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COMPARATIVE ASSESSMENT OF THE VERTICAL DISTRIBUTION OF SOIL ORGANIC MATTER IN CULTIVATED AND NON-CULTIVATED LAND AND ITS IMPACT ON SOIL pH

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ABSTRACT

Cultivation can lead to declines in soil organic matter (SOM) which is central to soil quality. The aim of this study was to assess the impact of cultivation on SOM and how it impacts soil pH, another vital indicator of soil health. The study was carried out at the Korpa Experimental Station in Iceland, in a cultivated field (CL) and a non-cultivated (NC) field. Data were collected from two soil depths, the upper (0 – 15 cm) and bottom (15 – 25 cm) depths, and from one soil profile in each field. SOM was measured using the loss-on-ignition method, whereas pH was measured in water (1:5 soil-water ratio). The results showed a significant effect of treatment (cultivation/non-cultivation) ($F = 8.0$; $p = 0.008$) and soil depth ($F = 7.15$; $p = 0.012$) on SOM. SOM was significantly highest in the upper layer of the NC field. The effect of treatment on soil pH was not significant ($F= 2.23$; $p=0.147$) whilst the effect of soil depth was significant ($F = 18.61$; $p = 0.0002$). There was a significantly strong negative correlation between SOM and pH in the CL ($r = -0.771$, $p = 0.0005$) and NC fields ($r = -0.785$, $p = 0.0003$). There was a significantly strong negative correlation between SOM and pH in the bottom depth ($r = -0.824$, $p = 0.0001$) but not in the upper depth ($r = -0.291$, $p = 0.275$). There was a strong relationship between SOM and soil structure and soil colour. The low BD values observed in the CL profile (0.46 – 0.63 g/cm^3) and NC profile (0.34 – 0.60 g/cm3) were indicative of richness in SOM. This study showed the importance of good agronomic practices to maintain SOM. In the poorer countries, there is a need to promote cheap options such as mulching, compost manure addition, fallowing and crop rotations that enhance SOM and ensure good quality of soils.

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1. INTRODUCTION

Soil is a fundamental resource that sustains life in all its forms. The contribution of soil to the functioning of several vital ecosystem processes and its direct support to agricultural productivity makes it a very useful natural resource (Franzluebbers 2001; Campbell 2008; Arnalds 2015). Soil directly influences the carbon and water cycles which in turn influence life processes. By so doing, soil directly impacts on plant growth, nutrient and water flow and consequently all other processes that are essential for the maintenance of soil health to sustain food production and ecosystem processes (Franzluebbers 2001; Liu et al. 2006; Campbell 2008).

Several factors determine the quality of soil. Organic matter content is one of the most important factors which is central to soil quality. Organic matter directly influences the nutrient supply to plants, impacts on the soil water holding capacity and soil pH (Liu et al. 2006; Viji & Rajesh 2011). Human activity, especially agriculture, has however greatly affected soils to such an extent that remedial actions need to be sought (US NRC [US National Research Council] 1993). Tillage leads to changes in aggregation, aeration and temperature conditions in the soil. This leads to exposure of SOM to oxygen and subsequently accelerates the rate of SOM oxidation by soil microorganisms. The oxidative decomposition results in the formation of less stable humus (due to mineralization) and an increased liberation of CO_2 and thus a reduction in SOM (Thomas et al. 2007; Fenton et al. 2008).

To have good quality soils that support crop growth (and hence make farming more productive), consideration of the water & nutrient holding capacity, organic matter content, biological activity, texture and permeability, among others, should be prioritised. The quality of most soils has deteriorated due to erosion, compaction and decline in biological activity (US NRC 1993). A better understanding of these trends and the extent of decline (especially in developing countries where a majority of farmers are subsistence farmers) still has some knowledge gaps that need to be bridged.

1.1 Problem statement

The level of soil fertility has continued to decline across many farming systems. The decline has been characterised with reduction in agricultural productivity as evidenced by low yields which have exacerbated food insecurity and low incomes amongst farmers (Bot & Benites 2005; Campbell 2008). As a result of this, some farmers and governments have had to resort to expensive measures of using artificial inorganic fertilizers in a bid to improve fertility of the soil, while those who can’t afford this continue to grapple with low yields. The significance of soil to food security in the wake of climatic change is likely to exert increasing and enormous pressure on soil, and subsequently management practices to ensure sustainable use of soil ought to be pursued.

Despite the decline in soil fertility, some rural farmers (especially from developing countries) have not comprehended the dynamics of soils. Although they acknowledge that the fertility of soil has declined, limited or no affirmative actions are taken at the farm level to address the situation. A majority of the rural farmers continue to use the soils and the cycle of deteriorating crop yields continues. Farmers’ understanding of the changes taking place in the soil, especially its fertility, structure and other vital characteristics, is limited. However, information on soil characteristics is very useful since it can lead to a greater impact on the potential of soils to support plant growth and thus provide good yields.

1.2 Significance of the study

This study sought to investigate how soil organic matter (SOM) changes with cultivation. Following cultivation, SOM levels keep changing; subsequently other soil factors, especially pH, bulk density (BD) and porosity, among others, are impacted. Since these factors determine the quality of soil and directly influence the potential of soil to support crop growth, assessing them in this study becomes important. When agricultural fields are cultivated, it is important to maintain good conditions of the soil so as not to jeopardise the soil's ability to function effectively and support subsequent crops. Since cultivation practices and soil characteristics are two inseparable scenarios, lessons from this study will become an important basis for advising and supporting farmers (especially the rural poor) as to how to enhance the conditions of their soils to support optimum agricultural productivity.

This study was carried out in Iceland, but with the intention of developing my ability in soil quality assessment that I can use in my work with farmers in Uganda.

1.3 Project purpose

The purpose of the study was to assess the impact of cultivation on soil organic matter.

1.4 Overall goal

To conduct a comparative assessment of the vertical distribution of soil organic matter in cultivated (CL) and non-cultivated (NC) land and to evaluate its impact on soil pH.

1.5 Specific objectives

a. To estimate the soil organic matter content and pH at the ploughed (0 – 15 cm) and below-ploughed depth (15 – 25 cm) in a cultivated field and corresponding depths in a non-cultivated field.
b. To assess the soil pH and its relationship to SOM in the cultivated and non-cultivated field.
c. To conduct profile assessments of pH, bulk density, soil colour, structure and texture in the cultivated and non-cultivated fields and relate these to SOM.

2. LITERATURE REVIEW

2.1 Concept and importance of SOM in soil science

Soils have been classified in different ways by different authors, farmers and scientific associations. The classifications presented by Brady and Weil (2008) and a review of other literature indicates that parameters such as colour, parent material, fertility, texture and drainage, among others, have been used to classify soils. The significance of SOM in these classifications has been very important since it influences a number of soil features. Though soil characteristics are largely dependent on the material from which it was formed, these characteristics change with time following erosion and other biophysical processes. Subsequently, the proportion of silt, clay and sand which determine the soil texture changes (Brady & Weil 2008).

The soils of Iceland are generally Andosols whose formation has been the result of volcanic activity. Andosols have been further classified into sub-categories based on colour, carbon content and other factors. The tephra of Icelandic soils is basaltic, which has influenced the dark colour, the organic content and other soil physical characteristics (Arnalds 2015). Soil colour is a vital parameter used to classify soils and provide a clue to soil characteristics. The soil colour can vary from place to place and with changes in depth. Colour is largely influenced by SOM, water and oxides (iron and manganese). Water influences SOM accumulation and oxygen levels in the soil; oxygen subsequently influences the rate of iron and manganese oxidation and these directly impact on soil colour (Brady & Weil 2008; Guertal & Hall 1990). In temperate soils, when the SOM becomes humidified, it imparts a dark colour, especially in the surface horizons. The reddish and yellow colours often found in the subsurface horizons are a result of iron and manganese oxides. The distribution of mottles in the soil relates to the saturation levels of the soil and the subsequent oxidation processes - all of which are influenced by temperature (Guertal & Hall 1990).

