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SOIL QUALITY ASSESSMENT OF CULTIVATED VOLCANIC SOILS OF SOUTH-WEST ICELAND

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ABSTRACT

Good soil quality is the basis for human, plant, animal and microorganism life as well as for environmental sustainability. Bad cultivation practices deteriorate soil quality and volcanic soils are particularly sensitive. This study aimed to evaluate the impact of cultivation on the soil quality of volcanic soils in South-west Iceland, and to compare the quality of cultivated soils that have received different managements. The hypothesis was that there was a measurable difference in soil quality between cultivated and non-cultivated soils. Soil quality indicators were measured on soil samples from five sites: land that had been cultivated for 17 years; 13 years; grass covered land (all wetland soils); erosion spots; and a birch tree cluster (dryland soils). The results showed that 17 years of cultivation had lowered carbon content and reduced aggregate stability. The erosion spot soil was structureless and had lower aggregate stability but a higher clay content than the soil under birch trees. The birch site, however, showed signs of improved soil quality with a higher carbon content, better structure and stronger aggregation compared to the erosion spot site. Total carbon, aggregate stability and soil colour seem to be the most sensitive indicators for cultivated versus non-cultivated soils, and for wetland versus dryland soils. Structure and C/N ratio are also usable indicators. For comparison of wetland and dryland soils, bulk density, porosity, water holding capacity, total nitrogen, CEC and clay % are also very sensitive indicators. Soil pH, consistency, and texture were less sensitive indicators of soil quality in this study. It is important to monitor organic content and aggregate stability of soils under cultivation in Iceland. In order to build up good soil characteristics it may be necessary to rest cultivated areas periodically. The methods applied here may be applicable to volcanic soils in Ethiopia.

Keywords: Volcanic soils; cultivation; soil quality

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1. INTRODUCTION

Soil is a living and important resource that supports plants, offers a physical, chemical and biological environment for living organisms and a strainer to maintain the quality of water, air, and other resources (USDA 1996). ”Soil quality” has been used as an indicator of the capacity of a soil to provide a functioning environment for living organisms (Scott & Cooper 2002). Healthy soils are crucial to sustained ecological and agricultural productivity, environmental quality, and plant and animal health. Soil erosion, pollution, deforestation, overgrazing, wrong irrigation practices and bad cultivation practices deteriorate soil quality. This results in food insecurity, pollution of water, water scarcity, economic crises, and climate change.

Soils that form in volcanic regions have andic soil properties and are classified as Andosols (World Reference Base WRB) or Andisols (Soil Taxonomy). These soils are often fertile but fragile and therefore susceptible to physical disturbance such as compaction, landslides and erosion (Arnalds 2004). Icelandic soils (Arnalds 2004) and most Ethiopian soils (Haileslassie et al. 2005) are volcanic in their origin. Soil erosion is a serious problem in Iceland and about 45,000 km^2 are affected by considerable to extremely severe erosion (Arnalds et al. 2001). More than 2 million ha of Ethiopian land are severely damaged due to water erosion (UNCCD 2008). Erosion decreases agricultural yield on average by approximately 4% for each 10 cm of top soil lost (Bakker et al. 2005) but the yield decrease depends on soil thickness, bedrock and organic matter content; relatively minor soil loss from thin soil can lead to complete loss of fertility. It is therefore important to monitor the effect of agriculture on soils.

Icelandic agriculture is characterized by extensive rangelands used for grazing and the production of hay for winter feeding but the cultivated land is of limited extent (Helgadóttir et al. 2013). Ethiopian agriculture involves both crop and livestock production and provides the livelihood for 85% of the population (Beshah 2003). This study aimed to evaluate the impact of cultivation practices on the soil quality of volcanic soils in South-west Iceland.

1.1 Hypothesis and objective of the study

The objective of this research was to assess the soil quality of cultivated land in volcanic areas. The specific objectives can be outlined as follows:

- To evaluate the impact of cultivation on soil quality.
- To compare the quality of cultivated soils that have received different management practices.
- To examine carbon content, nitrogen, phosphorus, soil pH, aggregate stability, soil structure, soil texture, clay %, cation exchange capacity, bulk density, soil colour and water retention of these different soils as a measure of soil quality.
- To develop my capacity in soil quality assessment.

To meet the objectives stated above, the following fundamental hypothesis was tested:

- There was a measurable difference in soil quality between cultivated and non-cultivated soils.

2. LITERATURE REVIEW

2.1 Definition of soil quality

Soil has many functions, which include sustaining biological diversity, regulating water, filtering organic and inorganic materials, storing and cycling nutrients and carbon, and providing physical stability (USDA 2011). Soil quality is defined as "the ability of a soil to perform the functions necessary for its intended use" (USDA 2011, p.1).

2.2 Indicators of soil quality

Soil quality indicators are divided into physical, chemical and biological indicators, depending on how they impact soil quality (Lewandowski et al. 1999). The physical indicators include bulk density, soil structure, aggregate stability, soil texture, water dynamics (infiltration, hydraulic conductivity, water holding capacity) and soil depth. Chemical indicators include soil pH, total carbon, total nitrogen, the carbon to nitrogen ratio, available phosphorus, cation exchange capacity, base saturation, electrical conductivity, exchangeable sodium percentage, sodium adsorption ratio, organic matter, active carbon and active nitrogen. Biological indicators include soil respiration and microbial biomass (Lewandowski & Zumwinkle 1999).

2.2.1 Bulk density

The density of the mineral fraction of the soil (sand, silt and clay) and soil organic matter particles affect bulk density, in addition to their packing arrangement. Most rocks have a bulk density of 2.65 g/cm^3 but medium textured soil with about 50% pore space will have a bulk density of about 1.3 g/cm^3 (USDA 2008a). Porous soils and soils that have a high organic matter content have lower bulk density. Sandy soils have a comparatively higher bulk density because the total pore space in sand is less than that of silt or clay soils. Well-textured soils with good structure have a higher pore space and lower bulk density compared to sandy soils (USDA 2008a).

2.2.2 Soil structure

Soil structure refers to the arrangement of the primary soil particles (sand, silt, and clay) and other soil materials into discrete aggregates (USDA 2008b). Soil structure affects water and air movement through the soil, significantly influencing the soil's capacity to sustain life and achieve other vital soil functions. Soil structure is affected by clay particles and the shrinking and swelling of clay masses (USDA 2008b). The types of soil structure (Fig. 1) include single grain without structure, spheroidal, plate like, block like and prism like (Brady & Weil 1996).

2.2.3 Soil aggregate stability

Soil aggregates are groups of primary soil particles and organic matter that stick to each other more strongly than to other surrounding particles (USDA 2008c). Soil aggregate stability is affected by the predominant type and amount of clay, adsorbed cations such as calcium and sodium, and iron oxide content. It is also affected by organic matter, the biological activity in soil, and tillage. Aggregate stability affects infiltration, root growth and resistance to water and wind erosion.

