar	31	44.9
Familiarity with biochar use in Belize	14	20.3
Potential higher yield	64	92.8
Potential improved plant health	56	81.2
Potential improved soil health	55	79.7
Environmental protection	46	66.7
Ease of handling and application	40	58.0

Note. Motivation items allowed multiple selections; percentages therefore do not sum to 100%.

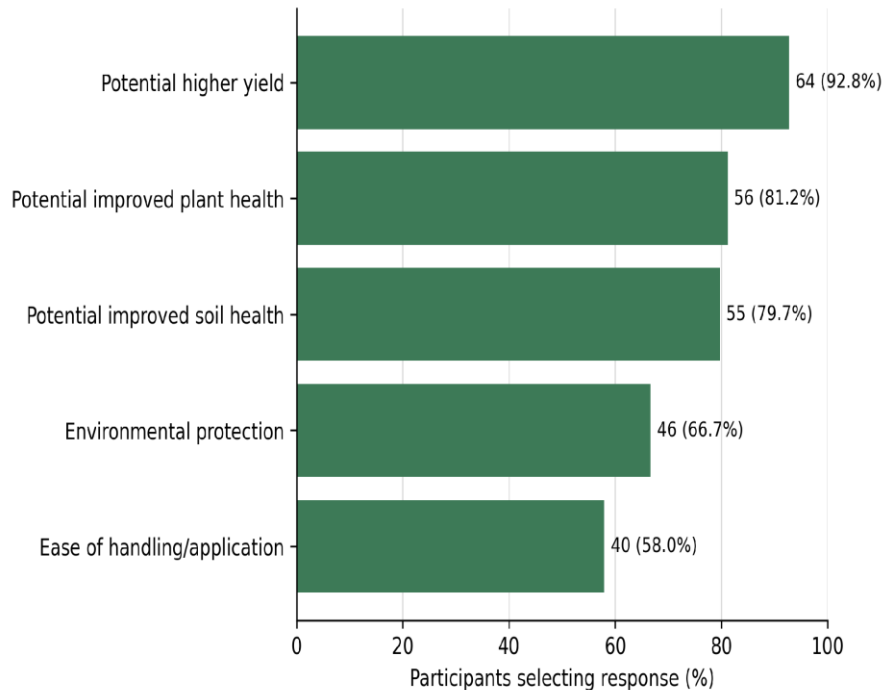


Figure 2. Motivations for possible biochar use among interview and survey participants (n = 69). Multiple responses were permitted.

Perceived Barriers and Recommendations for Biochar Implementation

Stakeholders selected several perceived barriers to biochar adoption (Table 3c). The most frequently selected were biochar cost (54; 78.3%), skepticism about effectiveness (52; 75.4%), transportation cost (48; 69.6%), limited processing technology (36; 52.2%), and an underdeveloped market (34; 49.3%). Government regulations were selected by 24 participants (34.8%), and lack of feedstock by 18 (26.1%). Because this was a multiple-response item, percentages do not sum to 100%. Focus-group recommendations included education, training, local field trials, research, and stronger stakeholder collaboration (Figure 3).

Table 3c. Perceived barriers to biochar adoption among interview and survey participants (n = 69).

Barriers	n	%
Biochar cost	54	78.3
Skepticism about effectiveness	52	75.4
Transportation cost	48	69.6
Limited processing technology	36	52.2
Underdeveloped market	34	49.3
Government regulations	24	34.8
Lack of feedstock	18	26.1

Note. Participants could select multiple barriers; percentages therefore do not sum to 100%.