Several concepts of defining SOM have been put forward by different scholars; however, all these revolve around similar ideologies. According to Brady and Weil (2008) and Overstreet & Huges (2016) the scientific meaningful way of classifying SOM is to refer to it as active/labile (living biomass), slow/intermediate (dead roots & litter) or passive/stable organic matter (humus). Though many views have been expressed on the subject of plant residues at the soil surface and that they should not be considered as part of SOM, this is true when practical soil analyses are to be made since most of the plant residues exceed 2 mm and are often sieved out before any analysis is done. However, litter is functionally part of SOM since it largely contributes to SOM when decayed (USDA, NRCS [US Department of Agriculture, Natural Resources Conservation Services] n.d.; Lickacz & Penny 2001; Fenton et al. 2008; Murphy 2014). Though humus does not directly contribute to soil fertility, it influences the structure, cation exchange capacity and the tilth of the soil.

SOM has varying functions which influence the biological, chemical and physical processes in soil and these have an impact on the general environment. SOM directly controls soil hydrology, nutrient cycling and energy flow through its impact on soil structure and biological activity (Liu et al. 2006; Brady & Weil 2008). In all terrestrial ecosystems, SOM is the main pool for all essential plant nutrients; the supplies of carbon, nitrogen, phosphorus, and sulphur required by plants is from the SOM. It is believed that these essential nutrients occur in almost constant ratios in the SOM (Lickacz & Penny 2001; Liu et al. 2006; Brady & Weil 2008; Murphy 2014). A complex array of how important SOM is in soils and the general environment is presented in Figure 1.

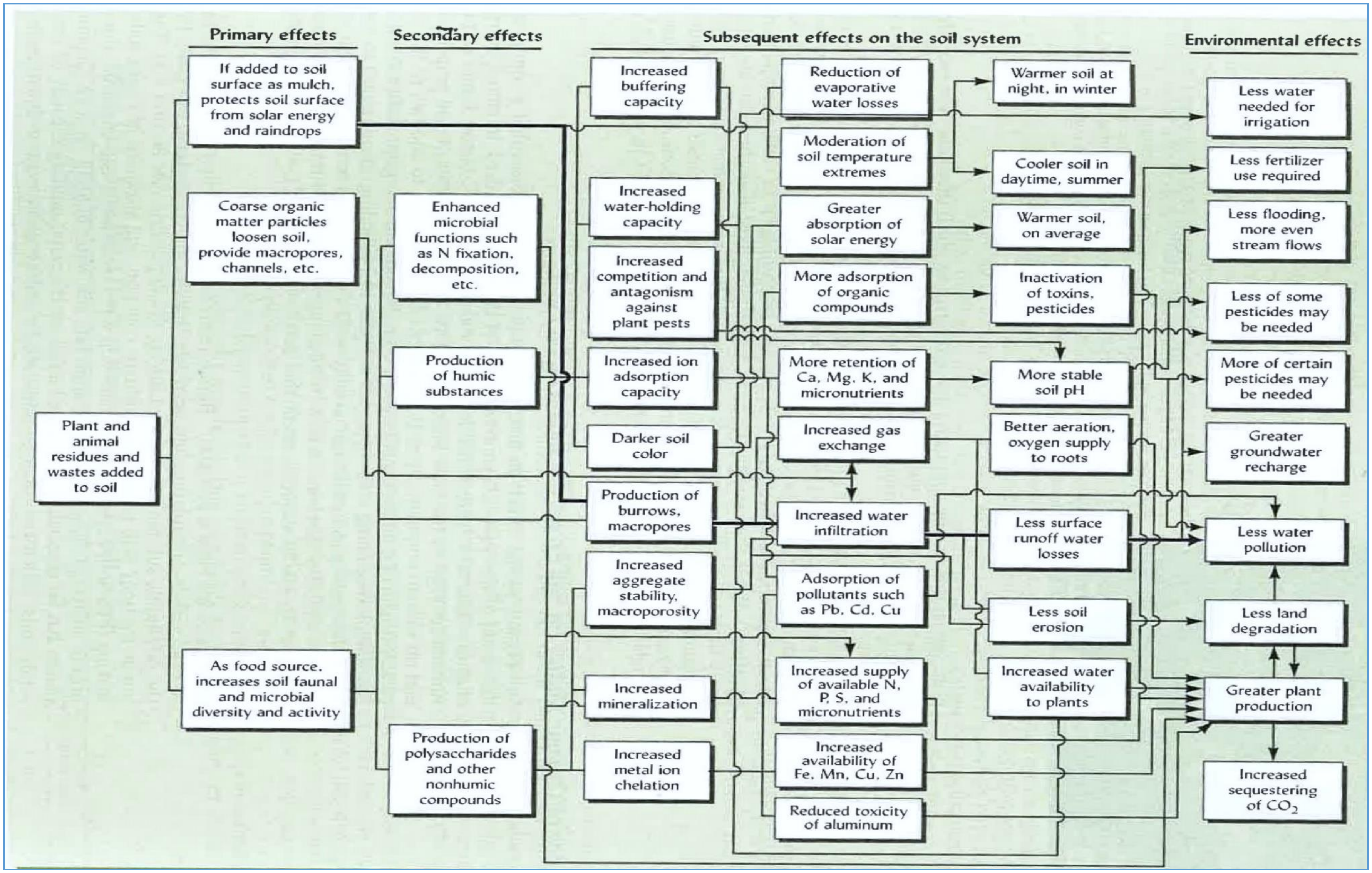


Figure 1. Some of the ways in which soil organic matter influences soil properties, plant productivity and environmental quality (From Brady & Weil 2008, p. 516).

From a farming perspective, good quality soils ensure good yields. Liu et al. (2006) presents varying contextual views from different scholars on the definition of soil quality where many linked it to its ability to support growth of crops. According to the US NRC (1993), these views are narrowed to consider the holistic contribution of soil to the agricultural systems and the natural ecosystem functioning and integrity. In all these views, SOM is central to soil quality since it directly influences WHC, pH, cation exchange capacity, infiltration rate, nutrient exchange, tilth, bulk density, porosity, compaction, and aggregation of soil, all of which are vital in determining the quality of soil (USDA, NRCS n.d.; Bot & Benites 2005; Overstreet & Huges 2016).

2.2 The relationship between SOM and pH

Soil pH is an indication of the acidity or alkalinity of the soil. It is a very important factor and must be considered when interpreting how healthy a soil is and how suitable it is for plant growth. The influence of soil pH on the biological and chemical conditions of soils, especially nutrient availability and micro-organism activity which have a direct impact on the growth and yields of any crop, makes it a very significant factor in several vital soil processes (Thomas 1996; Brady & Weil 2008). Soils high in clay and SOM are generally resistant to pH changes as compared to sandy soils (USDA, NRCS 2014b). This is due to more buffering capacity connected to the cation exchange properties of these soils. Understanding the relationship between SOM and soil pH is therefore important in soil science and agro-ecosystem studies. The soil WHC, apart from influencing the supply of water (and also nutrients) for plant growth, also indicates the physical and chemical characteristics of the soil. USDA, NRCS (n.d.) has documented that SOM can behave in such a way that it can absorb and hold water equivalent to 90% of its weight. Similarly, when plants require water held by SOM, it can release nearly all of it. This therefore makes SOM central to the soil water conditions, plant growth and other water-demanding processes in the soil. As the amount of water in soil changes, it causes changes in pH levels as well (though minimal); a 10-fold increase in the water to soil ratio causes a 0.4 pH increase (Thomas 1996).

Although SOM plays a vital role in buffering soil pH changes through the influence of the proportions of cations and anions in the soil, it directly increases soil acidity, especially in the upper horizons (Brady & Weil 2008; Murphy 2014). Increased microbial activity (especially in conditions of limited oxygen supply) facilitates the anaerobic decomposition that generates organic acids, thereby raising soil acidity. However, an increase in acidity levels has far reaching effects on other processes taking place in the soil - especially those driven by microorganisms, and subsequently this will influence the levels of biomass production and nutrient availability (Brady & Weil 2008; Thomas et al. 2007). Management practices that involve liming and proper application of nitrogen and sulphur fertilizer alongside good agricultural practices (such as diverse crop rotations, cover crops and application of solid manure) that increase SOM content and improve the overall health of the soil can result in minimal changes in soil pH (USDA, NRCS 2014b).

Most crops can generally grow at a pH range of 6 to 7.5; however, pH levels which tend to be too high or too low can lead to significant deficiency of a number of plant nutrients and at the same time impact on the microbial activity in the soil. These in the long run can reduce crop yields and generally lead to a decline in soil health. Studies have shown that pH values that fall below 5.5 and those in the range of 7.5 to 8.5 cause limited availability of phosphorus required for plant growth (USDA, NRCS 2014b). In Table 1 below, the level of yield performance for some crops under different pH conditions is shown.

