Awareness and interest in Biochar Soil Amendments in Northern Namibia

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Abstract. Bush encroachment is a major driver of soil degradation in Northern Namibia, threatening rangeland health and agricultural productivity. This study investigated local awareness and interest in biochar production as a soil amendment derived from encroached bush biomass. We delivered identical workshops in three constituencies in the Ohangwena Region, targeting smallholder farmers and combining technical lectures on biochar with both technical and practical sessions on composting and tree planting, and then measured the determinants of attendance, knowledge gains, and practice preferences. Our results found that households living farther from the training venue and local administrative office were more likely to attend and rate the training as more valuable, suggesting that formal workshops fill an information gap in remote areas. In contrast, tenure-secure households showed less urgency to adopt organic soil amendments and practices that demand extra labor, time, and on-farm biomass, which may strain their available resources. These findings underscore the need for decentralized training programs closer to remote and smaller village clusters, targeted engagement with land-secure farmers, and community-based forestry arrangements to support collective soil fertility management and tree-planting efforts.

1 Introduction

Sub-Saharan Africa has suffered a chronic decline in soil fertility due to intensified cropping practices, including continuous cultivation, declining manure inputs, extensive removal of crop residues for fuel and fodder, and loss of protective ground cover [1]. Limited access to inorganic fertilizers and insufficient organic amendments under escalating demand for productivity further exacerbate nutrient mining [2]. In Namibia, persistently low fertility has driven heavy reliance on chemical fertilizers to maintain

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yields; however, overapplication, particularly of nitrogen-rich formulations, can accelerate soil organic matter mineralization, degrade structure, and induce environmental harm [3]. Consequently, chemical fertilizers alone are insufficient to sustain soil fertility and long-term yield.

Therefore, it is imperative to promote soil amendment practices. Soil amendments are added to improve the soil's physical structure, chemical properties, and nutrient-holding capacity, thereby enhancing overall soil quality and crop productivity. While inorganic nitrogen fertilizers effectively replenish N deficits and boost short-term yields, organic amendments such as compost and biochar sustainably increase soil organic carbon (SOC), improve porosity, and enhance water and nutrient retention [4]. As organic materials typically contain lower nutrient concentrations than synthetic inputs, integrated application strategies that combine both amendment types are recommended to optimize soil health and crop performance.

Namibia's once-open savanna landscapes are now increasingly dominated by dense thickets of native woody species –a process known as bush encroachment. According to Uchezuba *et al.* (2019), 26-31 million hectares of Namibian farmland and rangeland have become bush-encroached, and this area continues to expand annually [5]. Encroachment reduces grass cover, degrades biodiversity, and impairs soil water-holding capacity, leading to a two-thirds loss in grazing productivity. Principal invader species in northern Namibia include *Senegalia mellifera* (formerly *Acacia mellifera*), *Vachellia reficiens* (*Acacia reficiens*), *Colophospermum mopane*, *Dichrostachys cinerea, Rhigozum trichotomum, Terminalia prunioides* and *Terminalia sericea*.

Recently, new technologies have gained attention for simultaneously addressing bush encroachment and converting woody biomass into biochar via slow pyrolysis under low-oxygen conditions. Biochar derived from encroaching bush biomass offers a sustainable solution. It is carbon-rich, stable product that improves soil properties, enhances nutrient availability, stimulates soil microbial activities, stabilizes contaminants, and increases soil organic carbon and carbon sequestration [6]. Its porous structure, large surface area, and resistance to decomposition make it preferable to other organic amendments.

Biochar not only improves soil fertility but also lowers soil pH, increases soil organic carbon and nutrient levels, activates nutrients, and enhances fertilizer efficiency. However, caution is required in alkaline soils [7]. Further literature shows that combined biochar and nitrogen application can improve soil fertility in low- to medium-yield fields, though effectiveness depends on dosage. However, excessive application may harm crop growth, soil fertility, and antioxidant systems. Biochar can greatly increase soil SOC, potassium, phosphorus, and calcium, thereby enhancing nutrient recycling, retention, and overall soil fertility [8]. The effects of organic soil amendments such as biochar, compost, and their combination on soil properties and yield have been documented for pearl millet [9], one of the region's staple crops. A few studies have also examined the combined use of organic amendments and nitrogen fertilizers [10].