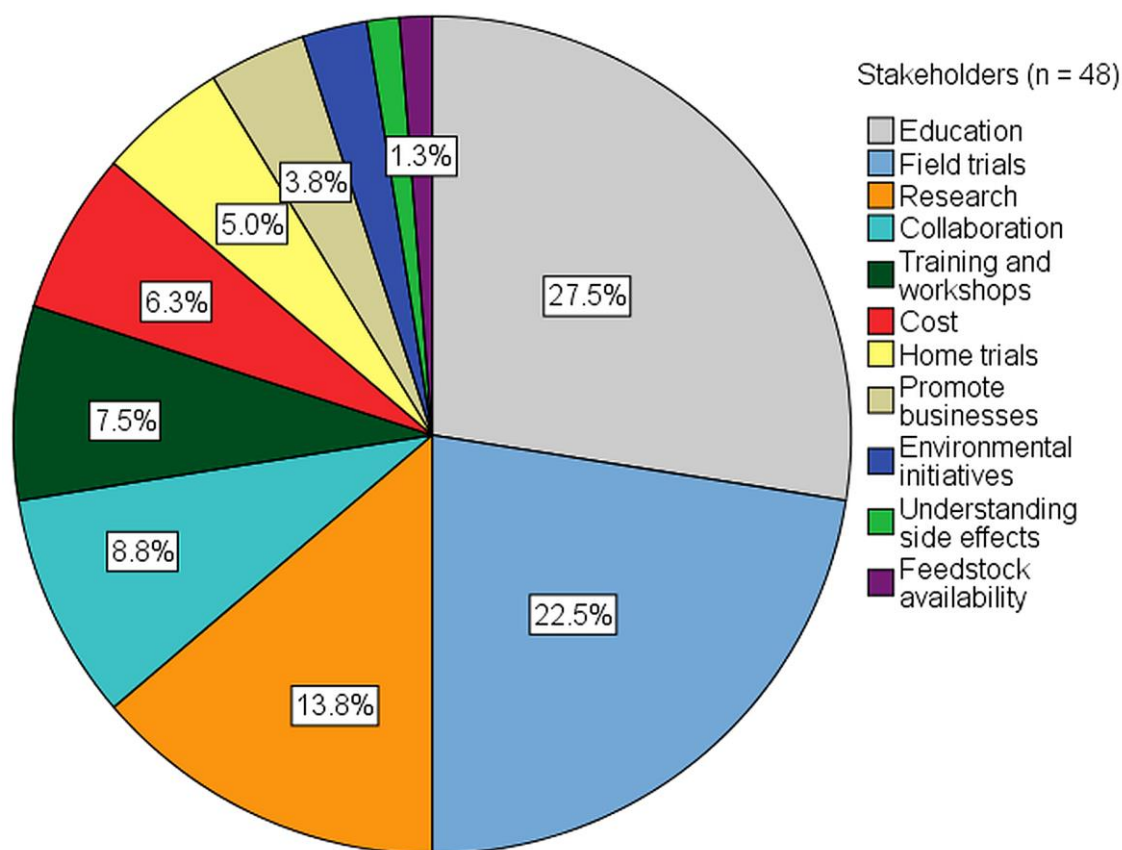


Figure 3. Distribution of recommendations coded from focus-group discussions (48 participants). Percentages refer to coded recommendations, not the percentage of participants selecting each response.

Discussion

Implications of Stakeholder Distribution for Biochar Adoption

The distribution of stakeholders highlights a diverse cross-section of Belize's agricultural sector, with farmers representing the majority. This is expected given the country's agrarian economy and the direct relevance of biochar to farming practices. The inclusion of extension officers, educators, researchers, and government agents reflects the multidisciplinary nature of biochar implementation, which relies on technical knowledge, outreach,

and supportive policy. The small percentage of agricultural suppliers and media groups underscores a gap in private sector and communication stakeholder involvement, which could be crucial for promoting awareness and facilitating adoption.

Addressing Sectoral Challenges to Enhance Biochar Feasibility

The prominence of climate change among stakeholder concerns is consistent with the vulnerability of tropical and subtropical agriculture to climate variability (Jones & Thornton, 2003). Participants' experiences may help explain interest in climate-smart strategies, but this study did not test whether such experiences predict willingness to adopt biochar. Empirical research indicates that appropriately produced and applied biochar can contribute to carbon storage and, under some conditions, improve soil properties; however, outcomes vary with feedstock, pyrolysis conditions, soil, crop, and application rate (Stavi & Lal, 2013; Zhang et al., 2016). The present results therefore establish perceived relevance and research priorities rather than the effectiveness of biochar in Belizean production systems.