Table 1. Levels of pH showing relative average crop yields (Source: USDA, NRCS 2014b).

Crop	**Soil pH**				
	4.7	**5**	**5.7**	**6.8**	**7.5**
	Relative average yield (100 is best; 0 is worst)				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Soybeans	65	79	80	100	93
Oats	77	93	99	98	100
Barley	0	23	80	95	100
Alfalfa	2	9	42	100	100
Timothy (grass)	31	47	66	100	95

2.3 Factors influencing SOM and enhancement strategies

SOM is generally affected by human activity interacting with environmental factors. There is increasing concern over the need to sustain SOM levels because too much decrease will affect agricultural productivity. Other natural processes in the soil which are directly influenced by SOM may be distorted and impaired (Liu et al. 2006). The major factors and processes that have caused decline in SOM include tillage, burning biomass and deliberate removal of plant material as fodder or through deforestation. Furthermore, wetland drainage, fallowing and increased use of chemicals in agricultural practices also deplete SOM (US NRC 1993; Bot & Benites 2005; Thomas et al. 2007). Tillage apart from disrupting biological activity in the soil, facilitates soil erosion and alters soil physical structure. Conversely SOM can be built or replenished in the soil through practices such as conservation tillage, crop rotations that involve legumes and perennial grasses, using cover crops, retaining crop residues in the fields and minimizing soil compaction. Furthermore, compost and fertilizer additions combined with better management practices can sustain SOM in the soil (Liu et al. 2006; Brady & Weil 2008).

Plant uptake of nutrients from SOM in addition to losses from other pathways implies that SOM levels are constantly changing in the soil. To maintain SOM in equilibrium, the gains and losses should more or less balance out (Lickacz & Penny 2001; Bot & Benites 2005; Brady & Weil 2008).

> "Organic matter releases nutrients in a plant-available form upon decomposition. In order to maintain this nutrient cycling system, the rate of organic matter addition from crop residues, manure and any other sources must equal the rate of decomposition, and take into account the rate of uptake by plants and losses by leaching and erosion. Where the rate of addition is less than the rate of decomposition, soil organic matter declines. Conversely, where the rate of addition is higher than the rate of decomposition, soil organic matter increases. The term steady state describes a condition where the rate of addition is equal to the rate of decomposition" (Bot & Benites 2005, p. 2).

The process of decomposition of organic material can be enhanced by several climatic factors combined with human management practices. The rate of decomposition of organic matter is faster under warm temperature coupled with adequate soil aeration and moisture conditions which provide a conducive environment for microbial activity that is largely responsible for decomposition. Based on this, decomposition rates are normally higher in tropical climates compared to temperate areas and hence SOM levels in temperate soils often exceed those from the tropics (USDA, NRC n.d.; Bot & Benites 2005). Across soil horizons, SOM levels vary depending on soil characteristics, biological activity and other processes in the soil. Although inversion of soils by ploughing tends to mix the soils, it has been observed that subsequent ploughing tends to homogenize SOM along the ploughing depth. The soil inversions over time coupled with other processes in the soil surface or column tend to cause stratification of SOM in the soil (Kay & VandenBygaart 2002; Brady & Weil 2008).

2.4 Bulk density and SOM

Bulk density is one of the dynamic soil factors that varies with soil structure and is influenced by soil organic matter and soil texture. It reflects the soil particle size, shape and arrangement, which are vital indicators of permeability and hence root growth and the movement of water, solutes and air along the soil (Brown & Wherrett n.d.; Chaudhari et al. 2013; Murphy, 2014). When the soil's bulk density is high (an indication that the soil is compacted and hence the soil porosity is low) the implication is that it can bring about restrictions in the plant root growth and also limit the movement of water, solutes and air within the soil. The overall outcome to the plants is shallow rooting, which causes poor growth and subsequently influences the yields (Grossman & Reinsch 2002; NRCS – ENTSC 2011). Some of the bulk density ranges that would permit or restrict effective root growth in plants are shown in Table 2 below.

Table 2. General relationship of soil bulk density to root growth based on soil texture (Source: NRCS – ENTSC 2011).

Soil Texture	Ideal bulk densities for plant growth (g/cm3)	Bulk densities that restrict root growth (g/cm3)
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

Studies conducted by Périé and Ouimet (2008) on forest soils in Quebec, Canada, and Chaudhari et al. (2013) in Coimbatore, India, have shown that there is a strong inverse relationship between bulk density and SOM. According to the USDA, NRCS (2014a), other soil features such as texture, Cation Exchange Capacity (CEC), sodicity and other factors such as compaction by livestock or machinery, rainfall and cultivation practices also influence soil bulk density. To avert this, the soil structure in a cropland should be improved through long-term practices that minimise soil disturbance while at the same time increase the SOM content through cover cropping, reduced tillage and maintaining crop residues in the fields. It can also be beneficial to adopt multi-cropping systems where crops that have different rooting patterns / depths are grown such that this can help in breaking up the compacted soils (NRCS – ENTSC 2011). High bulk density can lead to reduced infiltration rates which may increase surface runoffs and aggravate erosion effects, especially on sloping land (USDA, NRCS 2014a). Most soils contract upon drying and hence the bulk density keeps on changing due to the changes in the water content. Although the shrinkage is small and often ignored in sandy soils, clay soils on the other hand undergo considerable density change as a result of either wetting or drying; if this is not evenly distributed throughout the soil, then it can cause cracking (Grossman & Reinsch 2002).

3. METHODS OF STUDY

3.1 Study area - description and background information

The study was conducted in Korpa Experimental Station located in the Reykjavik Municipality, Iceland (Fig. 2). The land in Korpa has been used for diverse experiments and field trials for fertilizers, fodder production, crop production and reclamation, amongst others.

Figure 2. Map of Reykjavik Municipality showing the location of Korpa (inset is map of Iceland).

Following an interview conducted with the station manager coupled with on-site observations, the information regarding land use and management interventions shown in Table 3 was compiled.

Table 3. Information about the study area (Source: J Hermannsson, 2 June 2016, Agricultural University of Iceland – Korpa Research Station, personal communication).

Parameter	**Cultivated field:**	**Non-cultivated field:**
Vegetation cover	• Not seeded, natural vegetation growth just starting; <5% vegetation cover.	• Fully vegetated & covered mainly by grasses (75%) and forbs (25%); tree belt of *Salix alaskensis* located east of the site
Cultivation trends, fertilizer application & yields.	• Annually cultivated from 1995 and planted with barley (except 2 years in early 2000 when under fallow). • Inorganic fertilizer applied at rates of: 60Kg/Ha N; 25Kg/Ha P; 40Kg/Ha K. • Nutrients yield in barley harvest is almost proportionate to nutrients in the inorganic fertilizer applied.	• Not cultivated since 1960; previous to this, the area was for hay production. • No inorganic fertilizer applied since 1960 • All vegetation growth is cut and left to decompose on the field.
Drainage	Drainage ditches located approx. 10m off the quadrats at the closest point.	Drainage ditches located beside the sampling quadrats (See Fig. 4)

The annual rainfall recorded for Korpa for the last five years (2011 – 2015) was above 1,000 mm in each year. Over the same period, the mean annual temperature was above 5°C whilst temperatures in the summer (especially June – August) were all above 8°C (temperature values obtained from the Reykjavik Weather Station, which is close to Korpa). Detailed climate data for Korpa over the last 21 years [1995 – 2015] are presented in Appendix 1.

3.2 Sampling design and collection of samples

Soil samples were collected from two fields; the cultivated (Fig. 3) and the non-cultivated field (Fig. 4). The cultivated and non-cultivated fields were divided into quadrats using flag-posts; eight quadrats delineated for each field (Fig. 5). From each quadrat, five soil cores were randomly sampled; a soil probe was driven into the soil to a depth of approx. 30 cm. Soil for analysis was extracted from the soil probe at corresponding depths of 0 – 15 cm (upper) and 15 – 25 cm (bottom) to attain the two depths. To constitute a composite sample, the five samples taken from each quadrat were thoroughly mixed and placed in a labelled sample bag. This gave eight soil samples for each soil depth in each field (cultivated and non-cultivated).