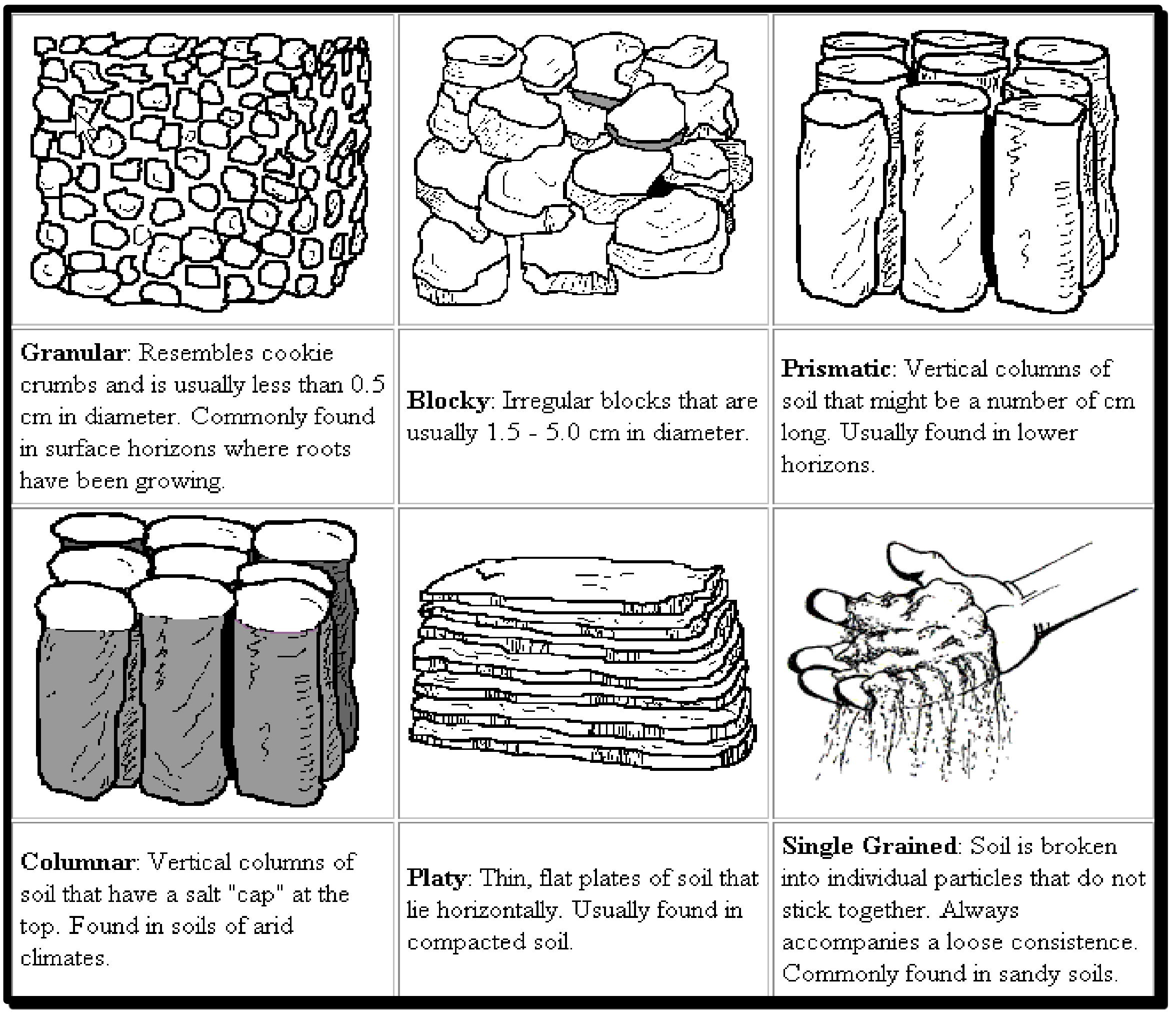

Fig. 1. *Types of soil structure (University of Hawaii n.d.).*

Unstable aggregates can split during rainstorms. The loose soil particles block surface openings and the soil can be changed to a hard physical crust when the soil dries which affects infiltration negatively. This can lead to increased runoff and water erosion and reduce the water available in the soil. Wind usually detaches loose particles on the soil surface but soil particles carried by the wind also hit bare soil with enough energy to break particles loose from weakly aggregated soils (USDA 2008c).

2.2.4 Soil texture

Texture refers to the comparative amount of sand, silt and clay present in the soil (Hughes. &. Venema 2005). Soil texture affects soil structure, aeration, water-holding capacity, water movement, nutrient storage, and root development. Sandy soils permit water to enter the soil at a fast rate and to move more freely downward in the soil, and they are easy to till. Clay particles have the ability to trap water and maintain nutrients for plant use. Loamy soils, which have a mixture of sand, silt and clay, are generally good for growing crops. Clay soils have good nutrient and water storage capacity, but water transfer is slow through such soils (Hughes & Venema 2005).

2.2.5 Water holding capacity

The quantity of water that can be held by soil is influenced by texture, organic matter, structure and percent of sand, silt and clay in the soil (Lewandowski et al. 1999). Available water of a soil is defined as the amount of water a soil can provide for plant use. It is the water held in soil between field capacity and the permanent wilting point (Brady & Weil 2004). Field capacity is the water remaining in a soil after it has been exhaustively saturated and allowed to drain freely, the metric potential usually is in the range of 10-30 KPa (0.11-0.33 bar) depending on soil type. The permanent wilting point is the moisture content of a soil at which plants wilt and the amount of water retained by 1500 KPa (15 bar) potential. The plant available water is calculated as the amount of water at field capacity minus the water content at the permanent wilting point (Brady & Weil 2004).

2.2.6 Soil reaction (pH)

Soil reaction, or soil pH, is defined as the soil's acidity or alkalinity. If the pH is equal to 7 the soil is neutral, if it is below 7 the soil is acidic, and if it is above seven the soil is alkaline. Most plant nutrients are available between soil pH 6 and 7.5 (Hughes. &. Venema 2005) and most crops grow best at this pH (Marx et al. 1996). On average, soil pH values less than 5.1 are classified as strongly acid, between 5.2 and 6.0 as moderately acid, between 6.1 and 6.5 as slightly acid, between 6.6 and 7.3 as neutral, between 7.4 and 8.4 as moderately alkaline and above 8.5 strongly alkaline (Marx et al. 1996).

2.2.7 Organic carbon

Organic carbon is a vital component of the soil added to it through the decomposition of organic matter (USDA 2009). Organic matter in soil contains about 58% carbon. Soil organic matter consists of organic material derived from former living things such as plant litter, dead roots, dead soil organisms and organic products obtained from the decomposition process**.** It is the main source of energy and nutrients for soil microorganisms. Humus contributes to aggregate stability and nutrient and water holding capacity (USDA 2009). Total organic carbon content less than 2% is classified as very low, between 2% and 4% as low, between 4% and 10% as medium, between 10% and 20% as high and above 20% as very high (Hill-laboratories n.d.).

