

Research article

Soil carbon status after vegetation restoration in South West Iceland

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ABSTRACT

Reclamation of degraded land using revegetation is one way of sequestering carbon into the soil. In this study an assessment was done to estimate the status of soil carbon amounts after revegetation with trees and grass in South West Iceland (Hafnarmelar). Natural woodland and eroded plots were part of the assessed plots as controls making four treatments. Soil samples were analysed for bulk density, carbon content and soil texture. Total % carbon (C) was analysed using vario MAX CN analyser (measured % C) and Loss on Ignition (calculated % C). The results showed that natural woodland had higher (9.32%) C than the tree treatment (4.91%), and both had significantly higher C than the grass (1.12%) and the eroded (0.76%) treatments ($p < 0.0001$). The amount of C in the grass and the eroded treatments were not statistically different ($p > 0.0566$). Notably, the grass treatment had carbon below the minimum expected level of 1.5% in Icelandic Andosol under vegetation. The natural woodland and the tree treatment had fine soil texture than the grass and eroded plots. Results suggest that where land has been properly restored or kept in natural condition, soil properties improve significantly especially when trees are part of the restored vegetation. The natural woodland had possibly not lost the old carbon-rich soil, as was the case with the tree, grass and eroded plots hence more time for development of various soil properties. Moreover, more litter deposits in natural woodlands and partly in the tree treatments might have contributed to higher carbon than in the grass and eroded treatments. Furthermore clay content variations (natural woodlands and the tree treatments had finer soil texture) might also be responsible for C limitations in the grass and the eroded treatments. Therefore, more restoration efforts are encouraged. The results also showed that LOI is a good method for C estimation but not very accurate estimator of soil organic carbon unless equations are developed with respect to known carbon content of particular soil type.

1. Introduction

Land degradation is one of the major problems affecting the physical, chemical and biological stability of the soil. Climate change has threatened global food and general agriculture especially in the Pacific, Asia, Latin America and sub Saharan Africa (Thornton et al., 2014). In these regions soil nutrient balance remains negative, further threatening capacity of soil for food production (UNCCD, 2017). Globally, 25% of arable land is highly degraded (Vlek et al., 2008) and approximately, 50–70 Gt of soil carbon was released from agricultural land into the atmosphere (Amundson et al., 2015). These challenges call for approaches that enhance soil restoration. Approaches that enhance soil to store carbon from the atmosphere would significantly contribute to climate change mitigation (Lal, 2004). There is need to raise awareness on importance of organic matter, generate and develop information for relevant stakeholders for informed choices (Keesstra et al., 2016). These solutions may contribute to the attainment of the United Nation's goal of

4% soil carbon increase annually (UNFCCC, 2015). Moreover, proper soil management would conserve over 20 000 species found in soil (Keesstra et al., 2016) which contribute to ecological dynamics in the ecosystems (Bardgett and Van der Putten, 2014). Overall, addressing challenges facing land and soil degradation could directly contribute to attainment of 47% of Sustainable Development Goals (SGDs 2,3,6,7,12, 13, 14 and 15) (Keesstra et al., 2016). Although, international network implementation approach is advocated, local action is key with focus on sustainable use and management (Keesstra et al., 2018).

Iceland has lost millions of tons of organic matter and soil carbon since settlement due to land degradation (Oskarsson et al., 2004). The country has up to 45 000 km² of degraded land in need of restoration (Arnalds et al., 2001). The Icelandic Government through the Soil Conservation Service of Iceland (SCSI) restores degraded areas to achieve carbon sequestration, stop erosion and improve land ecosystem condition (Arnalds et al., 2000). Intensive and systematic approaches to this started in 1907. Some of the methods include seeding grass mixtures,