Despite the multiple co-benefits and economic opportunities associated with biochar, its adoption remains low. This is due to limited awareness and technical knowledge in many parts of the country, as well as underdeveloped markets and a shortage of materials for large-scale biochar production in northern Namibia. An additional institutional barrier is the restriction on harvesting encroaching bushes in communal areas under the Forest Act No. 12 of 2001. This regulation limits biomass utilization in Namibia's predominantly communal northern regions. However, harvesting is permitted through legally recognized entities such as community forests and cooperatives.

The Namibian government has outlined governance frameworks and management systems for sustainable bush control in communal areas through the National Strategy on the Sustainable Management of Bush Resources 2022–2027 [11]. This strategy encompasses both communal and commercial areas. Therefore, understanding the levels of awareness and interest among land users, agricultural stakeholders, and local communities is essential for developing inclusive, context-specific strategies to promote biochar adoption.

Compared to composting, biochar is a relatively new technology that requires technical expertise and is often labor-intensive. Interest in biochar is often accompanied by other sustainable practices, such as composting and tree planting. This study builds on these premises by examining the factors that influence smallholder households' engagement with biochar and composting as soil amendment technologies. Specifically, it addresses three questions: (1) What drives households to participate in soil amendment training? (2) What determines their interest in applying biochar and compost on their farms? (3) Which household characteristics best predict knowledge of biochar and composting techniques?

To explore these questions, we implemented a training program targeting smallholders in northern Namibia. The program promoted the planting of drought-resistant native and indigenous tree species with multipurpose benefits (see [12]) and provided instruction on the use of biochar and compost as soil amendments for tree planting.

2 Methodology

2.1 Data and context

We conducted our study in northern Namibia, specifically in the Ohangwena region, a natural habitat for important indigenous timber and fruit trees within the north-central regions. The vegetation is classified as dry Kalahari woodland and is dominated by species such as the Zambezi teak (*Baikiaea plurijuga*), Kiaat (*Pterocarpus angolensis)*, and Rosewood (*Guibourtia coleosperma*).

The study focused on communities in three constituencies: Omundaungilo village in Omundaungilo Constituency, Oluwaya village in Oshikunde Constituency, and Onehanga village in the Okongo Constituency. These sites were selected for their suitability for planting indigenous timber seedlings, including favorable environmental conditions, accessible village structures, and the availability of water, which is critical for seedling care. Proximity to and collaboration with local administration, particularly the Directorate of Forestry, was also a factor in site selection.

In July 2024, we used convenience sampling to select household heads and obtained completed surveys from 81 households: 22 in Omundaungilo, 26 in Oluwaya, and 33 in Onehanga (see Fig 1). These respondents were then invited to a two-day workshop in their respective constituencies. The workshop covered tree planting, composting, biochar production, and the region's ecological context, using identical materials across sites. On the first day, participants attended a lecture on the technical aspects; on the second day, they engaged in hands-on compost-making activities. To assess learning, the same quiz was administered before and after the lecture (see Table 1). Of the 81 surveyed households, 56 participated in the workshops: 15 in Omundaungilo (68 %), 14 in Oluwaya (54 %), and 27 in Onehanga (82 %).

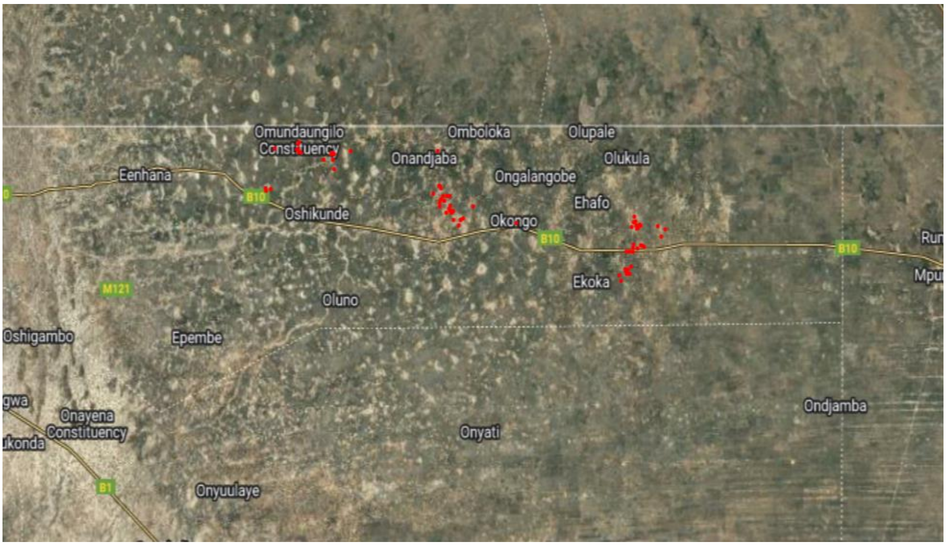


Fig. 1. Location of the targeted communities in three constituencies

Table 1. Questions on quiz (identical before and after)

