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Effect of grazing in Norwegian outfields related to the quantity and quality of soil organic carbon and other soil properties

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Abstract

Utilization of the outfield for grazing have long traditions in Norway. Not only as a pasture, but also mowed to provide food for the winter (Rekdal & Angeloff, 2021). From 1949 to 1999, grazing in Norway changed from being dominated by livestock to being equally grazed between wild herbivore and livestock (Austrheim et al., 2011). This change in usage has led several of the semi-natural habitat types to end up on the red list of the Norwegian Biodiversity Information Centre, such as Semi-natural meadow and Hayfields (Hovstad, 2018). Therefore, grazing in outfield areas in Norway are desired as a way of keeping the cultural landscape. Resent years events particularly, in addition to a growing concern about the world's food situation has increased the interest for local food production. The latest analysis of grazing and the outfield suitable of such, indicates that Norway's unused potential in outfield is about 55% (Rekdal & Angeloff, 2021).

In addition to recent years events, the world is facing changes in climate. Still debated on how extensive and where the greatest changes will appear, a change in food production are required to undergo adjustments. Knowledge of management and "best practice" models are therefore crucial. Also in Norway, information on how the soil in outfields are affected by grazing is as important than ever.

In this thesis five locations who differs in climate and vegetation are sampled. All these locations are grazed during the summer season by suckler cows which is a part of the Norwegian meat production. Throughout this thesis grazing was not found to significantly affect the SOC-stock, SOC concentration or the thickness of the organic layer. While grazing was found to significantly decrease the HWEC-stock in all mineral layers and the CN-ratio in the organic layer.

The decrease in the HWEC-stock is suggested caused by removal of organic matter by grazers. The basis for this assumption is partly the combination of the significant decline in HWEC-stocks and difference between grazed and non-grazed site in the thickness of the organic layer mean values (not significant). In addition, the CN ratio was found to significantly decrease under grazing in the organic layer.

The HWEC-stock is viewed as a measure of the labile fraction (Dong et al., 2021), and is a useful indicator of the soil quality in soil-plant ecosystems (Ghani et al., 2003). The form and behaviour of the SOM and SOC is fully reliant on microbial mass (Bhattacharyya et al., 2022), and a decrease of the HWEC might therefor be a sign that a decline of microbial biomass pool (Ghani et al., 2003) are taking place. Since a significant decrease were found between the grazed site and the control sites (non-grazed) it might be an early indicator of degradation of the soil structure.

A significant increase in bulk density between sites in the two top layers (the organic layer, mineral 0-10 cm) were found for all locations. In accordance with other studies on grazing effects (Byrnes et al., 2018; Martinsen et al., 2012; Piñeiro et al., 2010), it was concluded that the pastures were influenced by the grazing animals.

On the background of different utilizing periods and grazer densities, the management of the pastures is suggested to might be influencing the HWEC-stock. Amongst the tested factors related to geography and effect on the SOC-stock, only MAT were found significant. Precipitation and content of fine texture quantity were not found to significantly effect SOC-stocks. Therefore, geography was found somewhat related to the SOC-stock.

Only Mg-stock had a significant difference between sites. Grazing was not found to significantly affect the soil's pH. No plausible explanation for this significant result was found. The other macronutrient stocks were not found to significantly change with grazing.

Sammendrag

Beiting i utmark har lange tradisjoner i Norge. Ikke bare er utmarka benyttet som beite, men ble før også slått for å skaffe dyrene mat til vinteren (Rekdal & Angeloff, 2021). Fra 1949 til 1999 endret beite i Norge seg fra å være dominert av husdyr til å bli likt beitet mellom ville dyr og husdyr (Austrheim et al., 2011). Denne bruksendringen har ført til at flere av de semi-naturlige naturtypene har havnet på rødlista til Artsdatabanken, som for eksempel Semi-naturlig eng og slåttemark (Hovstad, 2018). Beiting som en måte å opprettholde kulturlandskapet er en av grunnene til at beiting i den norske utmarka er ønsket. Med tanke på de siste årenes begivenheter, i tillegg til en økende bekymring for verdens matsituasjon har interessen for lokal matproduksjon økt. Den siste analysen utført på beitebruk og utmarkas egnethet for dette, indikerer at Norges ubrukte potensial i utmark er om lag 55 % (Rekdal & Angeloff, 2021).