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planting/seeding trees and applying inorganic fertilizers. The aim is to bring back the lost soil nutrients, physical and biological condition of the land and soil. In Iceland, land restoration is done partly to implement and contribute to the provisions in the United Nations Framework Convention for Climate Change (UNFCCC) (Arnalds et al., 2000). One of the SCSi's major approaches in achieving land restoration has been the project called 'Farmers Heal the Land' (FHL), a project which started in 1994. The project targets completely bare land, slightly bare land, lightly or not grazed farmland. This project was an improved set up after its predecessor, the *Neighbourhood Project*, which focused narrowly on restoration of small portions of land around homesteads. FHL aims at placing more focus on the roles of farmers in land restoration and emphasises on restoration activities as being 'owned' by farmers (Crofts, 2011). The number of participating farmers rose from 370 in 1994 to around 612 (Soil Conservation Service of Iceland, 2014). Sheep farmers are the dominant participants. However, the project is open to all owners and custodians of degraded land (S. Askelsdottir, 10 September 2015, Soil Conservation Service of Iceland, Hvaneyri, *personal communication*). There is almost uniform distribution of participating farmers throughout Iceland. In the FHL project, the SCSi covers 85% of the costs for seed and inorganic fertilizer to be used in the restoration of degraded areas. Extension staff from the SCSi provide advice to the participating farmers. Farmers contribute labour and 15% of the fertilizer costs. The project is seen as yielding good land reclamation results in terms of ha restored and has also enhanced mutual relationship between farmers and the SCSi as an institution (Berglund et al., 2013).

According to Arnalds et al. (2000), the reclamation of severely degraded soil in Iceland could result in sequestration of 0.6 tons (t) of carbon per hectare (ha) per year. The Icelandic carbon sequestration rates thus fall within the Intergovernmental Panel on Climate Change (IPCC) carbon sequestration rates of 0.1–0.7 t C ha⁻¹ per year (Arnalds et al., 2000). Aradottir et al. (2000) reported sequestration rates ranging from 0.01–0.5 t C ha⁻¹ per year for the above ground and underground vegetative matter. In assessing the carbon accumulation in restored unstable sandy desert, Arnalds et al. (2013) observed that soil carbon increased from 0.3% to 0.7% in some grass reclaimed plots. However, the average annual accumulation was 0.4–0.63 t C ha⁻¹ during the first stages of restoration. The accumulation was significant in areas treated with grass seeding and inorganic fertilizer and not in untreated degraded areas (control). The untreated (control) plots had no carbon increase. This finding corresponds to that of Bjarnadottir et al. (2009), where they reported use of birch and other trees in carbon sequestration in Iceland as successful. The ability of Icelandic soils to accumulate carbon after revegetation provides a favourable environment for carbon sequestration. By 2001 close to 130 km² were restored (Agustsdottir, 2004). The continued assessment of carbon in soils is desirable in Iceland and at global level (Sigurdsson and Snorrason, 2000). In Iceland, research has been done to assess the impact of land restoration on carbon sequestration in some parts of the country but there has not been much emphasis on assessing carbon amounts in land reclaimed under the FHL project in farm fields.

This research intended to generate evidence based information on carbon accumulation on FHL reclaimed land. Four treatments were examined, namely: reclamation with trees, reclamation with grass, natural woodland as a positive control and eroded area as a negative control. In this paper, these four land uses will be referred to as 'treatment' or just 'plots'. Specifically, the study intended to achieve the following objectives: 1) assess the difference in soil carbon content between reclaimed and non-reclaimed land; 2) compare the effect of grass and tree reclamation respectively on soil carbon content. A null hypothesis: 'Restoration of degraded land using trees and grass does not contribute to soil carbon increase,' and an alternate hypothesis: 'Restoration of degraded land using trees and grass contribute to soil carbon increase' were analysed to achieve the objective of this study.

2. Materials and methods

2.1. Study area

The study was conducted in South West of Iceland, in Hafnarmelar area at latitude 64° 3' N and longitude 21° 55' W. The mean annual temperature was 5.3 °C, with mean January temperature of 0.9 °C and mean July temperature of 11.4 °C (Icelandic Meteorological Office, unpublished data). The data also showed a mean annual precipitation of about 1,100 mm. According to the soil map of Iceland (Arnalds, 2015), the common soil types are Histic Andosols, Gleyic Andosols and Brown Andosols. Two farms in the area, participating in the Soil Conservation Service of Iceland FHL's project were selected as study sites. This sites were chosen because they had a variety of management and reclamation examples. The study sites were characterised by 1) islands of natural birch woodland, 2) land revegetated with trees and grass, 3) land revegetated with grass and 4) some highly degraded land; hereafter these will be referred to as natural woodland, tree plot, grass plot and eroded plot respectively.

