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Carbon accumulation in Icelandic desert Andosols during early stages of restoration

Olafur Arnalds *, Berglind Orradottir, Asa L. Aradottir

Agricultural University of Iceland, Hvanneyri, 311 Borgarnes, Iceland

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ABSTRACT

Carbon accumulation in soils is an important method to offset the release of carbon based GHG into the atmosphere. We investigated carbon accumulation during early stages of ecological restoration of a desertified area in Iceland. The study site, a part of a larger experimental area, consisted of 24 1 ha experimental plots with nine different restoration treatments and untreated control, all replicated 2–3times. The barren desert soils were sandy with unstable surface conditions subjected to intense cryoturbation and wind erosion. Initial carbon stocks in soils of eroded, untreated areas were 0.1–0.3 kg m^{-2}, largely consisting of inert metal–humus and/or clay–humus complex characteristic of Andosols. Carbon content in the 5 cm surface layer increased from <0.3% up to >0.7% in some treated plots. Annual carbon accumulation of 0.04–0.063 kg C m^{-2} yr^{-1} was observed over the first seven years after initiation of restoration efforts, highest in treatments seeded with grasses and fertilized but no accumulation was observed in untreated controls. Carbon accumulation rate of >0.05 kg C m^{-2} yr^{-1} can potentially be maintained over >100 yr due to the nature of Andosols and a steady burial by an influx of eolian materials. There are large areas of desertified surfaces in Iceland (thousands of km^2), many of which are undergoing restoration treatments. Restoration efforts in Iceland can play a significant role in sequestering carbon in ecosystems to balance national greenhouse gas emissions as well as restoring biodiversity and important ecosystem services.

1. Introduction

Soils are an important component of the global carbon cycle. Variations in soil carbon levels depend on factors such as soil type, environmental conditions and land use history (Chapin et al., 2009; Jobbagy and Jackson, 2000). A substantial proportion of elevated carbon levels in the atmosphere result from depletion of soil organic carbon pools due to land use (e.g., Lal, 2008). Undisturbed soils of the northern latitudes contain especially large pools of carbon (Tarnocai et al., 2009). The northern location of Iceland and the volcanic nature of the soils have resulted in large soil carbon stocks in undisturbed soils (Oskarsson et al., 2004). Carbon accumulation in soils is recognized as means to offset emissions in national budgets in relation to the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Article 3.4); (IPCC, 2006).

Iceland has experienced large scale ecosystem degradation and soil erosion mainly due to the interaction of intense land use since the settlement of the island in 874 AD, with cold climate spells and volcanic eruptions (Aradottir and Arnalds, 2001; Arnalds, 2000). This has resulted in the formation of desert areas with limited vegetation cover and low soil organic carbon pools (Arnalds et al., 2001b; Oskarsson et al., 2004). Deserts presently cover about 40 000 km^2 or about 40% of Iceland, including desertified areas and natural deserts of the highland interior and within volcanic areas (Arnalds, 2011). The desert soils have on average 0.1–4.5 kg C m^{-2} with sandy desert soils such at the experimental site commonly having about 0.1 kg C m^{-2} (Oskarsson et al., 2004). This is orders of magnitude lower than can be expected in fully vegetated ecosystems in Iceland which have 22 to >190 kg C m^{-2} (Oskarsson et al., 2004). This difference in organic carbon (OC) pools indicates a substantial potential for accumulating carbon by ecological restoration of deserts. Restoration of Icelandic desert areas enhances carbon enrichment in the soils and complies with targets set by UN conventions such as the Aichi Biodiversity Targets of enhancing ecosystem services and restoring 15% of degraded lands by 2020 (CBD, 2011). Revegetation is often an initial step in ecological restoration of desertified areas and it is therefore important to understand the ensuing carbon dynamics and verify accumulation rates.

In 1999, a large scale restoration research site was established in an eroded desert area in South Iceland (Fig. 1) in order to investigate ecosystem development during restoration of desert areas in Iceland. At this site, different revegetation treatments were applied in a replicated experiment with large plots to create conditions comparable to real restoration projects. The purpose of the research reported herein was to investigate the dynamics and rate of carbon accumulation in soils during the first stages of restoration efforts within a desertified area.

* Corresponding author. Tel.: +354 433 5000; fax: +354 433 5001.
E-mail address: oa@lbhi.is (O. Arnalds).