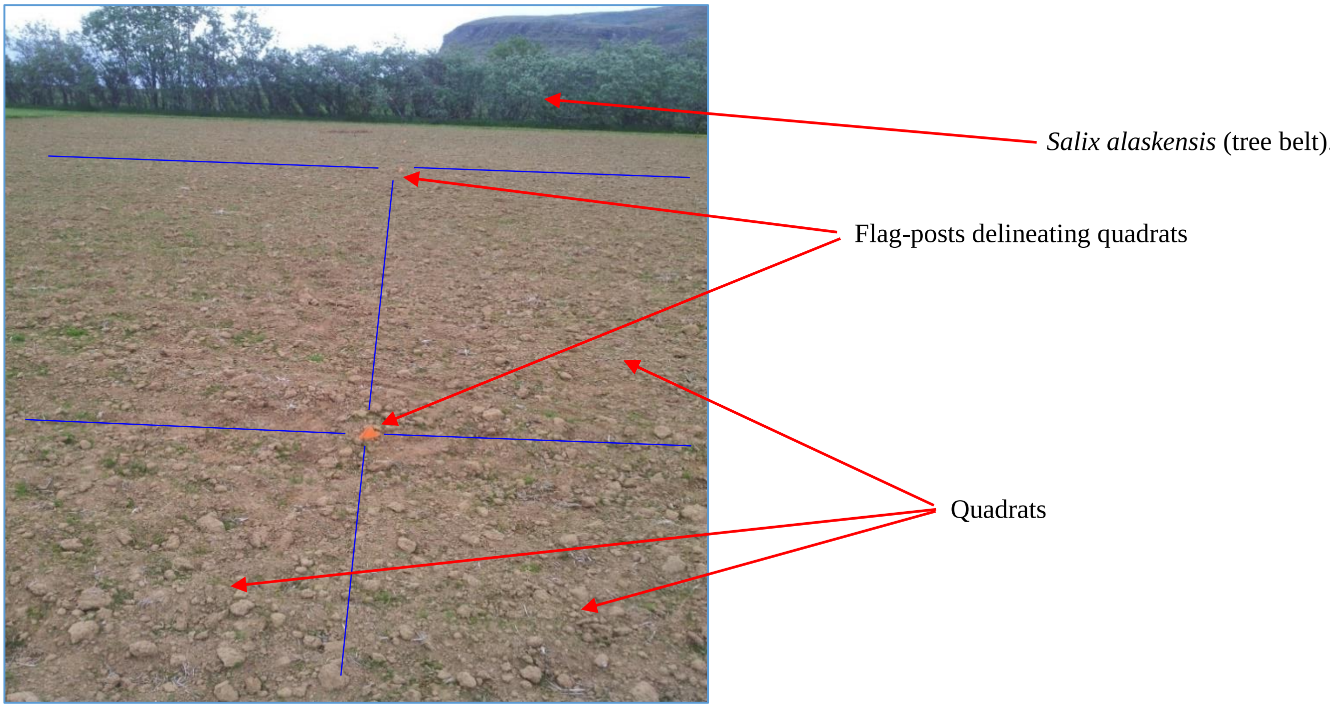


Figure 3. The cultivated field showing background features and quadrats delineated (Photo: C Otim, 15 June 2016).

Figure 4. The non-cultivated field showing drainage ditches and nearby cultivated field (Photo: C Otim, 15 June 2016).

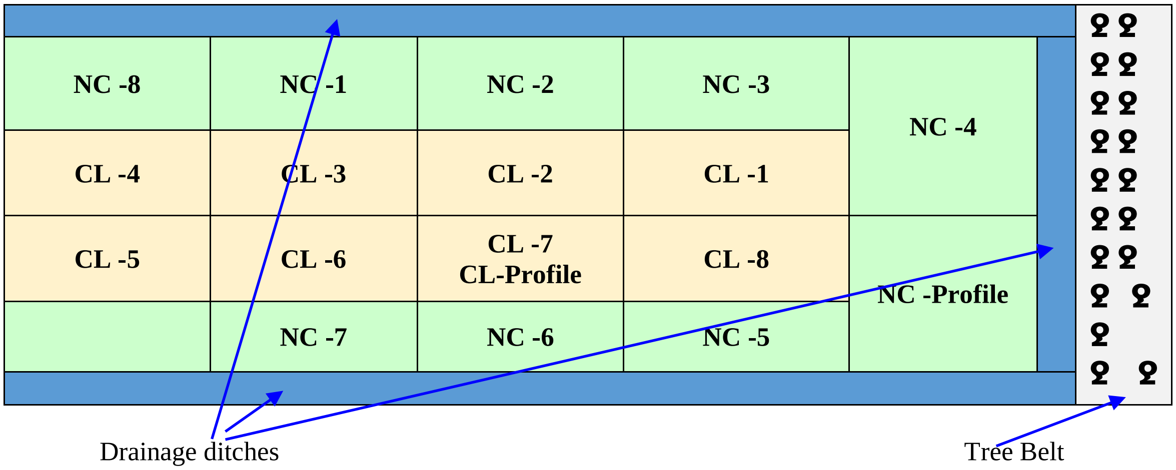


Figure 5. Detailed quadrat partitions in the study area (CL = cultivated; NC = non-cultivated).

Two profiles (Fig. 6), each reaching down to 50-60 cm depth were dug, one in a cultivated and the other in a non-cultivated quadrat; the walls of the profile were cut-shaped using a trowel to get a clear view of the soil horizons. The horizons were identified and the length for each recorded. Observation and record of soil colour (Munsell Colour 2000), nature of mottles, rooting pattern and horizon boundary transition were made. A soil sample from each horizon was collected and used to determine soil texture by the “feel method” (kneading moist soil sample); this was deduced using a soil textural triangle. The soil structure identity and grade were determined by observing the crumb behaviour once extracted from the horizon; the NASIS code and soil class were appropriately deduced with reference made to USDA, NRCS (2012). Soil sampling from each horizon in each profile was done to obtain samples for pH and SOM analysis; samples for bulk density analysis were also extracted from each horizon using a core cylinder sampler.

Cultivated profile

Non-cultivated profile

Figure 6. The cultivated and non-cultivated soil profiles; nails were used to mark the horizon boundaries (Photo: C Otim, 15 June 2016).

3.3 Laboratory handling and analytical methods

3.3.1 SOM estimation

Soil organic matter was measured using the loss on ignition (LOI) method described in Rowell (1997). The samples were air-dried and then screened through a 2-mm soil sieve. Duplicates of sieved samples from each composite weighing approx. 3 g were placed in a crucible dish of known weight (crucibles weights had been standardized by heating) and heated in an oven at 105°C for 24 hours. After determining the weight at 105°C, the samples were then transferred into a furnace where temperature was auto-regulated and ignited at 550°C; thereafter the samples were cooled and heated again in an oven at 105°C and the weight of each sample was recorded. The SOM was calculated as follows:

$$SOM = ((DW_{105} – DW_{550}) / DW_{105}) \times 100$$

where DW_{105} is the weight of the sample after heating at 105°C and DW_{550} is the weight of the sample after ignition at 550°C.

3.3.2 pH analysis

Soil pH was measured in water (1:5 soil-water ratio) using an OAKTON pH electrode in a procedure adapted from Blakemore et al. (1987). A total of 5 g of thoroughly mixed duplicate samples from each composite were placed in a 50-ml plastic tube (a standard soil sample was included in each batch); 25 ml of distilled water were added into each plastic tube and samples shaken for two hours before pH analysis. The pH electrode was calibrated using buffers of 4.01 and 7.00. The electrode was immersed in each sample and a pH reading taken. The electrode was re-calibrated using buffers after every five measurements.

3.3.3 Bulk density

Bulk density was measured following a procedure described by Burt (2004). Each sample was placed in an aluminium dish of known weight and heated in an oven at 105°C for 24 hours. The samples were cooled in a desiccator and the dry weight measured. The dried samples were sieved through a 2-mm sieve, fragments removed and then weighed. The volume of the fragments was determined by the volumetric displacement method. The BD was calculated as follows:

$$BD = (DW_{105} – FW) / (CS_v – FV)$$

where DW_{105} is the weight of the sample after heating at 105°C, FW is the weight of sieved fragments, CS_v is the volume of the core sampler and FV is the volume of the sieved fragments.

3.3.4 Data analysis and presentation

The statistical package that was used in data analysis was SAS Enterprise Guide 7.1. SAS was used to generate box plots of SOM and pH in the study area. Two-way ANOVA was used to assess the effect of cultivation/non-cultivation (referred to as treatments) and soil depth on SOM and pH.