Verden står i tillegg til de siste årenes hendelser på trappene av klimaendringer. Omfang og område for hvor været vil endres mest drastisk er usikkert, men matproduksjonen vil mest sannsynlig uansett måtte omstilles og berede seg på disse endringene. Kunnskap om forvalting og «best practice»-modeller er derfor avgjørende. Kanskje viktigere enn noen gang, også i Norge, er informasjon om hvordan jorda i utmark påvirkes av beiting.

I denne oppgaven er fem lokasjoner som er forskjellige i klima og vegetasjon prøvetatt. Alle disse lokalitetene beites i sommersesongen av ammekyr som er en del av den norske kjøttproduksjonen. Gjennom denne oppgaven ble det ikke beiting funnet til å signifikant påvirke det organiske karbonet i jorda (SOC-stock), konsentrasjonen av organisk karbon (SOC%) eller tykkelsen på det organiske sjiktet. I motsetning ble beiting funnet å signifikant redusere hot water extractable carbon (HWEC) signifikant i alle mineralsjikt og CN-forholdet (karbon:nitrogen) i det organiske sjiktet.

Nedgangen i HWEC antas å være forårsaket av at kyrenes beting, altså fjerning av organisk materiale. Bakgrunnen for denne antakelsen er delvis kombinasjonen av den signifikante nedgangen i HWEC og forskjellen i median verdiene av tykkelsen på det organiske sjiktet (dog ingen signifikant forskjell). I tillegg ble det i det organiske sjiktet funnet en signifikant nedgang i CN-forholdet ved beiting. HWEC blir sett på som et mål på den labile fraksjonen (Dong et al., 2021), og er derfor en nyttig indikator på jordkvaliteten i jord-plante-økosystemer (Ghani et al., 2003). Formen og oppførselen til det organiske materialet i jorda (SOM) og SOC er avhengig av

den mikrobielle massen (Bhattacharyya et al., 2022), og en reduksjon av HWEC kan derfor være et tegn på en nedgang av den mikrobielle biomassen (Ghani et al., 2003) er i ferd med å skje. Siden det ble funnet en signifikant nedgang av HWEC ved beiting, kan det være en tidlig indikator på nedbrytning av jordstrukturen.

Det ble funnet en signifikant økning av tettheten i jorda (BD) ved beiting for alle lokasjoner i de to øverste lagene (det organiske laget, mineral 0-10 cm). I samsvar med andre studier på beiteeffekter (Byrnes et al., 2018; Martinsen et al., 2012; Piñeiro et al., 2010) ble det derfor konkludert med at beitene var påvirket av beitedyrene.

På bakgrunn av de ulike bruksperiodene og beitetetthetene, antydes det at forvaltningen av beitene kan ha påvirket HWEC. Blant faktorene knyttet til geografi som ble testet i forhold til effekten på SOC, ble kun årstemperatur (MAT) funnet signifikant. Nedbør (MAP) og innhold av den fineste kornstørrelsen ble altså ikke funnet til å signifikant påvirke SOC. Derfor ble geografi funnet delvis relatert til SOC.

Innholdet av Magnesium (Mg) var det eneste makro næringsstoffet som viste en signifikant forskjell mellom beite og ikke beitet område. Beiting ble ikke funnet til å signifikant påvirke jordens pH. Det ble ikke funnet noen mulig forklaring på at hvorfor akkurat Mg ga en signifikant forskjell. De andre makro næringsstoffene ga ikke signifikant utslag mellom beite og ikke beite.

Preface

Here’s a small contribution to soil science, a wonderful hidden world always just beneath our feet. Here's to everyone who has helped me on my journey to delivery. Here’s to thinking and learning new things every day. Here’s to everyone who wants to make a difference. Here's to a livable climate and the right to live in a world that still holds beautiful nature. Here's to people who engage in things and cares. Here's to curiosity and amazement.