No	Module	Question
1	Tree planting	(1) When is the best time for transplanting?
2		(2) What to do with the soil before planting?
3		(3) How is spacing arranged between trees?
4		(4) What to do right after transplanting?
5		(5) How to protect trees after transplanting?
6	Biochar	(1) What is biochar made from?
7		(2) How is biochar produced?
8		(3) How to apply biochar?
9		(4) Which picture shows the benefit of biochar?
10	Composting	(1) Which one is the soil type in Namibia?
11		(2) What are the brown materials for compost?
12		(3) What are the green materials for compost?
13		(4) How to make compost using brown and green materials?

2.2 Descriptive statistics

Table 2 presents descriptive statistics for all respondents, including those who did not attend the training. Overall, households engage in diverse livelihoods beyond farming; 65 % of household heads reported working in non-farm occupations. About 16 % were returning migrants (defined as household members who had lived outside the households for at least 6 months), 61 % of household heads were female, and 24 % had completed primary school. The average household size was 12 members, and 57 % had received welfare support in the past 12 months. Access to planted tree areas (89 %) and woodlands (88 %) was high, indicating favorable conditions for implementing tree planting and soil amendment practices. Although 91 % of the respondents reported cultivating their land, only 9 % held individually inherited or individually-sourced land, suggesting that most land access is communal or governed by customary arrangements.

Table 2. Descriptive statistics of the respondents

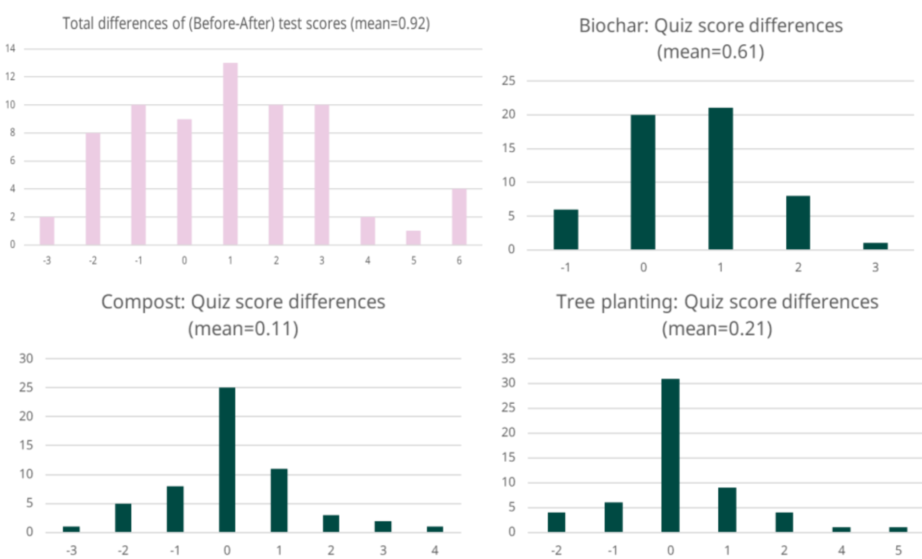
	(1) Mean	(2) SD	(3) Min	(4) Max	(5) Observation
Socioeconomic variables					
Head working on a non-farm job (1=Yes)	0.654	0.479	0	1	81
Lived outside Ohangwena for more than 6 months (1=Yes)	0.160	0.369	0	1	81
Total no of household members	12.250	6.802	0	32	80
Completed primary school (1=Yes)	0.235	0.426	0	1	81
Principal component analysis: Asset index	0.000	2.180	-3	10	79
Received aid from welfare office in the past 12 months (1=Yes)	0.568	0.498	0	1	81
Perception: generally, people can be trusted (1=Yes)	0.296	0.459	0	1	81
Number of participants from the same village	21.667	8.746	1	31	81
Access to tree-planted area (=1 if Yes)	0.877	0.331	0	1	81
Access to woodland (=1 if Yes)	0.889	0.316	0	1	81
Female head (1=Yes)	0.617	0.489	0	1	81
Source of land: Individually inherited	0.087	0.284	0	1	80
Land cultivated (1=Yes)	0.914	0.283	0	1	81
Access					
Distance from home to training place (in km) (all)	16.02	22.336	0.33	129	81
Distance from home to training place (in km) (only those attending training)	17.605	24.869	0.50	129	56
Distance (minutes walking) to Market	19.800	16.578	1	90	80
Distance (minutes walking) to Neighbor	5.062	3.491	1	20	80
Distance (minutes walking) to the Local administrative unit office	88.338	71.465	7	500	80
Distance (minutes walking) to the Research Center	88.213	71.594	7	500	80
Distance (minutes walking) to Paved road	62.013	60.874	1	360	80