The natural woodland was dominated by birch trees (*Betula pubescens*), shrubs and some grass covering the understory (Figure 1A). The ground was completely covered by vegetation and litter was visible. The plot had dark, fine textured soil. There were no signs of gravel, at least not at the sampling depth. The tree plot was dominated by birch trees (Figure 1B). Initially, the area was a degraded land without vegetation. After reclamation through use of inorganic fertilizers and birch trees, the area was under tree vegetation. The trees were still at a young stage during the time of this study. There was also some growing grass scattered in the plot. Some litter could also be noticed. The soils were brown, and slightly gravelly at the surface. The soil had fine texture. Restoration work in the tree plot started in 2004. A total of 80–100 kg ha⁻¹ (equivalent of 25 kg ha⁻¹ N per year) of inorganic fertilizer was applied every year until 2015. The plot was used for light grazing in the fall. The grass plot was dominated by native grass such as *Festuca richardsonii* (Figure 1C). Bare patches could be noticed too, suggesting unstable surface, unfinished revegetation and possibly frost heaving. Litter was not visible. The plot was gravelly and some rocks could be noticed in parts of the area. The plot had dark grey soils with coarse texture. About 200 kg ha⁻¹ (equivalent of 50 kg ha⁻¹ N per year) of inorganic fertilizer had been applied every other year since 2002. The plot was mainly grazed in spring and fall. The eroded plot was gravelly with scarce vegetation (Figure 1D). The surface was loose and stony. There was no litter in the plot. The soil was brown and had coarse texture. Each treatment was 0.25 km².

2.2. Soil sampling and handling

Soil samples for bulk density (BD) were collected using a core of 5 cm in diameter and 5 cm in length. Ten samples were collected at 0–5 cm and 5–10 cm depths every 20 m on one transect (two transects per depth) for each treatment. Therefore 40 samples were collected per treatment per depth for BD. This aimed at understanding BD changes along the depths. Along the same transect where samples were collected at 0–5 and 5–10 cm depths, other 20 soil samples meant for carbon analysis and BD were collected at a depth of 0–10 cm per transect (one transect per treatment). Therefore, 40 samples were collected per treatment for carbon analysis and 40 samples for DB at a depth of 0–10 cm (Table 1). Two random points were also selected along each transect to select two samples for soil texture analysis (two soil texture samples per treatment). These samples were used for soil site description. A soil auger, 2.8 cm in diameter, was used to collect soil samples in the natural woodland and tree plot. Five cores from each sampling point were collected, making a composite sample. It was not possible to use the auger in the eroded and grass plots because they were too gravelly. Instead a shovel was used to



Figure 1. The four sites where soil sampling was done. A = Natural woodland, B = tree plot, C = grass plot and D = eroded plot.

Table 1. Summary of soil samples collected and the analysis categories.

| Soil depth (cm) | Number of soil samples collected | Analysis category |
|-----------------|----------------------------------|-------------------|
| 0–5 | 40 | Bulk density |
| 5–10 | 40 | Bulk density |
| 0–10 | 40 | Bulk density |
| 0–10 | 40 | Soil carbon |
| 0–10 | 8 | Soil texture |

create a hole to a corresponding depth, where soil samples were collected. Soil samples meant for carbon analysis were air-dried in a room with proper ventilation. The individual soil samples were then sieved in a 2 mm sieve to remove materials >2 mm. The samples for carbon analysis were ball milled for 24 h. Samples for bulk density analysis were oven dried at 105 °C for 24 h (Brady and Weil, 1999).

2.3. Soil analysis

The soil samples for bulk density were sieved to determine soil fractions of <2 mm. The density and weight of rock fragments were also determined. The BD was calculated using the procedures described by Burt (2004) given by:

$$BD = (ODW - RF - CW) / [CV - (RF/PD)]$$

where BD = Bulk density of <2 mm fabric at sampled, field water state (g cm^{-3}); ODW = Oven dry weight; RF = Weight of rock fragments; CW = Empty core weight; CV = Core volume; PD = Density of rock fragments.