During this thesis I have learned a lot about soil and all the complex interactions that take place in it. I have also learned how much that is unknown, and how much I still need to learn. I want to take this opportunity to thank my supervisors for all help and guidance along the way, and not least for taking me along on the fieldwork. Therefore, a big thanks to Vegard Matinsen, Line Tau Strand and Jan Mulder.

I also want to thank everyone on the soil lab at NMBU for guidance at the lab, help with all the soil sample analysis and all lovely conversations. Therefore, a big thanks to Irene Eriksen Dahl, Byron Spencer, Oddny Gimmingsrud, Christian Solheim and Valentina Zivanovic.

A thanks to my support system at home, my family, and friends. Thanks to my man who tolerate me going on about all the new things I read about, and for that you still manage to act interested. Thanks to my cousin for the proofreading. At least, thanks to my fellow students for the academic discussions and the not so academic ones when a break is needed.

Ås, Norway, May 2022,

Tonje Forsethlund Ellingsen

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Table of abbreviations

BD	Bulk density
CN	Carbon : Nitrogen ratio
Gr	Grazed sites
HWEC	Hot water extractable carbon
IC	Inorganic carbon
LOI	Loss on ignition
MAT	Mean annual temperature
MAP	Mean annual precipitation
MOM	Mineral associated organic matter
NG	Non-grazed sites
POC	Particular organic carbon
POM	Particular organic matter
SOM	Soil organic matter
SOC	Soil organic carbon
SIC	Soil inorganic carbon
TotC	Total carbon
TotIC	Total inorganic carbon
TotN	Total nitrogen

1. Introduction and hypotheses

1.1 The carbon cycle and Soil Organic Carbon (SOC)

Carbon is part of the global biogeochemical cycle. Carbon is a part of everything alive and made bioavailable through the astonishing process of photosynthesis. As aptly put by Schlesinger et al. (2020): "photosynthesis provides the energy that powers the biochemical reactions of life". When herbivores and other living organisms feed on plants or carnivores feed on other organisms, carbon recycles back to the atmosphere due to cell respiration. In addition, carbon in dead animals and plants is returned to the atmosphere through decomposition performed by microorganisms.

Other parts of the carbon fluxes are slower and can function as a storage or sink for longer time periods. Example of such a sink or storage is the oil reservoirs deep down under the sea or a limestone mountain. Ever since the industrial revolution the global carbon cycle have been experiencing an unbalance due to anthropogenic activities. This has increased the composition in the atmosphere from 285 ppm at the beginning of the industrial revolution to about the level 366 ppm in 1998 (FAO, 2004). FAO attributes the cause of the increase to two main factors: 67% due to fossil-fuel burning and cement production, and the resisting 33% due to land-use change (FAO, 2004).

Back in 2019 the Norwegian authorities signed a binding climate agreement to reduce emissions and capture 5 million tons of CO_2-equvivalents over the time period 2021-2030 (Moderniseringsdepartementet, 2021). In addition, the Parliament signed the suggestion from the government to "increase uptake in forests and take care of the carbon stocks in the soil in forests, agricultural areas and other green areas" (Moderniseringsdepartementet, 2021). The organic matter in soil contains four to six times as much carbon as all the world's vegetation (Weil et al., 2017). It is of interest to everyone to not only manage this carbon pool with the best managing strategies but also to understand the mechanisms driving and controlling this pool. By doing so the soil might sequester carbon and hence serve as a sink. Although, Weil et al. (2017) notes that soils have a finite capacity to sequestrate stable carbon and therefore only a method of buying time, not the solution itself.

1.2 Carbon in soil and soil organic carbon (SOC)

Carbon exits in different forms and fractions in soil. These forms determine qualities, residence time and responsiveness. Soil organic matter (SOM) provide much of the soil's cation exchange capacity (CEC), ability to hold and lead water and are largely responsible for aggregation of the soil, both formation and stabilization (Weil et al., 2017). The soil organic carbon (SOC) is a part of the SOM and often estimated to constitute 50% of the weight of the organic matter (Weil et al., 2017).