2.2.8 Nitrogen (N)

Nitrogen is a primary macro nutrient for plants and is used in the form of nitrate (NO_3^-) and ammonium (NH_4^+) ions. Nitrogen biologically combines with carbon, hydrogen, oxygen and sulphur to create amino acids, which are important for all of the enzymatic reactions in a plant. In addition, it is a major portion of the chlorophyll molecule. Nitrogen is also a component of vitamins and increases the quality and quantity of dry matter in leafy vegetables and protein in grain crops (Silva & Uchida 2000). Soil total nitrogen (STN) is an important indicator of soil fertility and soil quality (Huang et al. 2007). Total nitrogen less than 0.1% is classified as very low, between 0.1% and 0.2% as low, between 0.2% and 0.5 % as medium, between 0.5% and 1% as high and above 1% as very high (Hill-laboratories n.d.).

2.2.9 Carbon to nitrogen ratio (C/N)

The C/N ratio of the soil influences the rate of decomposition of organic matter and these results in the release (mineralisation) or immobilization of soil nitrogen. If the soil has more nitrogen in proportion to carbon, then nitrogen is released into the soil. On the other hand, if the organic material in the soil has a lesser amount of nitrogen in relation to the carbon then the microorganisms will utilize the soil nitrogen for further decomposition and the soil nitrogen will be immobilized and will not be available to plants (Brady & Weil 2004). A carbon to nitrogen ratio less than 8 is classified as very low, between 8 and 10 as low, between 10 and 15 as medium, between 15 and 25 as high and above 25 as very high (Hill-laboratories n.d.).

2.2.10 Phosphorus (P)

Phosphorus is a plant macronutrient and a component of key molecules such as nucleic acids, phospholipids, and adenosine triphosphate (ATP). Therefore, plants cannot grow without a reliable supply of this nutrient (Schachtman et al. 1998). Phosphorus is relatively plentiful in many soils but it is mainly unavailable for plant uptake (Vance et al. 2003). It can exist in several chemical forms, depending on soil pH. Plant available phosphorus is highest in the pH 6-7 range. In very acidic soils (low pH), phosphorus is fixed by aluminium and iron, and at higher pH (alkaline) it is fixed by calcium and magnesium (Ashman & Puri 2009). If phosphorus determined by the Olsen extraction method is less than 10, it is classified as low, between 10 and 20 as medium, between 20 and 40 as high and above 40 as excessive (Marx et al. 1996).

2.2.11 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) is defined as the capacity of the soil to adsorb or hold cations at a specific pH (Foth 1991). CEC is controlled by the reactive amount of colloids in the soil (Brady & Weil 2010). Clay loams are higher in colloidal material than silt loams and sandy soils. High CEC is also associated with humus content (Brady & Weil 2010). If the CEC value is between 5 and 12 $cmol_c$/kg, the CEC is classified as low and the soil is sandy or low in organic matter. If it is between 12 and 25, the CEC is classified as medium and between 25 and 40 as high and the soil is fertile. If greater than 40, the CEC is classified as very high and the soils are likely to be clay soils with high organic matter levels, or peat soils (Hill-laboratories n.d.).

3. MATERIALS AND METHODS

3.1 Description of study area

Iceland is located between the 63°23’ and 65°32’N latitude and 13°29’ and 24°32’W longitude. The population of the country is approximately 320,000 and nearly 80% of the population live in the south-west corner of the country close to the capital city of Reykjavik (Helgadóttir et al. 2013).

Even though Iceland is located just below the Arctic Circle, it enjoys a mild maritime climate. The growing season is cool and generally fairly wet and extends over four months, from May to September. The mean temperature in Reykjavík is -0.55 and 10.8°C in January and July, respectively. The maximum precipitation occurs in October. (WWIS [World weather information service] n.d.). The yearly average precipitation was 848 for the period 1996-2012. The maximum average annual precipitation was 1125.4 mm in 2007. The maximum average annual temperature was 6.1°C in 2003 but the yearly average temperature was 5.2°C for the period 1996-2012 (IMO [Icelandic Met Office] n.d.).

The study was carried out at three sites in South-west Iceland: 1) the Agricultural University of Iceland's Research Station Korpa, 2) the Agricultural University grounds at Keldnaholt in Reykjavik, and 3) in the Hafravatn area a few km east of Reykjavik (Fig. 2).