Pearson correlation was used to assess the relationship between SOM and pH for the different cultivation treatments and soil depths. The guide provided by Fowler et al. (1998, p. 132) to describe correlations was followed.

Results for the profiles (outlining SOM, pH, BD, soil structure, soil texture, colour, horizons and rooting pattern) have been presented in tabular format to provide a summary of the key observations and measurements made. Graphs showing the relationship between SOM and pH in each soil profile were generated using Microsoft Excel. The classification of horizons (in Table 6A and 6B) was based on FAO (2006) with additional information from Arnalds (2015).

4. RESULTS

4.1 SOM and the effect of cultivation and soil depth

SOM was generally high (mean ≥ 20%) in both treatments and at both depths. The percentage of SOM was highest (25.2%±1.1) in the upper layer of the non-cultivated field (NC-U) while the other three soil layers (CL-B, CL-U and NC-B) had almost the same percentage of SOM (Fig. 7).

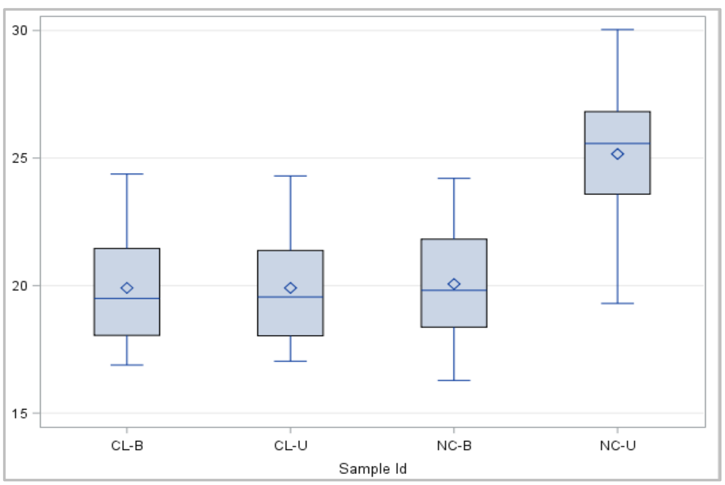


Figure 7. The percentage of SOM at the two soil depths (U = 0 – 15 cm and B = 15 – 25 cm) of the cultivated (CL) and non-cultivated (NC) fields. Horizontal lines and diamonds within the boxes show the median and mean, respectively. Boxes represent 25% and 75% percentiles, but whiskers represent the lowest and highest values of the data.

The treatment ($F = 8.0$; $p = 0.008$) and soil depth ($F = 7.15$; $p = 0.012$) had a significant effect on SOM and their interaction was also significant ($F = 7.15$; $p = 0.012$).

4.2 pH and the effect of cultivation and soil depth

The pH values varied greatly in all the four depths. As shown in Figure 8, the pH in the CL-U depth (5.36±0.04) differed from that in the CL-B depth (5.50±0.04). Likewise, the pH in the NC-U depth (5.40±0.03) differed from that in the NC-B depth (5.57±0.03).

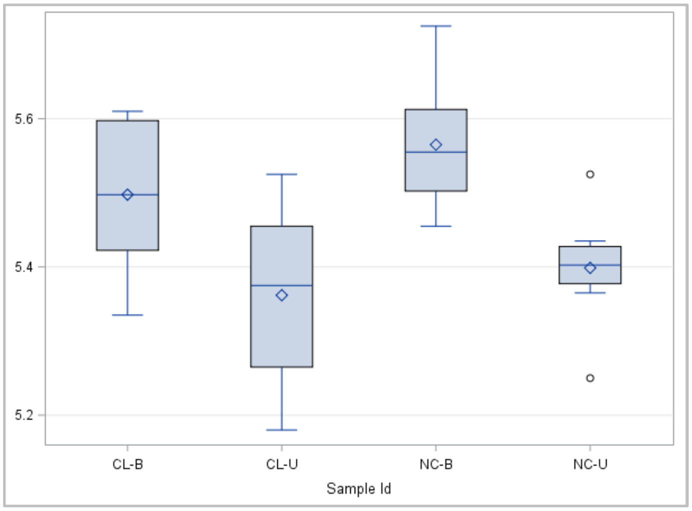
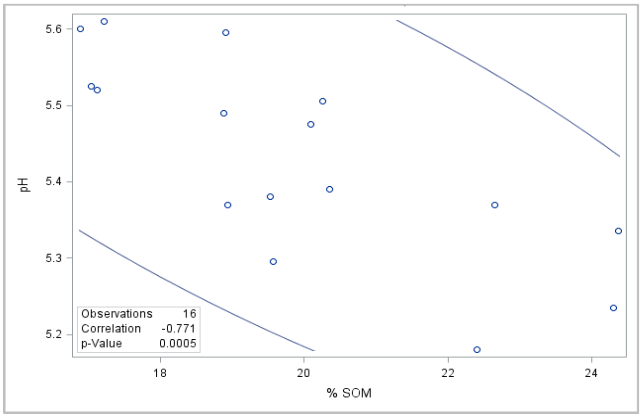


Figure 8. The pH at the two soil depths (U = 0 – 15 cm and B = 15 – 25 cm) of the cultivated and non-cultivated fields. Horizontal lines and diamonds within the boxes show the median and mean, respectively. Boxes represent 25% and 75% percentiles, whiskers represent the lowest and highest values of the data, and the circles outside the whiskers represent outliers.

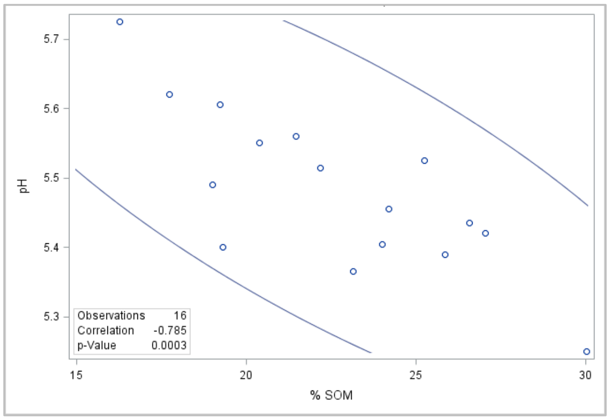
The effect of treatment (cultivation or non-cultivation) on soil pH was not significant ($F= 2.23$; $p=0.147$) while the effect of soil depth was significant ($F = 18.61$; $p = 0.0002$). The interaction of treatment and soil depth was not significant ($F = 0.19$; $p = 0.665$).

4.3 Relationship between SOM and pH (correlation analysis)

Considering the treatment, there was a significantly strong negative correlation between SOM and pH ($r = -0.771$, $p = 0.0005$) in the CL field; the same was the case for the NC field ($r = -0.785$, $p = 0.0003$) (Fig. 9).



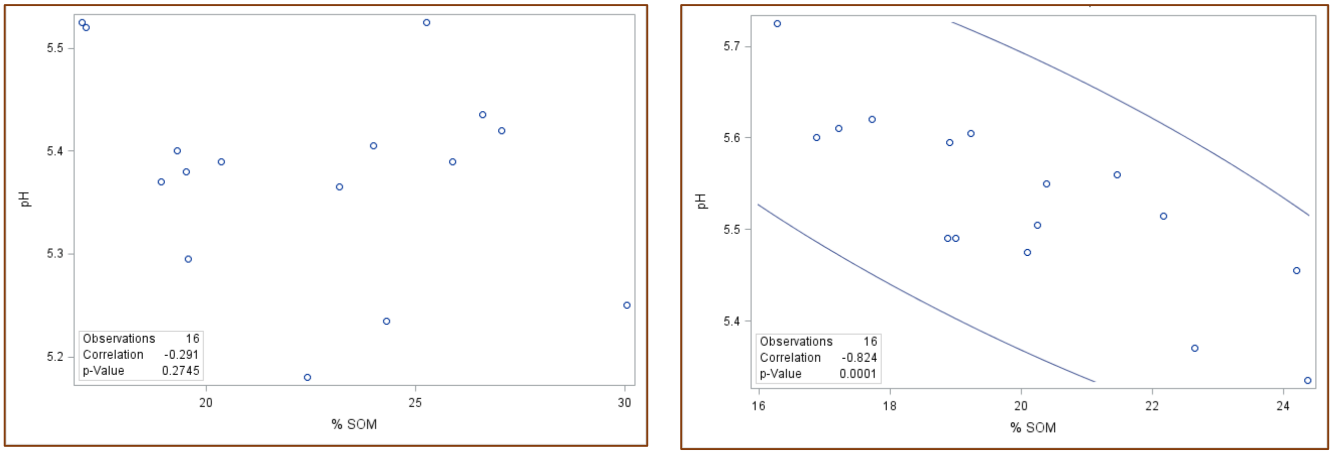
(a) Cultivated field



(b) Non-cultivated field

Figure 9. Correlation between SOM and pH in the CL and NC fields with 95% prediction ellipse.