Total soil carbon consists of organic, and inorganic soil carbon. The soil organic carbon (SOC) is the carbon part of the organic matter and consist of a variety of signs of life, either living such as roots and soil fauna or post living matter as fine fragments of litter or products of microbial decay (FAO, 2019). In short, the inorganic carbon (SIC) consists of nonliving nor residues of living organisms, but comprises pedogenic carbonates and bicarbonates (FAO, 2019). The standard operational definition of SOC is used when referring to SOC in this thesis; "organic carbon present in the fraction of the soil that passes through the 2 mm sieve" (FAO, 2019).

SOC are generally divided into labile and stabile matter. As pointed out by Weil and Brady (Weil et al., 2017) the labile part of SOC is easily altered, and rapidly oxidized by soil organisms over periods from months to years. This labile SOC is therefore a relatively young fraction, and is in turn more sensitive to management change therefore widely used as a measure of dynamics in SOC (Dong et al., 2021). The humus part of the soil appears to be stabilized by various mechanisms and stay in for centuries or even millennia (Weil et al., 2017). The humus pool is often also referred to as the stable organic carbon or the passive organic matter.

These two parts of the organic part of soil carbon - labile and stabile - are often additionally divided into underlying categories. In both the labile and stabile SOM, the fraction referred to as particulate organic matter (POM) occurs, hence the carbon part of the POM fraction is referred to the particular organic carbon (POC). The difference between POM in the labile and the stabile part is how and how well the organic matter (OM) is protected from degradation. The POM as a fraction of the labile part is free bits of partially degraded tissue. In addition to this POM, the labile OM consists of three other groups: the living organisms (biomass), the free identifiable dead litter (detritus) and the free dissolved biomolecules of degraded products (DOC) (Weil et al., 2017). POM is also a fraction of the stable carbon, hence grouped in two categories by what the POM is composed of. First group consists of bits of degraded cell walls and tissue, the other POM group consists of biomolecules, supramolecules and degradation products (Weil et al., 2017). These two groups is protected either physically from degradation especially mineral associated organic matter (MOM), or by its composition of the matter (Weil et al., 2017). Additionally, the stable part contains the category of char produced by biomaterials during a fire (Weil et al., 2017).

Often used as a measure of the labile fraction are hot water extractable C (HWEC) or particulate organic C (POC) (Dong et al., 2021). Since this hot water carbon is a fraction of the labile it is also closely related to the microbial biomass in the soil, hence also the micro aggregation, therefore a useful indicator of the soil quality in soil-plant ecosystems (Ghani et al., 2003). Found by Ghani et al. (2003) the HWEC is a measure to estimate microbial biomass-C and hot-water carbohydrates, therefore able to detect changes in the SOM due to for example grazing. In this study Ghani et al. (2003) conclude that loss of HWEC indicates a decline of microbial biomass pool, also labile nutrients and might additionally indicate degradation of the soil structure.

1.3 The pathway of carbon in soil

The soil organic carbon (SOC) is broadly determined by three environmental factors; temperature, moisture and soil texture (Weil et al., 2017). The residence time of this carbon depends mainly on the environmental conditions in the soil and the quality of litter and residues added to it (Weil et al., 2017). Numerous biogeochemical processes unfold in soils, though constantly influenced by its surroundings. The residence time of carbon in soil is determined by the balance between inputs quantity and quality and the ability of the soil to stabilize the carbon, see figure 1. The main mechanisms influencing the stabilization of SOC is the living part (biotic) and the non-living part (abiotic) (Dignac et al., 2017). Both biotic and abiotic factors contribute to the physical stabilization and the physiochemical stabilization of SOC. Physical stabilization of SOC can be simplified as the physical barrier that prevents microorganisms from reaching the carbon. By preventing microorganisms from reaching the carbon it remains in the soil instead of being oxidised to CO_2. The physical stabilization is mostly related to the aggregation in soil that forms a barrier, thus also stabilization by preventing leching and erosion. Physiochemical stabilization also prevents microorganisms from reaching the organic material. This mechanism distinguishes by binding to the organic molecules itself. Minerals bind chemically with the organic molecules, thus making them inaccessible to decomposition (Rasse et al., 2019). The difference between the physical and the physiochemical stabilization is somewhat fluid and occur simultaneously in soils.