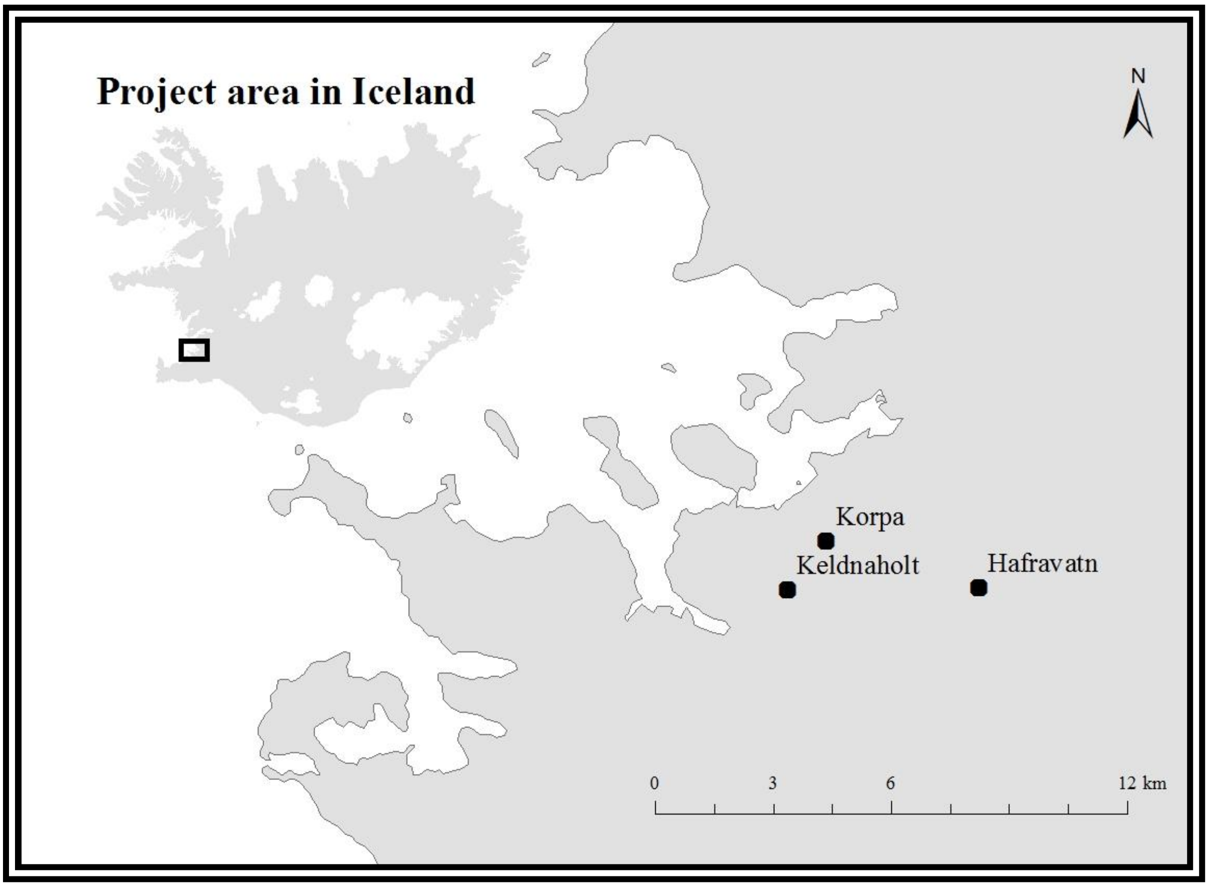

Fig. 2. *Map of project area in Iceland.*

3.2 Site description

Three fields with different management histories at the Korpa research station, erosion spots in a degraded area near Lake Hafravatn, and soils under birch trees on the Agricultural University of Iceland grounds at Keldnaholt were sampled; five sites all together. Further description of the sites and the land use history of the three fields is as follows:

Land cultivated for17 years at Korpa (17-C)
The land (Fig. 3) had been drained, ploughed annually since 1995 and seeded with barley.

Land cultivated for13 years at Korpa (13-C)
The land (Fig. 4) had been drained. It had been ploughed annually for the last 13 years, and only occasionally before that.

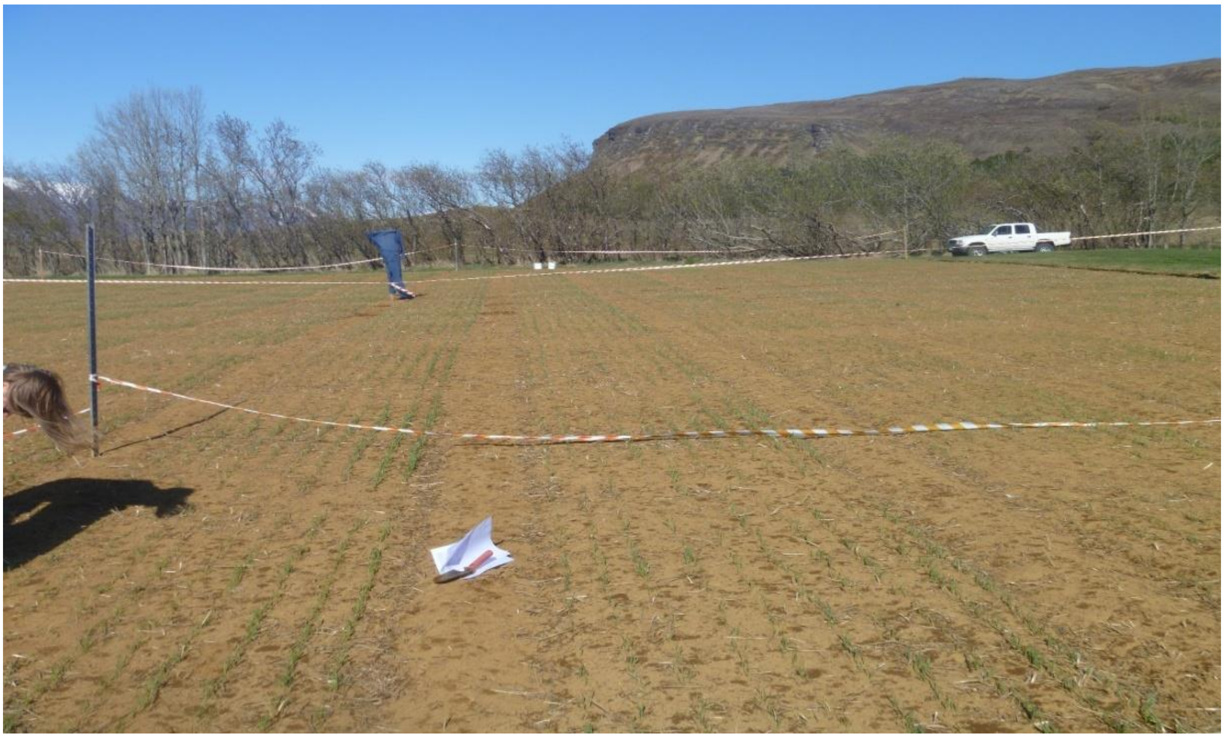

Fig. 3. *After 17 years of cultivated land, Korpa Research Station (22 May 2013).*

Fig. 4. *After 13 years of cultivated land, Korpa Research Station (22 May 2013).*

Grass covered land at Korpa (G-C)

The land (Fig. 5) has been an undisturbed (not tilled) hayfield since 2000 but before that it had been used occasionally for experiments. Perennial grasses grow on it and the grass has been cut annually. The soil is considered fertile.

Fig. 5. *Grass covered cultivated land at the Korpa* Research Station (*22 May 2013).*

Erosion spots in the Hafravatn area (ES)

In the Hafravatn degraded area (Fig. 6), the samples were obtained from erosion spots between otherwise vegetated land, where succession is slowly returning vegetation cover to previously completely barren land.

Fig. 6. *Erosion spots in the Hafravatn area (22 May 2013).*

Birch stand at Keldnaholt (SUBT)
The samples were obtained from under a birch stand at the Agricultural University grounds in Keldnaholt. This site was representative of undisturbed soils under robust vegetation with functional water and nutrient cycles.

3.2.1 Soils

The soils of the Korpa Research Station were wetland soils (O. Arnalds, personal communication, August 14, 2013), but were relatively dry at the surface. They were typical Gleyic Andosols, as described and classified by Arnalds et al. (2005), gleyic because of ox/redox features at some depth. The texture was silt loam. The soils of the Hafravatn site were also Gleyic Andosols, but they were sandy loams and low in organic matter with broken nutrient and water cycles. These soils were under the influence of intense frost heave and cryoturbation. The soil under birch trees at the Keldnaholt site was a Brown Andosol that has been left undisturbed for soil development for 30-40 years, but before that it had similar characteristics to the Hafravatn soil. The Keldnaholt and Hafravatn soils were dryland soils (O. Arnalds, personal communication, August 14, 2013).

3.3 Data collection method

3.3.1 Soil sampling

To analyse relevant physicochemical properties of the soil, three soil samples were obtained at each study site making the total number of samples 5x3=15. The samples were taken with a shovel from 0-15 cm depth and each sample consisted of 6 sub-samples (Fig.a. in Appendix 1). For the bulk density analysis, 6 undisturbed core samples were also taken from each site.