Table 2. Descriptive statistics of the respondents

	(1) Mean	(2) SD	(3) Min	(4) Max	(5) Observation
Outcome variables					
Attended the training (1=Yes)	0.691	0.465	0	1	81
Total quiz score	9.018	3.666	0	13	56
Total differences	0.929	2.088	-2	6	56
Quiz score: Biochar (before)	2.111	1.022	0	4	54
Quiz score: Biochar (after)	2.741	1.136	0	4	54
Quiz score: Tree planting (before)	3.942	1.420	0	5	52
Quiz score: Tree planting (after)	4.019	1.380	0	5	54
Quiz score: Compost (before)	2.481	1.284	0	4	54
Quiz score: Compost (after)	2.593	1.381	0	4	54
Most valuable knowledge: tree planting	0.745	0.440	0	1	51
Most valuable knowledge: composting	0.745	0.440	0	1	51
Most valuable knowledge: biochar	0.333	0.476	0	1	51

Distance to information sources affects access to agroecological practices. On average, households are a five-minute walk from their nearest neighbor and 19 minutes from the local market. Based on GPS coordinates, the average distance from respondents' homes to the training venue was 16 km for the full sample and 17 km for participants, suggesting that travel distance likely played a minor role in workshop attendance. However, these communities are relatively far from local administrative offices and research centers, highlighting the need for more frequent extension and training programs near residential areas to ensure timely access to information.

Fig. 2. Distribution of test scores (total score, biochar, compost, and tree planting)



Regarding outcome variables, 69% of households attended the training. Following the lecture, average quiz scores increased by 0.9 points out of a possible 13. As shown in

Fig 2, knowledge gains were highest for biochar (0.61), followed by tree planting (0.21) and composting (0.11). When asked which topic was most valuable, 75% of respondents cited tree planting and composting, while one-third identified biochar.

3 Identification strategy

This study aimed to explore the determinants of training participation in soil amendment techniques and tree planting and management practices, as well as factors influencing knowledge acquisition and interest in these techniques during training. Our key outcomes were attendance, test score differences, and participants' main interests in the technologies. To investigate the first outcome, we estimate a Linear Probability Model (LPM) for training attendance ($Attend_i$) as follows:

$$Attend_i = \alpha + X_i'\beta + \varepsilon_i \quad (1)$$

Where $Attend_i \in \{0,1\}$ indicates whether the household i attended the training, X_i' is a vector of socio-demographic, distance, and trust control variables, and ε_i is the error term. We report heteroscedasticity-robust standard errors. Next, we estimate an outcome model for knowledge gains (test score differences) among attendees only ($Attend_i = 1$), regressing post-lecture quiz scores ($Post\ Score_i$) on pre-lecture scores($Pre\ Score_i$) and the same vectors of control variables X_i':

$$Post\ Score_i = \delta + \rho Pre\ Score_i + X_i'\gamma + \xi_i \ \textit{for Attend = 1} \quad (2)$$

Lastly, we estimate an LPM (restricted to $Attend_i = 1$) for whether a respondent identifies a given practice as their "most valuable learning" ($Valuable_i \in \{0,1\}$):

$$Valuable_i = \theta + X_i'\vartheta + \tau_i \ \textit{for Attend = 1} \quad (3)$$

4 Results

4.1 Motivation of training programs

We first report the descriptive results regarding motivation to attend the training program. As tree planting was central to the workshop, we began by examining respondents' familiarity with planting practices (Fig 3). Approximately 69% of respondents had previously planted trees; however, 68% reported limited access to the tools and resources needed to plant and maintain timber species. This underscores the importance of soil amendment training for successful tree planting programs. Next, we investigated participants' motivations for attending the workshop (Fig 4). The primary motivation was to learn how to care for and maintain timber trees, followed by understanding their ecological prerequisites and sustainable forestry practices. Although obtaining seedlings and networking were also cited, they were not the main drivers of attendance.