Carbon enters the soil from decomposition of litter aboveground but also belowground from plant roots. The belowground input of carbon depends on the plant diversity, persistence of plant residues, rooting architecture of plant species and interaction between plants and other biota living in the soil (Dignac et al., 2017). Quantity as well as quality of carbon input both influence the SOC. As shown in a meta-analysis conducted by Xu et al. (2021) of 237 studies across 248 sites included grassland, plantation, natural forest, and cropland on litter impact on SOC. The findings overall, across all mentioned ecosystems, were a significant increase in soil C content but not in soil C stock, hence a significant decline in soil C content and stocks with litter removal at all measured depth (Xu et al., 2021).

For a long time, it was believed that the molecular structure of plant inputs had an important role in stabilizing SOC. Schmidt et al. (2011) found that this might not be as important as assumed, rather it having a secondary role in the determination of residence time. Instead, the stabilization mainly depends on the surroundings in the soil, both biotic and abiotic (Schmidt et al., 2011). Though, this does not mean that the compound chemistry is irrelevant, but that the decomposition and persistence of organic matter in soil is dependent on a complex of factors and the interactions between them. Schmidt et al. (2011) lists the following: "interdependence of compound chemistry, reactive mineral surfaces, climate, water availability, soil acidity, soil redox state and the presence of potential degraders in the immediate microenvironment". The chemical composition of the soil input of OM has an impact of C cycling in short term, thus over longer periods the persistence depend more on the environmental conditions (Dignac et al., 2017). In turn, the soil as a system where all factors interact, and the sum of these interactions determines the fate of carbon in the soil, see figure 1. Interactions between factors makes predictions and simulations complex and somewhat difficult.

Texture and particle sizes of the mineral soil fraction is said to be one of the most important factors for stabilizing soil carbon. An example is the paper by Six et al. (2002) that found a direct relationship between the content of silt and clay and the amount of protected POC. The content of fine texture in soil is important for stabilization and protection of the carbon in it. In addition, the aggregation among soil particles constitutes an important factor in protecting the POM because among other things it prevents diffusion of oxygen (Six et al., 2002). Pores and pore size determine the air exchange and water accessibility and is therefore important for the life of microbes. Increasing the clay content is suggested to increase the physical protection of POM within aggregates, thus having a reinforcing effect of stabilization on both POM and SOC (Six et al., 2002). On the other hand, in a field study in Germany, Meyer et al. (2017) found that the amount of labile or stabile C could not be assigned to a specific size fraction, thus the degree of C saturation was a major regulator of SOC stability and turnover rates (Meyer et al., 2017). Hence, the mineral fractions of the soil and the soil texture cannot stabilize SOC alone.

Climate is an important factor because it determines the temperature and the moisture and therefore both the litter production and decomposition rate. Correspondingly, the location constitutes an important aspect because it determines the parent material of the soil, the soil texture, time of development of the soil and the topography, see figure 1. Temperature is an important factor for SOC, because like any other biological process, respiration also increases with temperature (Weil et al., 2017). In general, an increase in moisture in the soil increases the SOM (Weil et al., 2017). Therefore, in cooler and wetter climates it is expected to find soils containing greater amount of carbon than in warmer drier climates. A study performed by Callesen et al. (2003) in the Nordic countries, northern boreal zone, found that SOC down to 1 m depth increased with annual temperature and precipitation in upland well-drained soils. In the study, the soil was separated into different texture classes, and they found differences between classes within the same climate, as well as differences between different climatic zones and same texture class (Callesen et al., 2003). Therefore, they concluded that SOC respond differently to climate (MAT and MAP) in different texture class soils (Callesen et al., 2003). Lastly, they conclude that 40% of variations in SOC is explained by other factors that climate and texture, such as time, vegetation, disturbances (natural and man-made) and sampling and measurements variation and errors (Callesen et al., 2003).