3.3.2 Soil analysis

The soil samples were air dried, sieved to pass a 2 mm size sieve screen and stored in sealed plastic containers for laboratory analysis. Soil colour was determined using a Munsell soil colour chart (Fig.c. in Appendix 1), bulk density (Fig.e. in Appendix 1) by the field core method (Elliott et al. 1999) and soil structure by the field method. Aggregate stability was determined by the soil stability test (Fig.f. in Appendix 2) (Herrick et al. 2001). Texture was determined by the hand texturing method and clay percentage was analysed by acid oxalate extraction (Blakemore et al. 1987) and calculated as clay% = 6Si+1.7Fe. Water retention (water holding capacity) was measured in a pressure plate extractor from Soilmoisture Equipment Corp (Fig.d. in Appendix 1) at 0.33, 1 and 15 bar. Soil pH was determined in a 1:5 soil to water ratio mixture (Blakemore et al. 1987). Total nitrogen and total carbon were quantified by catalytic tube combustion under an excess oxygen supply at 900°C using Vario Max CN equipment from Elementar Analysensysteme GmbH (Fig.b. in Appendix 1). Phosphorus was determined by the ammonium lactate extraction method (Egnér et al. 1960) and converted to Olsen's method by Olsen P = 2.35 + 0.45 AL-P (ammonium lactate extraction) (Do Carmo Horta et al. 2010). CEC was calculated as -3.94 +0.216(organic carbon) +0.277(Al_0 +Fe_0) +3.93([1/precipitation]^2) (Arnalds et al. 1995).

3.4 Statistical analysis

Data were analysed using JMP Discovery Version 10 (SAS Institute Inc. 2012). One way analyses of variance (ANOVA) and comparison for all pairs using the Tukey-Kramer HSD was performed to evaluate the main effects of land management type on indicators of soil quality.

4. RESULTS

4.1 Soil structure and consistency

All samples from the soils cultivated for 17 years at Korpa had blocky structure, fine, medium and coarse size, and weak grade (Table 1). All the samples from the soil cultivated for 13 years were fine (granular) and fine and medium (blocky) size, weak grade. All samples from the grass covered soils had granular structure, fine, medium, and coarse size, moderate and strong grade. Soils under birch trees had granular structure, fine and medium size; two samples had weak and moderate and one sample had weak grade. All soils from the erosion spots were structureless.

The soils cultivated for 17 years had a very friable consistency, grass covered soils were friable, and soils from under the birch trees and those cultivated for 13 years had a friable and very friable consistency (Table 1).

4.2 Texture and soil colour

The soils of the land cultivated for 17 years and 13 years and soils under the birch area were all silt loams (Table 2). Soil at the grass covered site was a clay loam and soil from the erosion spot was sandy loam. The soil cultivated for 17 years had a reddish brown colour, soils cultivated for 13 years, grass covered and erosion spots were darker, with a dark reddish brown colour, and the soil under the birch trees was the darkest with a dark brown colour (Table 2).

4.3 Aggregate stability, bulk density and porosity

The grass covered and the birch soils had an aggregate stability index greater than 5.5 (Table 3) but both the soils cultivated for 17 years and for 13 years and the soils from the erosion spots had an index less than 5.5. The soils cultivated for 17 year and 13 years and the grass covered sites had a lower bulk density and higher porosity than the other soils (Table 3). Soils from under the birch trees and from the erosion spots had a higher bulk density and lower porosity than the cultivated and grass covered soils.

4.4 Water holding capacity

The soils cultivated for 17 years and 13 years and the grass covered sites had higher moisture at field capacity and at permanent wilting point than soils from the birch tree area and the erosion spots (Table 4). Soils from the erosion spots had better water holding capacity than soils from under the birch trees.

Table 1. *Soil structure and consistency of soils: measured on soil sampled to a 15 cm depth after 17 years of cultivation (17-C), 13 years of cultivation (13*-C), *grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES).LUM means land use and management.*

LUM	**Replication**	**Structure**	**Structure size**	**Structure grade**	**Consistency**
17-C	1	Blocky	Fine, medium and coarse	Weak	Very friable
17-C	2	Blocky	Fine, medium and coarse	Weak	Very friable
17-C	3	Blocky	Fine, medium and coarse	Weak	Very friable
13-C	1	Structure less, granular and blocky	Very fine and fine (granu-lar);fine and medium (blocky)	Weak	Very friable and friable
13-C	2	Structureless, granular and blocky	Very fine and fine (granu-lar); fine and medium (blocky)	Weak	Very friable and friable
13-C	3	Structureless, granular and blocky	Very fine and fi-ne(granular); fine and medium (blocky)	Weak	Very friable and friable
G-C	1	Granular	Fine, medium, and coarse	Moderate and strong	Friable
G-C	2	Granular	Fine medium and coarse	Moderate and strong	Friable
G-C	3	Granular	Fine, medium and coarse	Moderate and strong	Friable
SUBT	1	Granular	Fine and medium	Weak and moderate	Friable and very friable
SUBT	2	Granular	Fine and medium	Weak	Friable and very friable
SUBT	3	Granular	Fine and medium	Weak and moderate	Friable
E-S	1	Structureless			
E-S	2	Structureless			
E-S	3	Structureless			

Table 2. *Texture and soil colour of soils : measured on soil sampled to a 15 cm depth after 17 years of cultivation (17-C), 13 years of cultivation land (13-*C), *grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES).LUM means land use and management.*

LUM	Replication	Texture	Soil colour
17-C	1	Silt loam	5yr 4/4, reddish brown
17-C	2	Silt loam	5yr 4/4, reddish brown
17-C	3	Silt loam	5yr 4/4, reddish brown
13-C	1	Silt loam	5yr 3/3, dark reddish brown
13-C	2	Silt loam	5yr 3/3 dark reddish brown,
13-C	3	Silt loam	5yr 3/3,dark reddish brown
G-C	1	Clay loam	5yr3/4, dark reddish brown
G-C	2	Clay loam	5yr ¾, dark reddish brown
G-C	3	Clay loam	5yr ¾, dark reddish brown
SUBT	1	Silt loam	7.5yr 3/2, dark brown
SUBT	2	Silt loam	5yr 3/3, dark reddish brown
SUBT	3	Silt loam	7.5yr 3/2, dark brown
E-S	1	Sandy loam	75yr 3/2, dark brown
E-S	2	Sandy loam	5yr. 3/3 dark reddish brown,
E-S	3	Sandy loam	5yr 3/4, dark reddish brown

Table 3. *Means and standard deviations of aggregate stability, bulk density and porosity: measured on soil sampled to a 15 cm depth on land cultivated for 17 years (17-C), land cultivated for 13 years (13-*C), *grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES). Land use management type (LUM) means followed by different letters are significantly different at 0.05.* ******* *means significantly different.*