This formula was used because the bulk density results especially for 0–10 depth was used to calculate carbon stocks which requires that coarse materials be subtracted so that only the active soil fraction is used. Organic matter (OM) calculation aid in the determination of the carbon content. The organic matter was determined using Loss on Ignition (LOI) as described by Rowell (1999). LOI has been used to estimate soil organic carbon for decades through estimation of organic matter loss. Soil samples were first oven dried at 105 °C for 24 h and weights recorded. Then samples were heated at 550 °C for 4 h to burn the organic matter and

inorganic carbon. Then samples were re-heated at 105 °C for 3 h and weighed. The difference in weight was divided by the initial oven weight multiplied by 100 to get the percentage of organic matter (Rowell, 1999). Then the organic matter was converted to percentage soil organic carbon. Commonly used conversions, use the principle that 40–58% of LOI is soil organic carbon (Brady and Weil, 1999) using the formula ($C\% = 50/100 * LOI$). A regression analysis was made to estimate how good LOI was for estimating % C. Then the results from the simple ($C\% = 50/100 * LOI$) calculation was compared to the results obtained from the regression. Forty subsamples (10 from each treatment) were analysed for total carbon (% C) using a vario MAX CN elemental analyser, manufactured by Elementar Analysensysteme GmbH. Carbon results were corrected for dry matter. This was done for accurate comparison of analysis method for soil carbon in order to plot applicable regression equation.

2.4. Statistical analysis

Data were tested for homoscedasticity (Levene test) and normality (Shapiro-Wilk normality test). After they met these conditions, analysis followed parametric statistics. Descriptive statistics were used to find the means for carbon content from the treatments. SAS Enterprise Guide 6.1 was used to test significant difference of means of carbon in the different treatments. One-way ANOVA analysis was conducted to test significance difference between values in bulk density, % soil organic carbon content, and carbon stocks among the treatments. A simple regression analysis was run in Excel to determine the relationship between % C and LOI and an equation was developed. Soil carbon was also expressed as stocks. This

was calculated by multiplying soil mass of one ha built on the bulk density of soil in the 0–10 cm depth by the measured % carbon in a plot (Arnalds, 2015). To calculate accumulation per year, the stocks in the tree and grass plots were subtracted with the amount in the eroded plot (baseline). Then the amount in the tree plot was divided by 11 years of restoration while the amount of soil carbon from the grass plot was divided by 13 years.

3. Results

3.1. Bulk density

The results indicated variations in the bulk density values among treatments as well as between depths (Figure 2). In the 0–5 cm depth, bulk density increased from the positive control (natural woodland), tree plot to the grass plot and the negative control (eroded plot). The same trend was observed in the 5–10 cm depth. Actual values of bulk density increased with increasing soil depth especially in the natural woodland, grass and tree treatments.

3.2. Soil carbon

More carbon was recorded where revegetation was under trees than where grass was used (Figure 3). The positive treatment had the highest soil carbon than all the treatments. However, there was no significant difference in soil carbon stocks between the natural woodland and the tree plot. The results showed higher mean values for % C from LOI in the tree plot and the eroded plot than from total carbon analysis. A simple regression equation was developed based on LOI values and the measured % C values (Figure 4). The % C calculated with the regression equation was closer to the measured %C by far than the calculated by 50% of LOI being carbon (Table 2). Revegetation by trees sequestered over 2 tons carbon ha⁻¹ per year than revegetation by grass which had lower than 0.5 tons in the study area (Table 3).

4. Discussion

4.1. Bulk density

Despite being under revegetation, the grass plot had higher bulk density in both depths than the natural woodland and the tree plot. The findings between depths were similar to that of Arnalds et al. (2013) where they found that the soil bulk density in 0–5 cm depth was lower (1.02 g cm⁻³) than in the 5–10 cm depth (1.10 g cm⁻³) in degraded soils. However, the bulk densities in the grass and eroded plots in this study were higher suggesting that the soil in these plots was Vitrisols. Icelandic Andosols have low bulk density ranging from 0.3–0.8 g cm⁻³ (Arnalds,

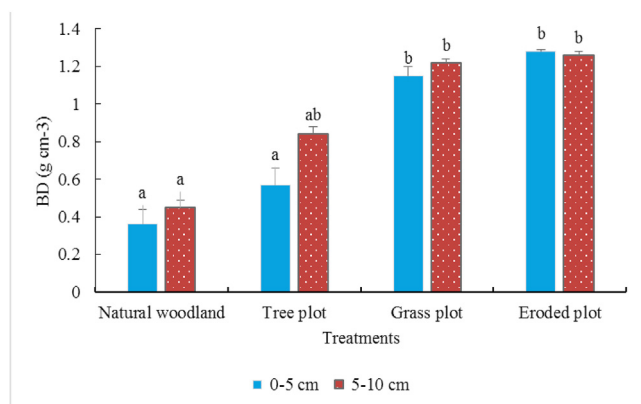


Figure 2. Mean bulk density of <2 mm soil in the 0–5 cm and 5–10 cm depths. Bars with same letters are not significantly different. BD = Bulk density.