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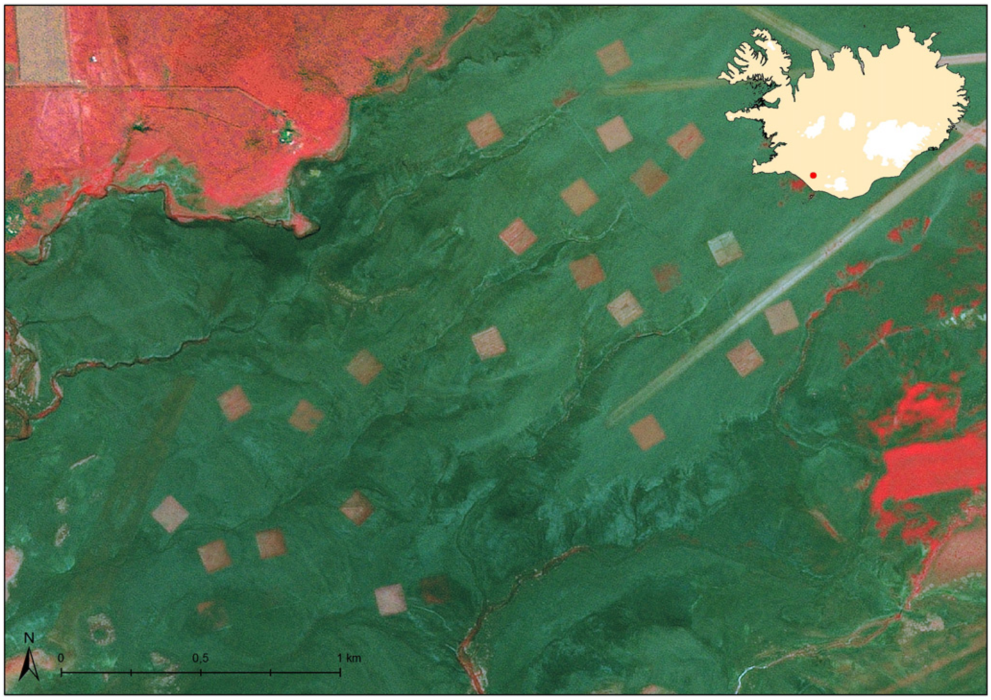

Fig. 1. Infrared satellite image of the Geitasandur Restoration Research Area. Vegetation is red on the image. The 1 ha plots show up as red squares surrounded by the dark colored sandy desert. Satellite image: © CNES/SPOT Image Corporation 2003.

2. Material and methods

2.1. Geographical setting

Iceland is a volcanic island situated on the Mid-Atlantic Rift Zone between 63°23′N and 66°32′N latitudes. The climate is oceanic with cool summers and mild winters (Einarsson, 1984). The parent material of Icelandic soils is mainly volcanic glass, deposited during eruptions and as eolian materials. Sandy areas cover about 22 000 km^2 while lag-gravel deserts are >10 000 km^2 (Arnalds et al., 2001b). The sandy materials consist not only of basaltic to andesitic volcanic glass but also of basaltic rock fragments (Arnalds et al., 2001a; Baratoux et al., 2011). The sandy areas have extremely unstable surfaces due to intense wind erosion and dust formation (Arnalds, 2010), water erosion in large snow-thaw events (Thorarinsdottir and Arnalds, 2012), and intense needle-ice formation and cryoturbation (Arnalds, 2004). The annual precipitation of these desert areas ranges from about 300 to >2000 mm with many of the desert areas being humid (>600 mm), especially in South Iceland.

2.2. Experimental site

The research site is located on Geitasandur sandy desert in South Iceland (Fig. 1). The area was sparsely vegetated due to severe desertification which most likely occurred in medieval times (Hjartarson, 1995; Sigurjonsson, 1958). The soils are dominated by volcanic glass and we classified them as Andosols (WRB; Vitric Andosol) or Andisols (Soil Taxonomy; Vitricryand). They commonly showed C–A–Bw–2C–R horizon sequences with a gravelly surface (C), but sandy loam and loamy sand textures in the A and Bw horizons. The soils had about 0.2% organic carbon content in top 10 cm and relatively low water retention (10–15% at 0.3 bar tension and 4–7% at 15 bar tension)

Table 1
Description of revegetation treatments and sampling schemes for soil samples (A–C; explained in Table 2). Plant species were seeded unless otherwise noted.

Treatment ID		Sampling scheme		
	Treatment	A	B	C
1-CTRL	Control (untreated, eroded land)	x	x	x
2-FERT	Fertilized	x		x
3-GR	Seeded with grasses (*Festuca rubra*, *Poa pratensis*) and fertilized	x	x	x
4-LY	Seeded with *Leymus arenarius* and fertilized	x		
5-LUP	Seeded with lupine (*Lupinus nootkatensis*)	x		
6-GR1-TR	Seeded with grasses (*P. pratensis*, *F. rubra* and *Lolium multiflora*, less hardy varieties than treatment nr. 3), fertilized and planted with clusters of birch and willows (*Betula pubescens*, *Salix phylicifolia* and *S. lanata*) in plowed furrows	x		
7-GR-TR	Seeded with grasses (same as nr. 3), fertilized and planted with clusters of birch and willows (same as nr. 6)	x	x	
8-NF-TR	No fertilizer; no seeds. Birch and willow clusters as in nr. 6 and 7 plus native nitrogen fixers (*Trifolium repens*, *Lathyrus japonicus* and *Vicia cracca*) planted into the clusters	x		
9-GR-BI/SPR	Same as nr. 3, plus birch and sitka spruce (*Picea sitchensis*) planted in plowed furrows in the whole plot in 2001	x		
10-LUP-BI/SPR	Same as nr. 5; plus birch and sitka spruce planted in plowed furrows in the whole plot in 2001	x		