	Aggregate stability Index		Bulk density g/cm^3		Porosity %	
LUM	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
17-C	4.33^{BC}	1.15	0.65^{C}	0.04	75.43^{A}	1.75
13-C	4.66^{AB}	0.57	0.65^{C}	0.05	76.97^{A}	1.99
G-C	6.00^{A}	0.00	0.66^{C}	0.04	74.99^{A}	1.51
SUBT	6.00^{A}	0.00	1.22^{A}	0.10	53.83^{C}	3.97
ES	3.00^{C}	0.00	0.92^{B}	0.14	64.99^{B}	5.45
P-value	.0004*		<.0001*		<.0001*	

The soil cultivated for 17 years and 13 years and the grass covered soils had better available water than soils from the birch tree site and erosion spots (Table 5). Also, the erosion spots had better available water than soils from the birch site. Generally the water retention decreased in the following order: grass covered, 17 years cultivated, 13 year cultivated, erosion spots and soil under the birch trees (Fig.7).

4.5 Total carbon, total nitrogen and carbon to nitrogen ratio

The soils cultivated for 13 years and the grass covered soils had higher total carbon than the soils cultivated for 17 years and also higher carbon content than the soils under the birch trees (Table 6). The soil under the birch trees had more carbon than did the erosion spots. The soils cultivated for 17 years and 13 years and the grass covered soils had higher total nitrogen than the soils under the birch trees and in the erosion spots (Table 6). The carbon to nitrogen ratio of the soils decreased in the following order: under birch trees, erosion spots, grass covered soils, 17 years cultivated and 13 years cultivated (Table 6).

Table 4. *Means and standard deviations of water retention (WR) at 0.33 bar, 1 bar and 15 bar. Measured on soil sampled to a 15 cm depth on land cultivated for 17 years (17-C), land cultivated for 13 years (13-*C*), grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES). Land use management type (LUM) means followed by different letters are significantly different at 0.05. * means significantly different.*

	WR at 0.33 bar		**WR at 1 bar**		**WR at 15 bar**	
LUM	**Mean %**	**Standard deviation**	**Mean %**	**Standard deviation**	**Mean %**	**Standard deviation**
17-C	89.62^{A}	7.01	72.58^{AB}	4.10	41.20^{A}	1.48
13-C	82.56^{A}	6.69	63.62^{ABC}	4.09	38.31^{A}	3.00
G-C	91.91^{A}	12.10	81.13^{A}	10.20	42.35^{A}	4.81
SUBT	34.54^{B}	3.24	29.32^{C}	4.85	15.68^{B}	2.85
ES	53.95^{AB}	33.53	44.79^{BC}	25.82	25.92^{AB}	16.26
P-value	0.0062*		0.0036*		<0.0076*	

Table 5. *Means and standard deviations of plant available water: Measured on soil sampled to a 15 cm depth on land cultivated for 17 years (17-C), land cultivated for 13 years (13-*C*), grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES) Land use management type (LUM) means followed by different letters are significantly different at 0.05.* means significantly different.*

	Available water	
LUM	**Mean %**	**Standard deviation**
17-C	48.41^{A}	5.54
13-C	44.25^{A}	3.81
G-C	49.55^{A}	7.30
SUBT	18.85^{B}	0.58
ES	28.03^{AB}	17.34
P-value	0.0059*	

Fig. 7. *Birch stand at the Agricultural University (24 May 2013).*

Table 6. *Means and standard deviations of total carbon (TC), total nitrogen (TN), and carbon to nitrogen ratio (C/N)**:** measured on soil sampled to a 15 cm depth at 17-C, 13-*C*, G-C, SUBT and ES. Land use management type (LUM) means followed by different letters are significantly different at 0.05. * means significantly different.*

LUM	**TC%**		**TN%**		**C/N**	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
17-C	7.76^{AB}	1.00	0.67^{A}	0.06	11.48^{CD}	0.37
13-C	8.18^{A}	0.50	0.72^{A}	0.04	11.27 ^{D}	0.03
G-C	9.83 ^{A}	0.90	0.73^{A}	0.02	13.27^{BC}	0.75
SUBT	4.70^{BC}	0.83	0.29^{B}	0.13	16.24^{A}	1.04
ES	2.54^{C}	0.83	0.17^{B}	0.05	14.36^{B}	0.70
P-value	0.0001*		.0001*		0001*	

4.6 Available phosphorus and pH

There was no significant difference in available phosphorus between the soils but there was a significant difference in pH (Table 7). The decreasing order of pH was: erosion spots, birch trees, grass covered soils, 17 years cultivated and 13 years cultivated.

Table 7. *Means and standard deviations of available phosphorus, Olsen method (*Olsen P*) and soil pH: Measured on soil sampled to a 15 cm depth on land cultivated for 17 years (17-C), land cultivated for 13 years (13-*C), *grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES). Land use management type (LUM) means followed by different letters are significantly different at 0.05. * means significantly different, ns means non-significant difference.*

	Olsen P ppm		pH	
LUM	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
17-C	3.89	0.20	5.96 ^{C}	0.09
13-C	3.67	0.21	6.02 ^{C}	0.05
G-C	4.45	0.46	6.14 ^{BC}	0.12
SUBT	15.49	13.51	6.44^{AB}	0.26
ES	2.93	0.12	6.73 ^{A}	0.05
P-value	ns		<0.0003*	

4.7 Cation exchange capacity, clay% and Al+0.5Fe

Both the soils cultivated for 17 years and for 13 years and the grass covered soils had a higher CEC than soils from the erosion spots and from the birch site (Table 8). The sites cultivated for 17 years and for 13 years and the grass covered sites also had a higher clay % than the erosion spots and the soils under birch trees. However, the erosion spots had a higher clay % than the soils under the birch trees. All the soils had Al+0.5Fe greater than 2%, which is the diagnostic criterion for Andosols, according to Arnalds et al. (1995).