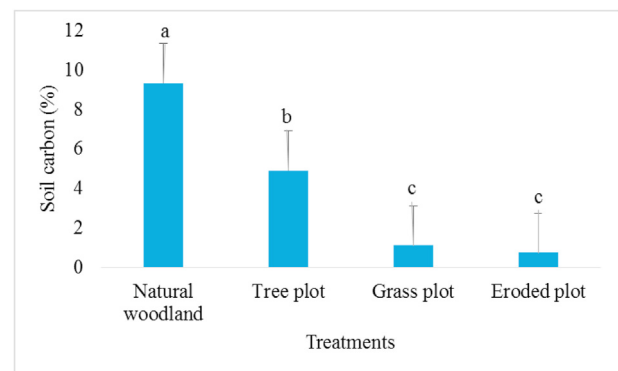


Figure 3. Percentage soil carbon in the 0–10 cm depth. Bars with same letters are not significantly different.

2004). A comparison by treatment, correlated with Han et al. (2010) who found higher soil bulk density in grassland than in woodlands and also higher in degraded areas than in reclaimed areas. Cerda et al., (2018), Di Prima et al. (2018) and Novara et al. (2019), reported a bulk density decrease in areas where OM had accumulated after years of use of catch crops and citrus fruits in Spain.

The lower bulk density in the tree and natural woodland could be attributed to the vegetation which is a source of organic matter after decay. By estimation, natural woodland and tree plot had finer soil texture (Clay loam) suggesting more developed soil and organic matter. Organic matter-rich soils could have lower bulk density than heavy non organic materials. These plots also had higher carbon content compared to the eroded and grass plots. Andosols with higher carbon content have lower bulk densities (Arnalds, 2015), usually less than 0.8 g cm⁻³ while desert soils have bulk densities higher than 0.8 g cm⁻³. The bulk densities in the tree plot and natural woodland were indicative of more organic matter content, porosity and good water holding capacity. In this case the higher bulk density in eroded and grass plots is likely to be due to low level of organic matter and carbon content thus a high proportion of mineral material as evidenced by Sandy loam and Loamy sand textures.

4.2. Soil carbon in different treatments

The natural woodland soil had higher % carbon probably because it had more vegetation cover and thus likely higher OM inputs to the soil. This area had possibly not lost the old carbon-rich soil, as was the case with the tree, grass and eroded plots hence more time for development of various soil properties. The area also had more litter deposits which after decomposition might have released nutrients. The plot might have had more clay content as indicated by the fine soil texture. Soils that have more clay particles have the ability to contain more carbon (Arnalds et al., 2000; Walker and Desanker, 2004). Clay particles adsorb carbon between them making it less likely to get lost to the atmosphere unless disturbed by erosion. This is one of the features of Andosols. Furthermore, slow decomposition due to low soil temperatures retain soil carbon and is typical for soils in cold regions (Arnalds et al., 2013). The tree plot had similar texture as the natural woodland but lower carbon content. The former had young trees as it was in early stages of restoration. It also had less litter, that could feed carbon back into the soil, compared to natural woodland, but more litter compared with grass and eroded plots. The natural woodland and tree plot had low bulk densities and higher organic matter which account for higher carbon content. This finding correlates with findings by Gudmundsson et al. (2004), Walker and Desanker (2004) and Arnalds (2015). Petursdottir et al. (2013) reported 1.1–1.2% carbon in untreated plots and 1.3–1.5% in plots treated with grass and lupine for 5–7 years of in South west Iceland.

Lower carbon levels in the grass plot could be due to limited organic matter build up. The plot had higher bulk density and coarse soil texture.