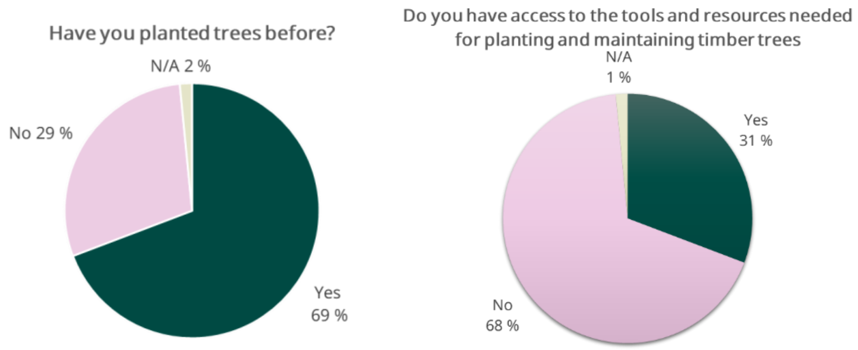


Fig. 3. Experiences and resources for tree planting activities

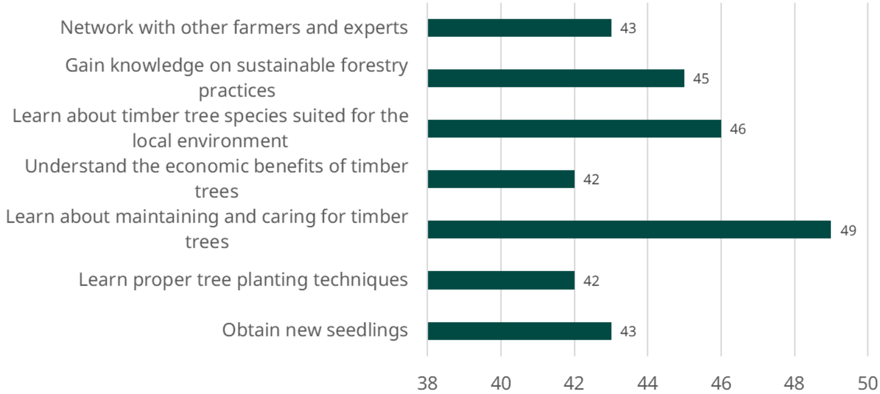


Fig. 4. Motivation to attend the training program

4.2 Determinants of training participation

We present our estimates of the binary indicators for training participation in Table 4. Our results indicate that each additional kilometer to the training venue is associated with a 4-percentage point higher probability of attendance (Column 2), although this effect does not hold across all specifications. Household heads employed in non-farm jobs are 15 and 17 percentage points more likely to participate, and higher trust in society is associated with 22 and 15 percentage points higher propensity for participation. Having access to tree-planted areas predicts a 51 and 53 percentage point increase in the probability of attending, while each additional minute of walking distance to the nearest administrative office corresponds to a 7 and 12 percentage point increase. Female-headed households show about a 6-point higher likelihood of attending, although this result is not robust across all estimations. In Namibia, women slightly outnumber men and are generally more likely to participate in educational programs and training sessions, as shown by gender disparities in national school enrollment. In rural areas, women typically remain at home while men migrate—often to urban centers—for employment opportunities. This pattern explains the high participation of female-headed households in our workshop.

Conversely, households headed by returning migrants are 16 and 22 percentage points less likely to attend the training program, and those with individually inherited land exhibit a 57-percentage point lower likelihood of participation. Proximity to information sources also shows negative associations: living near a research center is linked to a 7 and 12 percentage point lower probability of attendance, and living close to paved roads corresponds to a 2-percentage point decrease in the likelihood of participation.