The lack of funding and market access reflects broader development challenges. Without investment in infrastructure and logistics, agricultural productivity and value chain integration remain constrained. Stakeholder concerns about shifting policies align with Kirkpatrick and Parker's (2001) observation that developing countries rarely apply Regulatory Impact Assessments (RIAs), which could otherwise improve accountability and support sustainable development. Extension services emerged as a critical link between knowledge and practice. Goodwin and Gouldthorpe (2013) argue that for extension to be effective, it must align with farmers' specific needs and enhance interaction and trust.

The paradox of underutilized arable land—despite its availability—points toward issues in land governance. Policies that complicate land tenure discourage long-term investments in sustainable land management, including biochar application (Godfray et al., 2010). Lastly, the mismatch in perceived challenges between farmers and other stakeholders highlights the need for stronger communication and engagement. A multisectoral approach could bridge these perspectives and align priorities for more integrated agricultural development strategies in Belize.

Cultural and Knowledge Factors Influencing Environmental Attitudes

The findings suggest that while most stakeholders are environmentally aware, their understanding and actions are deeply influenced by cultural values, social norms, and traditions. This aligns with McFarlane and Boxall (2003), who argue that value orientation and socialization play a more significant role in shaping environmental behavior than factual knowledge. Thus, promoting environmental networks or organizations could enhance motivation among farmers to act in support of environmental protection goals. The strong awareness of pesticide-related issues further demonstrates stakeholders' concern for environmental health. However, as Villamizar and Brown (2016) highlight, many developing countries lack proper systems for pesticide monitoring and management. The cases of pesticide drift into protected areas and the presence of organochlorine contaminants in wildlife (Wu et al., 2000; Kaiser, 2011) underscore the urgency of this issue in Belize.

Given that pesticide misuse poses direct risks to both human and ecosystem health, stakeholder suggestions—ranging from education to regulation—are aligned with global best practices. The desire to protect the environment may be driven by both ecological awareness and lived experience. As Spence et al. (2011) noted, past encounters with environmental disasters shape core values, which, according to Michel-Guillou and Moser (2006), guide pro-environmental behavior. Therefore, promoting biochar as an environmentally beneficial strategy must go beyond technical facts. As Rajapaksa et al. (2018) argue, it should be framed as a tool not just for environmental preservation but also for safeguarding the economic and personal well-being of the stakeholders who depend on the land.

Motivational Drivers and Information Gaps in Biochar Adoption

Although biochar is a relatively new concept in Belize, the awareness among stakeholders was higher than anticipated. This may be due to targeted outreach efforts, increasing global attention on climate-smart agricultural practices, or the diverse composition of the stakeholder group surveyed. The general-familiarity level (44.9%) is notably higher than that reported in Latawiec et al. (2017), where only 27% of Polish farmers

were familiar with biochar. However, their study focused solely on farmers, while the current study engaged a broader range of stakeholders, similar to the inclusive approach used by Bjerregaard and Georg (2011).

The findings suggest that limited knowledge may be one factor constraining uptake, but the study did not measure actual adoption behavior or establish causation. Perceived costs, skepticism, infrastructure, market conditions, and institutional support were also prominent. Factual knowledge alone may therefore be insufficient; adoption decisions are likely to depend on whether locally demonstrated performance, costs, and risks align with stakeholder priorities.

The high proportion selecting potential yield improvement (92.8%) indicates that expected agronomic returns are central to stakeholder interest. Clare et al. (2014) similarly found that farmers' assessments of economic value depend on whether benefits offset costs. The 66.7% selecting environmental protection indicates that perceived environmental value may also influence interest. Neither result demonstrates that biochar will increase yield or reduce pollution in Belize; those outcomes require locally replicated field and laboratory evidence.