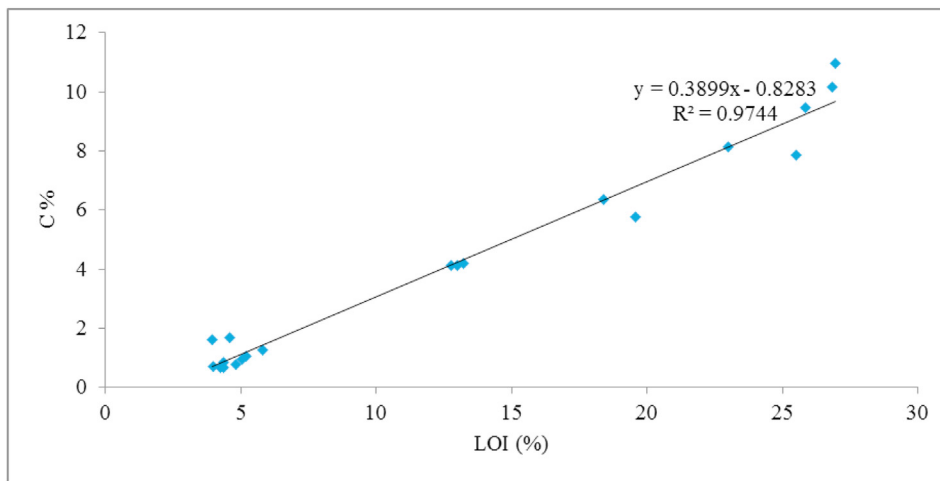


Figure 4. Simple linear regression equation for soil organic carbon (C) measured against Loss on Ignition (LOI) for all plots.

Table 2. Comparison of mean calculated % soil carbon from Loss on Ignition (LOI), measured soil carbon and the commonly used method of taking 50% LOI as carbon in the 0–10 cm depth for each treatment. Same letters along a column show no significance difference. DB = Bulk density.

| Treatment | Mean % LOI* | Mean % C measured** | Mean % C calculated*** | Mean % C at 50%**** | BD |
|-------------------------|-------------|---------------------|------------------------|---------------------|-------|
| Pristine birch woodland | 25.62a | 9.32a | 9.16a | 12.81a | 0.41a |
| Tree plot | 15.39a | 4.91a | 5.17b | 7.69b | 0.7b |
| Grass plot | 4.78a | 1.12b | 1.03c | 2.39c | 1.18c |
| Eroded plot | 4.48a | 0.76b | 0.92c | 2.24c | 1.27c |

* Loss on Ignition for all samples in a plot.

** Soil carbon amount using direct measurement (by vario MAX CN elemental).

*** Soil carbon amount obtained from simple regression equation between % measured carbon and LOI.

**** Soil carbon amount using the commonly used formula that 50% of LOI is carbon given by formula (50/100*LOI).

Table 3. Soil carbon stocks and sequestration rates in the 0–10 cm depth. Values with same letters are not significantly different. Same letters along a column show no significance difference.

| Treatment | Soil carbon stocks (t ha ⁻¹) | | Sequestration rate (t C ha ⁻¹ y ⁻¹) | |
|------------------|--|------------|--|------------|
| | Mean | Std. Error | Mean | Std. Error |
| Natural woodland | 38.21a | 2.42 | - | - |
| Tree plot | 34.38a | 3.329 | 2.2a | 0.051 |
| Grass plot | 15.31b | 1.867 | 0.4b | 0.003 |
| Eroded plot | 9.70b | 0.643 | - | - |

The soil would be expected to have poor water holding capacity and missing the finer soil particles. These conditions make it more difficult for the soil to hold nutrients and accumulate carbon. Despite not being significantly different from the eroded plot in carbon content, the grass plot showed signs of soil properties development as its trend in bulk density followed the trend in the natural woodland and the tree plot, i.e. it was lower in the 0–5 cm depth than the 5–10 cm. This shows that there could be some level of organic matter build up in the upper layers. It would be expected that with time a number of changes in the soil properties could occur. The grass plot was heavily grazed in spring and fall and some bare patches could be noticed and litter deposition was scarce. The grazing might have reduced above ground biomass leading to low primary productivity and consequently lower organic matter input into the soil. The bare patches exposes soil to erosion making it likely to be lost through run off. However, [Petursdottir et al. \(2013\)](#) found, in an evaluation of short term progress of restoration in a similar grass treatment that summer grazing did not impede the development of soil and vegetation. Other studies have, however, established strong linkages between intensity of grazing, condition of grazed land and carbon quantities in soils ([Nianpeng et al., 2012](#)). As an agro-ecosystem, the soil

in the grass plot would be expected to have lower carbon than the natural woodland which was a natural ecosystem ([Lal, 2014](#)). Improved grazing management of the grass plot area would be a proper advice. In their study on land use impact on soil carbon sequestration of Inner Mongolian grasslands, [Nianpeng et al. \(2012\)](#) observed that practices like systematic grazing exclusion helped increase the soil carbon, especially in the top 0–50 cm depth.