Table 8. *Means and standard deviations of Al, Fe, Si, CEC, clay % and Al+0.5Fe: Measured on soil sampled to a 15 cm depth on land cultivated for 17 years (17-C), land cultivated for 13 years (13-*C), *grass covered land (G-C), soils under birch trees (SUBT) and soils from erosion spots (ES). Land use management type (LUM) means followed by different letters are significantly different at 0.05 * means significantly different, ns means non-significant difference.*

	Al %		Fe %		Si %		CEC $cmol_c/kg$		Clay %		Al+0.5Fe %	
LUM	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**
17-C	4.58^{A}	0.13	3.07	0.97	2.45^{A}	0.04	18.94^{A}	3.26	19.96^{A}	1.71	6.12^{A}	0.61
13-C	4.53^{A}	0.11	2.92	0.2	2.29^{A}	0.07	18.51^{A}	0.20	18.77^{A}	0.18	6.00^{A}	0.01
G-C	3.76^{B}	0.50	3.66	0.74	1.99^{A}	0.25	18.77^{A}	3.29	18.18^{A}	2.68	5.6^{AB}	0.84
SUBT	2.28^{C}	0.70	2.71	0.60	1.39^{B}	0.32	10.92^{B}	3.62	12.99^{B}	2.56	3.64^{C}	0.91
ES	3.01^{Bc}	0.17	2.06	0.10	2.14^{A}	0.04	10.67^{B}	0.88	16.32^{AB}	0.16	4.04^{BC}	0.21
P-value	0.0001*		ns		0.0004 *		0.0036*		0.0015 *		0.0073 *	

5. DISCUSSION

5.1 Soil structure and consistency

Soils from the erosion spots were structureless (Table 1) but surprisingly the clay% was higher in the erosion spots than at the birch site (Table 8). This indicates that the clay in the erosion spots was aggregated into silt aggregates, as is common with allophane clays (Maeda et al. 1977). The soils under the birch were also structureless 45 years ago (O. Arnalds, personal communication, August 14, 2013) but they now had granular structure (Table 1), higher available phosphorus and more nitrogen than the erosion spots. The study also showed that the soil under the birch had more total carbon, likely because it had been well vegetated and undisturbed for 45 years and therefore had been able to accumulate carbon during that time. However, the water holding capacity of this soil was less than for the erosion spots. The land that had been cultivated for 17 years had a blocky structure while some part of the land cultivated for 13 years had granular structure (Table 1), which is better than blocky according to Brady and Weil (2010). The grass covered soil, which had been untilled and covered with grass for 13 years, also had a granular structure. According to Brady and Weil (2008) granular structure is related to the decomposition of organic matter and is common in grassland because of the presence of earthworms. The land cultivated for 13 years had some similarity in structure to the grass covered site, which might be a result of less cultivation. Similarly, the less developed structure of the land cultivated for 17 years could be attributed to cultivation, which reduces aggregation and changes the way soil particles are arranged (Gupta & Germida 1988). The study also showed that all soils except soils from the erosion spots (Table 1) had a friable to very friable consistency, which indicated fertile soils (O. Arnalds, personal communication, August 14, 2013).

5.2 Texture and soil colour

The results of the hand feeling texture analysis showed that the soils cultivated for 17 and 13 years, as well as those from under the birch trees, were all silt loams; the grass covered soil was clay loam and the soil from the erosion spots was sandy loam (Table 2). Clay determination using acid ammonium oxalate extraction, however, revealed that the erosion spots had a higher clay% than the soil under the birch trees (Table 8). This indicated that the hand texture feeling method is less accurate than the acid ammonium oxalate method in determining clay content, presumably because the hand texturing is more subjective and can be difficult for an untrained person to do.

The results also showed that the soils cultivated for 17 years had a reddish brown colour but the soils cultivated for 13 years and the grass covered soils had a dark reddish brown colour (Table 2). According to Peverill et al. (1999), a darker brown colour is a sign of more organic carbon. The results therefore indicated that the organic carbon content and colour of the soil was affected by cultivation practices and land management. The dark colour of the soil under the birch tree (Table 2) indicated the presence of more organic carbon compared to the erosion spots.

5.3 Aggregate stability, bulk density and porosity

According to the index of Herrick et al. (2001), soil with aggregate stability above 5.5 is considered very resistant to erosion, but low resistance if the index is less than 5.5. Soils under the birch and grass cover had an index higher than 5.5 (Table 3) but soils in areas cultivated for 17 and 13 years and from the erosion spots had an index less than 5.5 (Table 3). This shows that only the birch and grassland soils can be considered stable. A possible conclusion is that cultivation has reduced the stability of the cultivated soils while the soils of the erosion spots are lacking in the biological activity necessary to promote aggregation.

Bothe the 17 and 13 year cultivated sites and the grass covered soils had lower bulk density than soils under the birch trees and from the erosion spots (Table 3). This also had a direct relationship with clay % of the soils. According to Brady and Weil (2008), sandy soils have higher bulk density than silt and clay soils. Both the land cultivated for 17 year and for the 13 years and grass covered soils also had higher porosity than the soil under the birch trees and in the erosion spots (Table 3). The difference in bulk density and carbon, however, was probably more due to the different types of land (wetland vs. dryland) rather than a result of land use and management type.

5.4 Water holding capacity of the soil

The soils cultivated for 17 and 13 years and the grass covered soils had better available water than soils from the erosion spots and from under the birch trees (Table 5). This is attributed to more carbon in the wetland soils than the dryland birch site (Table 6). Higher water retention is related to carbon and clay content and the bulk density of the soil (Lewandowski et al. 1999).

5.5 Total carbon, total nitrogen and carbon to nitrogen ratio

Soils from the land cultivated for 17 and 13 years and from the grass covered land as well as the soil under the birch trees had a total carbon content between 4 and 10% (Table 6). According to Hill-laboratories (n.d.) this content is classified as medium. Soils from the erosion spot had a carbon content between 2 and 4%, which is classified as low. The mean value of total nitrogen (Table 6) showed that both the land cultivated for 17 and for 13 years and the grass covered land had between 0.5 and 1.0% N, and thus should be considered high in N according to Hill-laboratories (n.d.). Soils under the birch trees had between 0.2 and 0.5% and were classified as medium, while soils from the erosion spots had between 0.1 and 0.2% and were classified as low in nitrogen. The results indicate that cultivated soils had both significantly higher carbon and nitrogen levels than the other two. The birch soil was also significantly higher in carbon and nitrogen than the erosion spots.

The mean carbon to nitrogen ratio (Table 6) for the sites cultivated for 17 and 13 years and the grass covered site and soils from the erosion spots was between 10 and 15. These values are normal for arable soils with a good rate of organic matter decomposition (Hill-laboratories n.d.).

The soil under the birch trees had a C/N ratio between 15 and 25, which according Hill-laboratories (n.d.) is classified as high. This indicated slow decomposition of organic matter or build-up of the organic content in the soil.

5.6 Available phosphorus and pH

All soils except those under the birch had less than 10 ppm available phosphorus (Table 7) and should therefore, according to Marx et al. (1996), be classified as low in phosphorus. The soil under the birch trees had between 10 and 25 ppm P and therefore classified as medium. It should be noted that Andosols immobilize P (Dahlgren et al. 2004), which means that high P fertilization is required for cultivation of Andosols. The pH of the soils under cultivation for 13 years, the grass-covered soils and those under the birch trees was between 6.1 and 6.5 and should, according Marx et al. (1996), be classified as slightly acid. For the soils under cultivation for 17 years' the pH was between 5.2 and 6.0 and the soils classified as moderately acid, whereas soils from the erosion spot were between 6.6 and 7.3 and were classified as neutral. Marx et al. (1996) argue that soils with a pH between 6.0 and 7.5 are favourable for growing most crops. This applies to all soils in this study except the sites cultivated for 17 years. The lower pH at the Korpa sites (cultivated and grass land) was because they are drained wetland soils, which generally leads to lower pH compared to dryland soils (Arnalds 2004), but may also result from the long use of fertilizers.