Strategic Approaches to Overcoming Implementation Barriers

The findings indicate interest in biochar alongside overlapping practical and institutional constraints. Cost, transportation, processing capacity, market development, regulation, and skepticism were reported perceptions, not independently verified market or policy conditions. Nevertheless, their recurrence identifies issues that feasibility studies should examine. The response concerning feedstock is particularly informative: while 26.1% selected lack of feedstock as a barrier, Belize's production of sugarcane, citrus, corn, and timber indicates potential residue streams—including bagasse and cane trash, citrus processing residues, corn cobs and stover, and sawmill by-products—that warrant technical assessment (Statistical Institute of Belize, 2023). Availability should not be assumed: competing uses, moisture, collection distance, contamination, conversion efficiency, and sustainable removal rates must be evaluated before any residue is classified as a viable biochar feedstock.

Focus-group recommendations emphasized research, outreach, capacity-building, and stronger collaboration among stakeholders. Mehmood et al. (2017) noted that biochar research has been concentrated in developed countries, with less attention to tropical developing nations. Advancing biochar research in Belize will therefore require attention to technological and financial barriers, stakeholder networking, interdisciplinary research, and targeted education. Stronger linkages among government, researchers, extension officers, and farmers could support locally appropriate evaluation and, where evidence warrants, integration into agricultural practice.

Temporal relevance and study limitations

The data represent stakeholder perceptions in 2017–2018 and should not be interpreted as a current prevalence estimate. Awareness, policy attention, climate-smart agriculture programming, biochar research, input prices, and market conditions may have changed substantially since collection. The study nevertheless remains relevant as an early national baseline: it identifies the knowledge, evidence, cost, logistics, and coordination issues against which newer surveys and adoption studies can assess change. Belize's later climate-smart agriculture profile and more recent agricultural statistics continue to emphasize climate risk and substantial sugarcane, corn, citrus, and forestry activity (World Bank et al., 2018; Statistical Institute of Belize, 2023), preserving the relevance of questions about locally appropriate residue management and soil amendments. Additional limitations include purposive and snowball sampling, unequal stakeholder-group sizes, self-reported responses, possible overlap between interview and online-survey modes, and the absence of inferential subgroup tests.

Conclusion

Summary of Findings

This study documents stakeholder perspectives on biochar adoption in Belize using interviews and surveys conducted in 2017 and focus groups conducted in 2018. Participants reported moderate familiarity with biochar and frequently selected potential yield, soil, plant-health, and environmental benefits as motivations. They also identified cost, skepticism, transportation, processing, markets, regulation, and feedstock as perceived barriers.

These findings describe awareness and expectations at the time of data collection; they do not establish biochar effectiveness, current adoption levels, or causal relationships.

Participants also expressed concern about climate variability, funding, policy continuity, land access, and extension support. These themes help locate biochar within wider agricultural constraints: even a technically effective amendment may not be adopted if evidence, finance, logistics, advice, or markets are inadequate. The findings therefore support staged evaluation rather than immediate large-scale promotion.

Implications

Stakeholders perceived biochar as a potential multi-benefit technology, but the study provides social evidence about expectations and constraints rather than agronomic proof. Empirical literature supports possible contributions to soil management, carbon storage, and contaminant sorption, while also showing context-dependent outcomes. For policymakers and development organizations, the immediate implication is to test performance, safety, costs, feedstock supply, and farmer acceptability under Belizean conditions before designing incentives or scaling programs.

Recommendations

Four actions are recommended. First, conduct replicated field and laboratory studies across relevant Belizean soils, crops, feedstocks, and production conditions, including contaminant testing and cost–benefit analysis. Second, use demonstration plots and participatory trials to communicate both benefits and limitations. Third, map residue quantities, competing uses, collection costs, and sustainability constraints for sugarcane, citrus, corn, and forestry by-products. Fourth, strengthen coordination among farmers, extension officers, researchers, government agencies, processors, and suppliers. Policy or financial support should follow—not precede—credible evidence of agronomic performance, environmental safety, economic feasibility, and stakeholder demand.

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