Table 4. Determinants of training participation

Variables	Attended the training (1=Yes)	
	(1)	(2)
Distance from home to training place	0.001	**0.004***
	(0.002)	(0.002)
Head working on a non-farm job (1=Yes)	**0.153****	**0.173***
	(0.062)	(0.081)
Lived outside Ohangwena for more than 6 months	**-0.162***	**-0.217***
	(0.076)	(0.097)
Perception: generally, people can be trusted (1=Yes)	**0.219****	**0.151***
	(0.087)	(0.068)
Access to tree-planted area (=1 if Yes)	**0.508****	**0.533***
	(0.159)	(0.248)
Access to woodland (=1 if Yes)	-0.039	**-0.270****
	(0.192)	(0.108)
Female head (1=Yes)	0.028	**0.059***
	(0.085)	(0.026)
Source of land: Individually inherited (1=Yes)	**-0.574***	**-0.570****
	(0.284)	(0.194)
Distance (minutes walking) to the Local administrative office	**0.073****	**0.123*****
	(0.028)	(0.018)
Distance (minutes walking) to the Research center	**-0.073****	**-0.122*****
	(0.028)	(0.018)
Distance (minutes walking) to Paved road	**-0.002*****	**-0.002****
	(0.000)	(0.001)
Constant	0.248	-0.466
	(0.816)	(0.828)
Observations	79	79
R-squared	0.333	0.490
Religion dummy	Yes	No
Village dummy	No	Yes
Constituency dummy	No	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: Estimation is based on the Linear Probability Model (LPM) estimation, with standard errors clustered at the village level. The total number of household members, dummy of upper primary school education (1=Yes), asset index, being welfare recipient, no training participants from the same village, land ownership (1=Yes), distance (minutes walking) to market, and distance (minutes walking) to neighbors are included but not shown due to brevity and estimation results being non-significant.

4.3 Determinants of knowledge acquisition and interests in soil amendment techniques

Our analysis of knowledge acquisition uses post-lecture quiz scores (controlling for pre-lecture scores) as the dependent variables (see Table 5, columns 1 to 3). We find distinct drivers across topics: securing land tenure –indicated by possession of individually inherited or sourced land rather than communal land– is associated with lower post-lecture quiz scores by 1.5 points for biochar, 2.01 points for composting, and 1.03 points for tree planting. We delve deeper by examining various sources of land shown in Table 6, and find that the use of organic fertilizers is already fairly common in these communities, regardless of the source of land. Nevertheless, households with individually and jointly inherited (or sourced) land may be more familiar with these practices to begin with, which could explain why differences in post-quiz scores are less pronounced compared to those with other tenure systems. Household heads employed in non-farm jobs are also associated with post-lecture scores that are 0.27 points lower (column 1) on the biochar quiz, compared to those fully employed in farm jobs.