With regards to soil depth, there was no significant correlation between SOM and pH ($r = -0.291$, $p = 0.275$) in the upper soils. However, there was a significantly strong negative correlation between SOM and pH ($r = -0.824$, $p = 0.0001$) in the bottom soils (Fig. 10).



(a) Upper layer (b) Bottom layer

Figure 10. Correlation between SOM and pH in the upper (0 – 15 cm) and bottom (15 – 25) layers with 95% prediction ellipse.

4.4 Soil features from the profiles

In the CL profile (Table 6A), soils in the top 0 – 25 cm horizons were silty clay loams with dark reddish brown colour. The structure transition from the upper to bottom horizons was granular to larger granular which culminated into sub-angular blocky. The structure grade changed from moderate to very fine weak as depth increased. The roots for grasses and forbs were numerous in the Op-horizon and few very fine roots were still observable in the Ah-horizon.

In the NC profile (Table 6B), the soils in the top 0 – 25 cm horizons were silty loams with dark brown colour (yellowish and greyish colours interspersed in the Oa and Ah2 horizons, respectively). The transition in structure from the upper to bottom horizons was granular to angular blocky with fine grade. The roots for grasses and forbs were numerous in the Oa-horizon with few very fine roots observable up to the Ah2-horizon.

Table 6A. Soil features in the CL profile.

Horizon		Op	Ap	Ah	Bhg1		Bhg2	
Depth (cm)		0 – 5	5 - 13	13 - 25	25 - 40		40 - 55+	
Munsell No.		5 YR; 3/3	7.5 YR; 3/3	5YR; 3/3	7.5YR; 3/2	10YR; 3/6 - Mottles	10YR; 4/3	10R; 3/6 -Mottles
Colour		Dark reddish-brown	Dark brown	Dark reddish brown	Dark brown	Dark yellowish brown	Brown	Dark red
Structure	**Identity**	Granular	Larger granular	Subangular Blocky	Subangular Blocky	----	Subangular Blocky	----
	Grade	Moderate	Medium / moderate	Moderate	Very fine; weak	-----	Fine weak	-----
NASIS CODE		SICL	SICL	SICL	SIC	-----	C	-----
Conclusion		Loose; silty clay loam.	Packed; silty clay loam.	Packed; silty clay loam.	Silty clay	-----	Clay	-----
Rooting pattern		Common; fine size	Few roots; very fine	Very few; very fine	None	----	None	----
Boundary transition		Straight, clear & unbroken	Diffused & straight.	Clear & straight	Diffused	----	----	----

Table 6B. Soil features in the NC profile

Horizon		Oa	Ah1	Ah2		Bhg		
Depth (cm)		0 - 4	4 - 14	14 - 25		25 – 40+		
Munsell No.		10 YR; 3/4	10YR; 3/3	10YR; 4/2	2.5YR; 3/6 (Mottles)	10YR; 4/3	5YR; 4/4 (Mottles 20%)	2.5YR; 3/6 (Mottles 5%)
Colour		Dark Yellowish-Brown	Dark Brown	Dark Greyish-Brown	Dark Red	Brown	Reddish brown	Dark red
Structure	**Identity**	Granular	Granular	Angular Blocky	----	Angular Blocky	----	----
	Grade	Fine weak	Fine moderate	Fine weak	-----	Fine weak	-----	-----
NASIS CODE		SIL	SIL	SIL	-----	SICL	-----	-----
Conclusion		Silt loam	Silt loam	Silt loam	-----	Silty clay loam	-----	-----
Rooting pattern		Numerous; medium to fine size	Common & very fine	Very few & fine	----	None	----	----
Boundary transition		Clear & straight	Clear & straight	Diffused & wavy	----	-----	----	----

Note: In table 6A and 6B, *a = highly decomposed SOM; h = accumulation of SOM in mineral horizon; g = mottling distinct; p = ploughing & other human disturbance.*
SICL = Silty clay loam; SIC = Silty clay; C = Clay; SIL = Silt loam

In the cultivated profile (Table 7A), there was no big difference in SOM between the Op, Ap and Ah horizons (18.0%, 17.6% and 18.3%, respectively). There was low SOM in the Bhg1-horizon (13.2%) and the last observed horizon (Bhg2) had a very high percentage of SOM (32.8%) which was more than double the Bhg1-horizon just above it. The pH from Op down to Bhg2-horizon showed a gradual increase (from 5.33 to 5.82). The BD gradually increased from 0.46 g/cm^3 in the Op-horizon to 0.63 g/cm^3 in the Ah-horizon and slightly declined in the lower Bhg1-horizon (0.56 g/cm^3) and Bhg2-horizon (0.59 g/cm^3).

Table 7A. SOM, pH and bulk density values in the sampled cultivated fields and cultivated profile

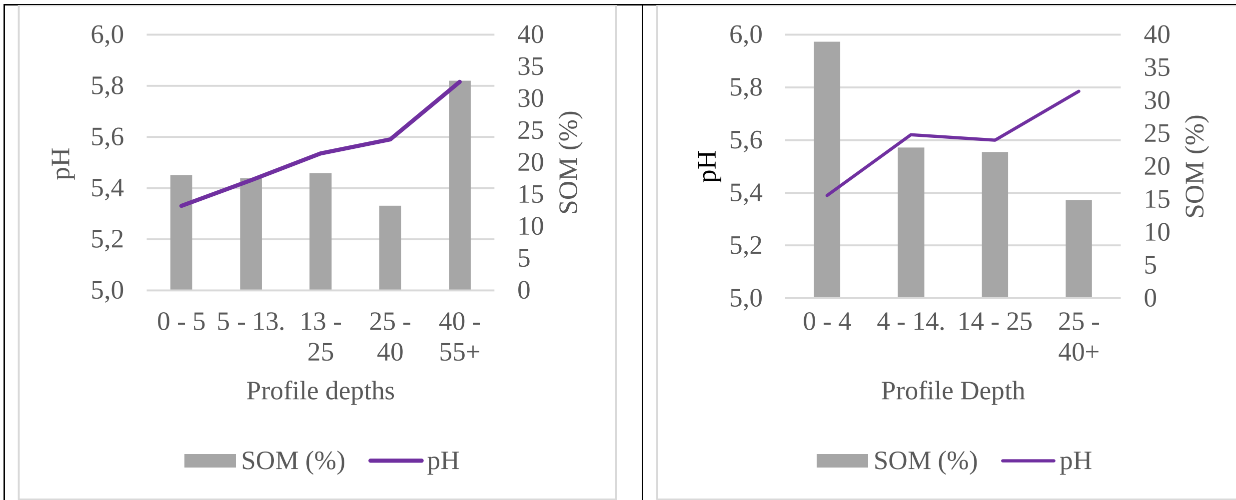
Cultivated field			Cultivated profile				
Depth	**Mean SOM (%)**	**Mean pH**	**Horizon**	**Depth**	**SOM (%)**	**pH**	**BD (g/cm^3)**
0 – 15	19.9	5.36	Op	0 – 5	18.0	5.33	0.46
15 - 25	19.9	5.50	Ap	5 - 13	17.6	5.43	0.61
			Ah	13 - 25	18.3	5.54	0.63
			Bhg1	25 - 40	13.2	5.59	0.56
			Bhg2	40 - 55+	32.8	5.82	0.59

In the non-cultivated profile (Table 7B), there was a decline in SOM down the profile; the Oa-horizon had the highest SOM (38.9%) while the next horizons (Ah1 and Ah2) had nearly similar SOM (22.9% and 22.2% respectively). There was a decline in the Bhg-horizon (14.9%). The pH showed a general increase from the Oa-horizon to the lowest Bhg-horizon (from 5.39 to 5.79). The BD in the Oa-horizon was low (0.34 g/cm^3); however, an increase to a more or less constant level was noted in the Ah1, Ah2 and Bhg horizons (0.60 g/cm^3, 0.58 g/cm^3, and 0.59 g/cm^3 respectively).