5.7 Cation exchange capacity, clay% and Al+0.5Fe

The soils cultivated for 17 and 13 years and the grass covered soils had a higher CEC than the soils under the birch trees and the erosion spot soils (Table 8). Based on the results, and according to Hill-laboratories (n.d.) interpretation guideline, these soils were therefore classified as medium, or between 12 and 25 $cmol_c$/kg on average. This is also characteristic of silt and clay soils with medium to low organic matter level (Hill-laboratories n.d.). On the other hand, soils from under the birch trees and from the erosion spots classified as low. This means that they had between 5 and 12 $cmol_c$/kg, which is also characteristic of sandy soils or soils low in organic matter (Hill-laboratories n.d.). The soils years cultivated for 17 and 13 years and the grass covered soils had a higher clay % than the soils under the birch trees and the erosion spot soils. Surprisingly, however, the clay content of the erosion spot soils was higher than in the soils from under the birch trees. This was due to a higher content of allophane (Si_o x 6) in the erosion spot. The study also confirmed that all the soils had andic properties, i.e.Al+0.5Fe >2% (cf. Arnalds et al. 1995).

6. CONCLUSIONS

The 17 years of cultivation had had a marked influence on soil properties, including lowering the carbon content and reducing aggregate stability. There was relatively little difference between the 13 year and 17 year cultivated soils. The erosion spot soils had a similar clay content as these soils, though they had low aggregate stability and no structure. This may be attributed to less organic matter, more frost action, and less biological activity. The water holding capacity of the soils in this study reflected both the organic and the clay content of soils. It was higher in the wetland soil than the dryland soils because of the higher level of organic matter in the wetland soils. The low water holding capacity of the birch site may be attributed to the lower clay content at that site, but also lower carbon content compared to the wetland soils. However, the birch site showed signs of improved soil quality with higher organic content, better structure and stronger aggregation compared to the erosion spot site. The lower C/N ratio of the cultivated land may be because less organic residues are added to the soil as the crops are harvested.

Total carbon, aggregate stability and soil colour seem to be the most sensitive indicators of soil quality for cultivated versus non-cultivated soils, as well as for wetland versus dryland soils, but structure and C/N ratio were also usable indicators. Bulk density, porosity, available water, total nitrogen, CEC and clay% are also very sensitive indicators for wetland versus dryland soils. The pH differences may reflect effects of nitrogen fertilizers but also land type, i.e. wetland (lower pH) versus dryland (higher pH). Soil pH was therefore a less sensitive indicator of soil quality in this study.

The results showed that it is important to monitor organic matter content and aggregate stability of soils under cultivation in Iceland and it may be necessary to rest such areas periodically to build up good soil characteristics. The methods applied here may be applicable to volcanic soils in Ethiopia.

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APPENDIX 1

Fig. a. *Soil sampling at the Korpa Research Station (22 May 2013).*

Fig. b. *Total nitrogen and total carbon analysis (13 June 2013).*

Fig. c. *Soil colour determination (17 July 2013).*

Fig. d. *Water retention test using pressure plates (16 July 2013*).

Fig. e. *Bulk density laboratory determination (15 June 2013).*

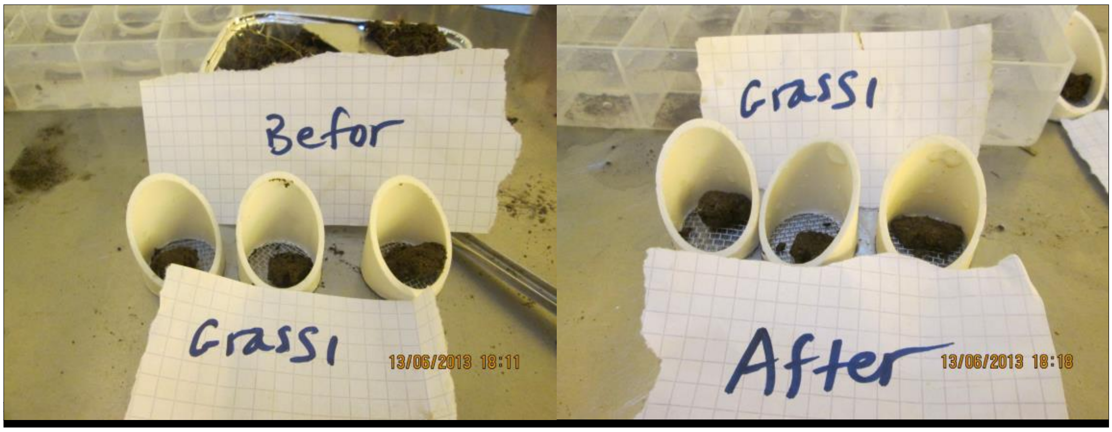

Fig. f. *Aggregate stability test (13 June 2013).*

APPENDIX 2

Table a. *Laboratory results.*

Land management type	Replication	N %	Total C %	C/N	P Olsen ppm	P-AL ppm	Bulk density g/cm^3	Porosity %	pH	Wet aggregate stability index
17-C	1	0.61	6.84	11.15	4.12	3.93	0.70	73.49	5.93	3
17-C	2	0.67	7.62	11.41	3.85	3.34	0.61	76.90	6.07	5
17-C	3	0.74	8.83	11.89	3.70	3.01	0.64	75.92	5.88	5
13-C	1	0.67	7.60	11.31	3.85	3.33	0.67	74.80	5.97	4
13-C	2	0.75	8.47	11.26	3.44	2.41	0.56	78.73	6.08	5
13-C	3	0.75	8.48	11.25	3.74	3.09	0.60	77.38	6.01	5
G-C	1	0.71	8.79	12.42	4.99	5.87	0.69	73.88	6.02	6
G-C	2	0.75	10.27	13.61	4.17	4.05	0.68	74.38	6.14	6
G-C	3	0.76	10.44	13.81	4.19	4.09	0.62	76.71	6.27	6
SUBT	1	0.24	4.21	17.39	30.67	62.94	1.34	49.61	6.18	6
SUBT	2	0.19	3.08	15.99	4.78	5.40	1.13	57.50	6.45	6
SUBT	3	0.45	6.84	15.35	11.03	19.28	1.21	54.38	6.7	6
ES	1	0.11	1.63	14.79	2.94	1.31	0.99	62.77	6.74	3
ES	2	0.20	2.74	13.55	2.80	1.00	0.76	71.21	6.67	3
ES	3	0.22	3.27	14.74	3.05	1.56	1.03	61.01	6.78	3