The eroded plot had the least amount of soil carbon though it was not significantly different from that of the grass plot. The soil was very gritty and loose and the plot had the highest bulk densities in both depths. The plot was bare and exposed to both water and wind erosion. The water and wind erosion could be responsible for loss of more fine materials from the area leaving it with only gravelly materials. Frost heaving in the winter months could also make it difficult for vegetation to establish itself. The quality and quantity of clay influence amounts of stabilised carbon in soils ([Yanadarg et al., 2014](#)). After comparing coarse textured sandy loam soil and finer textured silt loam soil, [Borches and Perry \(1992\)](#) found that the later had higher carbon levels than the former. This would explain lower carbon levels in the eroded and grass plots that had Sandy loam and Loamy sand soils than in the natural woodland and tree plots, which

had vegetation cover and fine textured soil. The eroded plot had scarce vegetation cover and consequently very limited litter inputs, hence no source of organic matter. It can be concluded that the low soil carbon is likely the result of lack of vegetation cover. Overall carbon sequestration rates in soils differ because of soil type, topography, history of land use, vegetation cover and hydrology (Marland et al., 2004; Arnalds et al., 2013). Contrary to the findings in this research, Marland et al. (2004) in their study on enhancing carbon sequestration in soils in East Tennessee, USA, found that grass plots had more carbon than tree and forest plots. Such differences are bound to occur as geography of sites, use and associated factors differ.

4.3. Soil carbon stocks

From the carbon stocks, it was estimated that restoration with grass sequestered 0.4 t C ha^{-1} per year and reclamation with trees 2.2 t C ha^{-1} per year. Low sequestration in the grass plot could be attributed to seasonal browsing by sheep which limit full development of the grass. The sequestration rate in the grass was lower than the results of Arnalds et al. (2000) of 0.6 t C ha^{-1} per year through reclamation of severely degraded sandy soils. In another study in a different area, Arnalds et al. (2013) also found sequestration rates of $0.4\text{--}0.63 \text{ t C ha}^{-1}$ per year which are comparable to the findings in this study in the grass plot. In Spain, Novara et al. (2019) reported a sequestration of $0.78 \text{ Mg C ha}^{-1}$. The sequestration rates in the tree and grass plots were encouraging considering the short period of restoration and the stage of trees in the plot. However, the sequestration rate in the tree plot could be considered higher than expected. This might have been influenced by the yearly application of fertilizer in the plot, compared to the biennial application in the grass plot. It could also be speculated that the tree plot might not have been as highly degraded before restoration started as the grass plot.

4.4. The use of Loss on Ignition

The calculated values using LOI were closer to the measured values than the values of the commonly used soil carbon estimation. This means that LOI can be a good estimator for soil organic carbon especially if specific equations are developed for specific soil types using known carbon values (David, 1988; Konen et al., 2002) as was done in this study.

5. Conclusion

This study showed that restoration of degraded land through revegetation resulted in soil carbon increase, therefore, the null hypothesis was rejected. The study found that reclamation with trees in addition to grass could lead to more carbon sequestration in the soil than reclamation with grass only. Soil carbon content in the tree plot was closer to natural woodland. The annual carbon sequestration were enhanced where tree were used than the grass. The results also showed that the condition of land and soil also affects the amount of carbon sequestered. The natural woodland and the tree plot had finer soil texture than the grass and eroded plots. It could suggest that land under the tree plot had not been as badly eroded or degraded as the grass and eroded plots. From this study, it can be generalised that the FHL project is contributing to sequestration of carbon into the soil. More reclamation endeavours are therefore, encouraged.

Declarations

Author contribution statement

Harrington Nyirenda: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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