Table 7B. SOM, pH and bulk density values in the sampled non-cultivated field and profile

Non-cultivated field			Non-cultivated profile				
Depth	**Mean SOM (%)**	**Mean pH**	**Horizon**	**Depth**	**SOM (%)**	**pH**	**BD (g/cm^3)**
0 – 15	25.2	5.40	Oa	0 - 4	38.9	5.39	0.34
15 - 25	20.1	5.57	Ah1	4 - 14	22.9	5.62	0.60
			Ah2	14 - 25	22.2	5.60	0.58
			Bhg	25 – 40+	14.9	5.79	0.59

In Figure 11, the relationship between SOM and pH down the cultivated profile showed no clear pattern. In the NC profile, there was an inverse relationship between SOM and pH.



(a) Cultivated Profile

(b) Non-Cultivated profile

Figure 11: Relationship between SOM and pH in the soil layers of the profiles in the CL and NC fields.

5. DISCUSSION

5.1 Soil Organic Matter across different soil depths

The findings of the two-way ANOVA revealed a significant effect of land use and soil depth on SOM with a significant interaction between these factors. This result provides reason to give consideration to the importance of these factors (land use and soil depth) on SOM. The findings of this study have shown that the SOM in the non-cultivated upper depth distinctly differed from all the other three depths sampled. In view of this, the impression gained is that cultivation does not bring a significant difference in SOM levels at the immediate below-plough depth. This is because the SOM content in all the bottom depths had no difference between them. However, the parity between the upper and bottom cultivated depths (Fig. 7) could be explained in relation to the fact that inorganic fertilizers added to the cultivated barley field (cultivated depth) tended to off-set any significant uptake of SOM by the barley and hence no considerable decline occurred. This can be supported by the assertion from the Korpa station management that nutrient yield in the barley harvest was almost proportional to the nutrients in the inorganic fertilizer applied (J Hermannsson 2016, personal communication). For this case, the cultivated depth did not experience decline in the SOM content. In addition, the barley straw left to decompose in the field can enhance and maintain considerable quantities of SOM at the cultivated depth. These findings go along with what was reported by Liu et al. (2006) and Goyal et al. (1999) who asserted that returning crop residues to the soil and adding inorganic fertilizer to the soil increases organic carbon. According to them, the levels of increase are further enhanced if inorganic fertilizer is supplemented by organic manure. The soil organic matter increase following inorganic fertilizers application is attributed to the greater root biomass input which results from better crop growth.

The significant difference in the SOM between the upper depths of the cultivated and non-cultivated fields (Fig. 7) can be attributed to the fact that SOM build-up in the non-cultivated area was higher since all vegetation growth in the non-cultivated area was seasonally cut and left to decompose on the ground. The lack of soil inversions limited the exposure of SOM to oxidation and hence its build-up. The continuous soil inversion in the cultivated area exposed SOM to continuous oxidation and hence its build-up remained low. If it was not for the addition of inorganic fertilizers, SOM levels in the cultivated field could have been lower than observed. This too conforms to what has been reported by Franzluebbers (2002) and Kay & VandenBygaart (2002) that there was uniform distribution of SOM within the plough layer following soil inversion, while the soil surface under non-tillage had higher levels of SOM.

The values of SOM from the cultivated and non-cultivated profiles support the observations from the sampled fields that were partitioned into quadrats. The results for each horizon have further revealed that the upper horizon (Oa-Horizon) in the non-cultivated profile had an exceedingly high SOM content (38.93%). Arnalds (2015) has reported that organic carbon levels reaching up to 40% have been noted in Icelandic soils at the O-horizon. The values for the subsequent depths are in parity with those from quadrat sampling of the upper and bottom depths, both for the cultivated and non-cultivated areas.

Overstreet & Huges (2016) reported that SOM accumulates to higher levels when environmental conditions are cool and humid than when conditions are warm and dry. This brings about poor aeration and reduction of oxygen in the soil, thus depriving soil organisms of the oxygen required for activity and leaving them to become either inactive or die. This leads to a decline in the mineralization rate of SOM and thus it tends to accumulate (most of it is held in the labile stage). The hydrological and temperature conditions in the study area (Iceland in general) should be one other reason for the high SOM obtained in this study. The high soil moisture leads to a slow breakdown of SOM due to the fall or cessation in microbial activity under low temperature. The occurrence of mottles in the profiles furthermore supports the notion that water saturation in the soils coupled with low temperature leads to soil mottling. The low temperature recorded in the study area (refer to Appendix 1 and Section 3.1) and the period of data collection (end of spring and start of summer) means that the soils still had a high water content. The percolation of water into the soils in the study area was not restricted due to the low bulk density of the soils (details in Table 7A and 7B).

Overstreet & Huges (2016) further reported that SOM associated with sand soils is more prone to decomposition than that associated with silt or clay soils. Relating their results to the results of this study gives a clear impression that any SOM in the soils under study (which had silty and clay properties) could have been accumulated and stabilised over time.

The results presented in Table 7A & 7B and Figure 11 show that there was a marked difference in SOM between the O-horizons of the cultivated and non-cultivated profiles. This indicates a higher accumulation of SOM at the surface of the non-cultivated field than the cultivated field. The minor differences in SOM in the three horizons below the Op-horizon of the cultivated profile are synonymous with the findings from the sampled cultivated field.

Since SOM directly and positively influences soil fertility and henceforth agricultural productivity, the need to increase or maintain its levels becomes imperative because it also contributes to carbon sequestration which reduces greenhouse gases. Lickacz & Penny (2001) reported findings from crop rotation studies involving perennial forages in Western Canada which led to stabilization of SOM at higher levels as compared to rotations that involved summer fallows. In view of this, farmers and other practitioners need to be rallied to engage in practices such as maintaining crop residue in croplands, including appropriate crop rotations that enhance soil quality and adding organic manure from different sources which can increase SOM.

5.2 Relation between SOM and pH

The need to ascertain the relationship between SOM and pH has been examined using Pearson correlation analysis. The results presented in section 4.3 show that there was a negative correlation between pH and SOM. This supports the notion that increase in SOM causes increase in soil acidity (lowering of pH), especially in the upper horizons as reported by Thomas et al. (2007) and Brady & Weil (2008).

The insignificant correlation between SOM and pH in the upper soils (Fig. 10a) can be attributed to the levels of SOM being highly variable at this depth. There is high biological and mechanical activity in the CL-U soils. As cultivation breaks soil particles, it impacts on the hydrology and chemistry of the soils that can bring about marked changes in soil pH. Furthermore, the inorganic fertilizers added to the cultivated filed can bring about an increase in salt levels and cause pH changes which in this case were not linked to SOM. In the NC-U zone, SOM changes were also linked to biological activity in this depth. However, the litter left to decompose on the NC surface was not uniformly distributed. The portions that got dense litter accumulated more SOM than areas with little litter. The Oa-horizon (in the NC profile) with highly decomposed SOM could be the reason for great variation. This high variability in SOM could bring about the lack of a significant correlation with pH (though the general inverse pattern of correlation exists from these results). The outliers noted in the NC-U (Fig. 7) could support the high variability of conditions in this layer; spatial differences in the deposition of litter that decompose and accumulate SOM can influence pH and cause wider disparities across the quadrats sampled.

The significant correlation between SOM and pH in the bottom soils (Fig. 10b) could have been the result of stable conditions at this depth. Since there were no inversions and with low biological activity, the levels of SOM did not change greatly. In the same way, changes in pH were minimal. The buffering effect of SOM on pH became a major factor limiting variations in pH. Assessment of correlation based on treatment (Fig. 9) which showed both scenarios having a significant strong negative correlation could be attributed to the uniformity of conditions under each treatment. Though there could have been differences in conditions, these cut across the whole area (cultivated or non-cultivated).

5.3 SOM, bulk density and other soil characteristics in the CL and NC profiles

The results of the CL and NC profiles presented in section 4.4 (especially Table 6A and 6B) indicate that the soils in the study area in general had silty clay loamy characteristics with dark reddish brown colour. However, these results, following a description of Iceland soils provided by Arnalds (2015), are generally characteristic of Histic Andosols.