Table 5. Determinants of knowledge acquisition and interests

	(1)	(2)	(3)	(4)	(5)	(6)
	Quiz score (After)			Most valuable knowledge (Yes=1)		
	Biochar	Compost	Tree planting	Biochar	Compost	Tree planting
Quiz score: Biochar (before)	**0.674****					
	(0.225)					
Quiz score: Compost (before)		**0.439****				
		(0.122)				
Quiz score: Tree planting (before)			**0.500****			
			(0.128)			
Source of land: Individually inherited	**-1.541***	**-2.014****	**-1.026***	0.056	**-0.430****	**0.415***
	(0.750)	(0.716)	(0.457)	(0.391)	(0.154)	(0.195)
Head working on a non-farm job (1=Yes)	**-0.268***	-0.459	0.238	-0.176	-0.153	-0.090
	(0.108)	(0.445)	(0.426)	(0.206)	(0.083)	(0.174)
Number of participants from the same village	**0.046****	0.005	0.041	**0.013***	-0.010	-0.001
	(0.018)	(0.029)	(0.022)	(0.006)	(0.007)	(0.006)
Distance (minutes walking) to Market	**0.022*****	0.022	-0.003	-0.015	0.006	-0.009
	(0.005)	(0.012)	(0.014)	(0.008)	(0.007)	(0.006)
Distance from home to training place (in km)	0.001	**-0.009****	**-0.008***	**0.003****	0.002	**0.006*****
	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)
Having upper primary school education (1=Yes)	-0.046	0.100	**1.222****	**0.428****	**0.244*****	0.122
	(0.295)	(0.708)	(0.378)	(0.164)	(0.040)	(0.133)
Lived outside Ohangwena for more than 6 months (1=Yes)	0.055	-0.178	**-0.670****	-0.125	-0.065	**-0.137****
	(0.336)	(0.190)	(0.188)	(0.219)	(0.154)	(0.053)
Perception: people can be trusted (1=Yes)	0.364	-0.317	**-0.409*****	-0.206	0.058	-0.017
	(0.254)	(0.387)	(0.098)	(0.229)	(0.157)	(0.123)
Land ownership (1=Yes)	-0.599	-0.860	**-0.700*****	0.269	-0.351	**0.507***
	(0.836)	(0.860)	(0.101)	(0.304)	(0.339)	(0.204)
Access to tree-planted area (=1 if Yes)	0.496	-0.863	0.567	0.061	0.194	**0.424***
	(0.826)	(0.901)	(0.703)	(0.334)	(0.398)	(0.197)
Constant	-0.302	3.410	0.529	0.047	1.043***	-0.294
	(0.439)	(3.005)	(0.937)	(0.244)	(0.150)	(0.225)
Observations	53	53	51	50	50	50
R-squared	0.757	0.740	0.796	0.408	0.485	0.577
Religion dummy	Yes	Yes	Yes	Yes	Yes	Yes
Village dummy	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: In Models 1-3, estimation is based on Ordinary Least Square estimation, while in Models 4-6, estimation is based on Linear Probability Model, with standard errors clustered at the village level. Total no of household member, dummy of upper primary school education (1=Yes), asset index, being welfare recipient, no of training participants from same village, land ownership (1=Yes), distance (minutes walking) to Market, and distance (minutes walking) to neighbor are included but not shown due to brevity and estimation results being non-significant.

Distance to various information sources has mixed effects on knowledge acquisition. Each additional minute's walk to the market is associated with an increase of 0.02 points in post quiz scores for biochar (column 1), whereas each extra kilometer between home and the training venue reduces composting and tree planting scores by 0.009 (column 2) and 0.008 points (column 3), respectively. Nevertheless, we also find that for each acquaintance living in the same village as the respondents and also participating in the training, biochar post quiz scores increase by 0.05 points (column 1).

The findings are more nuanced for tree planting training compared to soil amendment guidance, as shown in column 3. Respondents with upper primary school education score 1.2 points higher on the post-lecture quiz, while household heads who are return migrants and those with higher social trust score 0.67 and 0.41 points lower, respectively. Individual land ownership is also associated with a 0.7-point decrease in tree-planting post-lecture scores.

We next examine respondents' interest in the three practices by estimating separate binary-choice models for biochar, composting, and tree planting (columns 4 to 6). In each model, the dependent variable equals one if the respondent identified the practice as the most valuable knowledge gained from the training. Having upper primary education is associated with a higher probability of prioritizing biochar and composting by 43 and 24 percentage points, respectively (columns 4 and 5). Greater distance from home to the training site is also positively associated with selecting biochar and tree planting as the most valuable knowledge. Moreover, each additional fellow participant from the same village increases the likelihood of choosing biochar as most valuable by 13 percentage points. Conversely, ownership of individually inherited land reduces the probability of citing composting as the most valuable knowledge by 43 percentage points.

Interests in tree planting followed a more complex pattern than for soil amendments. Secured land tenure –both individual inheritance and general land ownership– was associated with 42 and 51 percentage point increases, respectively, in the likelihood of identifying tree planting as the most valuable practice. Access to tree-planted areas further raised this likelihood by 42 percentage points. By contrast, households headed by return migrants were 14 percentage points less likely to cite tree planting as the most important knowledge gained.

Table 6. Fertilizer usage and land tenure

No	Source of land	Total number of observations	Chemical fertilizer use		Organic fertilizer use	
			Yes	No	Yes	No
1	Individually-inherited/individually sourced	7	2 (29%)	5 (71%)	5 (71%)	2 (29%)
2	Jointly-inherited/jointly sourced	5	2 (40%)	3 (60%)	4 (80%)	1 (20%)
3	Purchased	3	0 (0%)	3 (100%)	2 (67%)	1 (33%)
4	Granted by the village head	65	8 (12%)	57 (88%)	57(88%)	8 (12%)
5	Given by parents	1	0 (0%)	1 (100%)	1 (100%)	0 (0%)

5 Conclusion and discussions

This study examines the drivers and motivations behind smallholders' participation in tree-planting and soil-amendment workshops—specifically composting and biochar—and identifies predictors of knowledge acquisition in northern Namibia, where heavy reliance on chemical fertilizers has exacerbated existing soil degradation [3]. Biochar, in particular, is a valuable soil amendment recommended for use alongside compost, which can enhance tree establishment in Namibia's sandy soils [4, 6, 7]. To investigate this, we conducted identical training and practical workshops in three locations and measured knowledge acquisition through a series of quizzes and feedback surveys upon completion of the training.