According to Brady & Weil (2008) and USDA, NRCS (2008), soil structure is affected by physical and chemical factors. However, several biological processes influenced by soil micro and macro organisms (such as fungi, bacteria, earthworms and mycorrhizae) and plant roots are the most important in the development of stable aggregates. In this process, SOM is a major contributing factor providing organic products and energy to facilitate the process. Granular structure in most cases is very porous and offers the most permeability, whereas angular blocky and subangular block structures also promote drainage, aeration and root penetration. According to Brady & Weil (2008) and Shanstrom (2014), granular structure in most instances has a high content of SOM. The soil structure findings imply that the high percentage of SOM greatly influences the soil structures observed.

These observations, when related to the results for bulk density and SOM, reveal that the high content of SOM in the study area confers the colour and structural features noted in the profiles. Furthermore, the higher SOM in these soils (and the low bulk density values) indicate that the soils are generally good and porous enough to permit root penetration. The presence of roots (for grasses and forbs) even up to a 25 cm depth (which were not churned by ploughing in the case of CL profile) confirms that the soils are very porous. It also implies that the transmission of water, solutes and decomposed SOM along the soil column cannot be impeded under these conditions. The values of BD obtained from this study are in line with what has been reported by Arnalds (2015) that BD values for Icelandic Andosols soils are < 0.8 g/cm^3.

5.4 Cultivation practices and soils

Tillage can bring about favourable effects on soil structure when the clods are broken apart and loosened such that soil porosity increases and SOM gets incorporated into the soil. However, the unfavourable effects of long term tillage on soil structure are that it increases the decomposition rate of SOM and hence reduces its aggregating effect (USDA, NRCS 2008). In this regard, the lower SOM levels in the CL study fields in comparison to the NC study fields can be attributed to tillage impact. This was specifically true when the SOM in the O-horizons of the CL and NC profiles and also between the CL-U and NC-U are considered.

In Iceland, tillage is mostly done using a tractor and causes significant inversion of soils to a greater depth. In most rural farming practices, tillage is done using ox-plough and soil inversion is shallow. The impact of tillage using a tractor and ox-plough on the soil structure (and hence SOM) differs. Although the cultivation practices in the study involved better management practices, this is, however, not the case in most rural farming communities in other countries. However, the findings in this study provide good insights for guiding rural farmers in understanding and applying ways to enhance the quality of their soils.

6. CONCLUSION AND RECOMMENDATIONS

The processes which influence soil characteristics happen at different magnitudes as a result of climatic conditions and human activity. These will either improve or damage soil. As a result, the SOM which is a major factor in soil quality becomes affected.

There is a strong relationship between SOM and soil pH, soil structure and bulk density. Therefore, when SOM is impacted, the effect is conveyed to these factors (and other factors influenced by SOM). The health of the soil is affected, depending on the magnitude of impact to SOM and level of human activity.

Cultivation significantly affects SOM. For this case, it is necessary to consider the pattern and depth of cultivation such that its impact on soil does not become detrimental. Besides this, good agronomic practices should be adopted by farmers to maintain good levels of SOM in soils. Practices such as leaving plant residues in the crop fields, adding compost manure and rotations that involve fallowing should be adopted as cheaper options for maintaining SOM in the soil. These practices also improve the chemical, biological and physical properties of soil. These practices should be promoted, especially in poor rural farming communities which may not be able to afford inorganic fertilizers and should consolidate good agronomic practices to enhance soil quality.

The management of soils needs to be treated beyond the agricultural context to recognise their importance to the general ecosystem services. This should drive the need to improve the productive capacity of soils.

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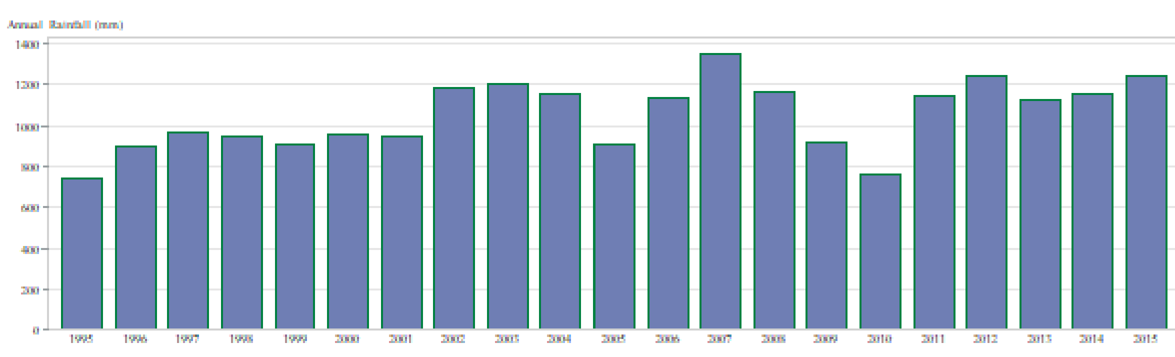
APPENDICES

Appendix 1A: Weather information for Korpa (Source: Icelandic Meteorological Office 2016).
Note: *Temperature and Relative Humidity data is for Reykjavik Weather Station close to Korpa)*

Year	Annual Rainfall	Mean Monthly Rainfall	Mean Annual Relative Humidity	Mean Annual Temperature
1995	742.9	61.91	78.2	3.8
1996	896.8	74.73	78.1	5
1997	969.5	80.79	78.8	5.1
1998	943.6	78.63	77	4.7
1999	903.8	75.32	78	4.5
2000	957.7	79.81	77.2	4.5
2001	947.4	78.95	77.6	5.2
2002	1187.5	98.96	76.6	5.4
2003	1202.2	100.18	78	6.1
2004	1155.3	96.28	76.8	5.6
2005	911.3	75.94	77.9	5.1
2006	1133.1	94.43	76.5	5.4
2007	1345.9	112.16	76.1	5.5
2008	1165.1	97.09	77.1	5.3
2009	914.9	76.24	76.7	5.6
2010	760.2	63.35	76.6	5.9
2011	1143	95.25	75.9	5.4
2012	1246.1	103.84	78.4	5.5
2013	1119.2	93.27	76.9	5
2014	1155	96.25	76.4	6
2015	1237.3	103.11	77.3	4.5
2016 (Jan-May)	371.9	74.38	73.2	2.66

Appendix 1B. Graph of annual rainfall data for Korpa: 1995 – 2015



Appendix 2A: Results of SOM and pH measurements from the cultivated and non-cultivated fields

Sample No.	CL-U-SOM (%)	CL-B-SOM (%)	NC-U-SOM (%)	NC-B-SOM (%)	CL-U-pH	CL-B-pH	NC-U-pH	NC-B-pH
1	19.6	18.9	27.0	20.4	5.30	5.49	5.42	5.55
2	19.5	20.1	26.6	22.2	5.38	5.48	5.44	5.52
3	22.4	22.6	25.9	19.0	5.18	5.37	5.39	5.49
4	24.3	24.4	25.3	21.5	5.24	5.34	5.53	5.56
5	20.4	20.3	19.3	16.3	5.39	5.51	5.40	5.73
6	18.9	18.9	23.2	17.7	5.37	5.60	5.37	5.62
7	17.1	17.2	24.0	19.2	5.52	5.61	5.41	5.61
8	17.0	16.9	30.0	24.2	5.53	5.60	5.25	5.46

Appendix 2B Descriptive statistics for SOM and pH

Parameter	CL-U-SOM	CL-B-SOM	NC-U-SOM	NC-B-SOM	CL-U-pH	CL-B-pH	NC-U-pH	NC-B-pH
Mean	19.9	19.9	25.2	20.1	5.36	5.50	5.40	5.57
Standard Error	0.9	0.9	1.1	0.9	0.04	0.04	0.03	0.03
Median	19.6	19.5	25.6	19.8	5.38	5.50	5.40	5.56
Standard Deviation	2.5	2.6	3.2	2.5	0.12	0.10	0.08	0.09
Sample Variance	6.1	6.6	9.9	6.5	0.02	0.01	0.01	0.01
Kurtosis	0.0	-0.2	1.3	-0.4	-0.89	-1.05	2.53	0.66
Skewness	0.7	0.7	-0.5	0.2	0.00	-0.50	-0.53	0.76
Minimum	17.0	16.9	19.3	16.3	5.18	5.34	5.25	5.46
Maximum	24.3	24.4	30.0	24.2	5.53	5.61	5.53	5.73
Confidence Level (95.0%)	2.1	2.1	2.6	2.1	0.10	0.09	0.06	0.07