We found that distance to the training location and to the local administrative office positively correlates with both participation and the perceived value of the knowledge gained. Several mechanisms could explain why remote households –those living farther away from official information sources– tend to value training more when they lack alternative sources of information. First, scarcity premium appears to be at play: in isolated communities, each new piece of technical knowledge represents a greater marginal gain compared to less-remote areas where information flows more freely through neighbors, markets, or extension services. In such contexts, if the nearest alternative sources (peer farmers, local offices) are too distant, the opportunity cost of attending a formal workshop decreases relative to the perceived benefits. Additionally, this may reflect social capital and signaling: attending a distant training can signal commitment and leadership within the village, which may enhance the participants' social standing upon return. This finding aligns with the study by Pratiwi and Suzuki (2020), which found that training held farther away induced stronger technology adoption than training conducted nearby [10]. Furthermore, having access to tree-planted areas and involvement in non-farm employment both increase the likelihood of attendance, as these participants may better understand the environmental, economic, and ecological benefits and risks associated with the practices.

Conversely, those with more secure land access may perceive less urgency to intensify land management or experiment with soil, leading to a reduced likelihood of attending training. These households may also be less likely to recognize the importance and value of soil amendment techniques such as composting. Organic amendments require additional labor, time, and on-farm biomass [13], so households with individually inherited land may face resource constraints, especially when labor is scarce. Another possible explanation is that land-secure households may rely more on formal extension channels and have had fewer opportunities to attend field demonstrations of biochar's benefits.

Regarding knowledge acquisition from different practices, biochar appears to be relatively new to the communities, despite government efforts to promote bush utilization benefits for both communal and commercial farmers. However, participants with stronger friendship networks within their village are more likely to have peers to discuss and validate the information with. While composting shares similar soil amendment functions, it seems to be more familiar to the communities. Several factors may explain the negative relationship observed: after a long journey to attend training, participants' ability to absorb new information may decline –especially when existing knowledge of composting interferes with new information introduced during the sessions.

Further, the education of household heads seems to be an important determinant for knowledge acquisition related to tree planting, as well as for appreciating more the value of soil amendment training. More educated farmers are more likely to ask questions in class, consult more resources available during the training, and discuss with their peers to check their understanding and ideas. Nevertheless, returning migrant household heads who have been exposed to risks outside of the locality may exhibit better understanding of the cost and benefits of planting timber trees, possibly associated with the intensive labour management and long return on investment, and thus are more likely to be risk-averse in practicing tree planting.

Our study provides important implications for future training and extension program design, particularly related to soil amendment and tree planting, that distance to training sites and friendship networks matter significantly to gauge more interests and knowledge on more unfamiliar techniques like biochar. Having decentralized delivery of training programs, with satellite sessions closer to small clusters of villages, would cut travel time and fatigue and potentially enlarge the number of participants. More diverse stakeholders' involvement, namely the private sectors, could also be encouraged, which can complement extension delivery by local government offices. Further, there should be more engagement with households with more secure land tenure to care for and maintain the soil fertility, particularly to expose them to the immediate benefits of soil amendment techniques. This also highlights the importance of institutionalization. When communities form cooperatives to maintain community forests, they might be able to benefit from soil amendment techniques to collectively maintain the trees.

Lastly, we acknowledge the limitation of our study, that due to the sparsely populated area and resource constraints, we could only reach a certain sample size, which may not be strong enough for further generalization. This way, there might also be selection bias in our sampling participants due to convenience sampling and distance being significant predictors of biochar knowledge acquisition. This means that more distant households who do make the trip may differ significantly in baseline knowledge or opportunity costs; thus, those unobserved differences could also depress the average score gains. Future studies should also consider exploratory qualitative interviews to strengthen the mechanisms and operationalization of the findings, as well as the interpretation of the results.

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