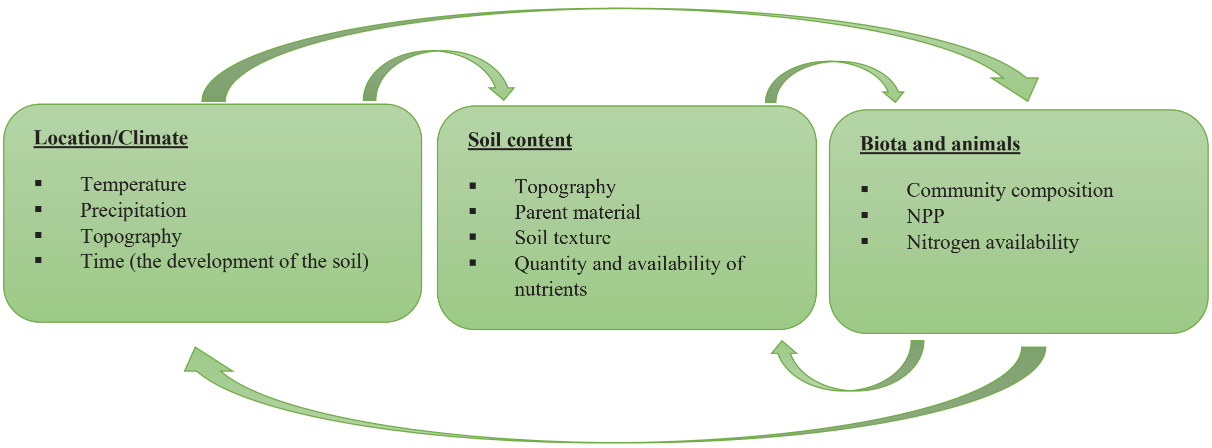

Figure 1: Factors influencing the pathway of carbon in soil. The factors are grouped by “Location/Climate”, “Soil content” and “Biota and animals”. Arrows between the boxes represent influence of the factor inflict on others.

1.4 Effects of grazing on carbon in soil

Grazing animals (herbivores), alter their surroundings in many ways, see figure 2. Herbivores can alter and change the biogeochemical processes, the aboveground plant composition (Austrheim et al., 2014; McSherry & Ritchie, 2013; Schmitz et al., 2018) as well as the underground root masses (Piñeiro et al., 2010) and densities of soil and nutrient contents (Byrnes et al., 2018; Martinsen et al., 2012; Piñeiro et al., 2010). The effect on SOC under grazing depends on the response of both the soils biochemical and physical factors (Byrnes et al., 2018).

Since grazing animals directly remove plant biomass, they might change the vegetation dynamics in the areas they utilize, depending on intensity and grazer. Besides, grazing effect the vegetation dynamics by selectively feeding on specific plants giving some plant species an advantage (Schmitz et al., 2018). This may alter the plant composition in the grazed area. Several experiments reviewed by Schmitz et al. (2018) found that exclusion of herbivores can affect carbon dynamics because the grazing changed the composition of plant species. An example is a study conducted by Austrheim et al. (2014) in alpine grassland in Norway where they found a decrease in above plant biomass of vascular plants over a period of five years. The decrease in plants was greater with higher grazing density and moderate with low grazing density (Austrheim et al., 2014). Similar results were reported by Brathen et al. (2007) from a study conducted on reindeer grazing in Finnmark, Norway. High density grazing suppressed productive plant species, although loss of ecosystem productivity could not be proven (Brathen et al., 2007).

In addition to grazing changing the vegetation dynamics, the effects of grazing might be different on SOC depending on the abundance of plant species. An example found by McSherry and Ritchie (2013) when performed a multifactorial meta-analysis of grazer effects on SOC. They found that sites dominated by one type of grasses had a positive effect on SOC with light grazing intensity only to shift to negative with moderate to high intensity (McSherry & Ritchie, 2013). Sites dominated by another grass type had the opposite result, although slightly negative effects when lightly grazed and positive for moderate and heavy intensities (McSherry & Ritchie, 2013). Therefore, grazing may also differ between a positive and negative effect depending on grass type, but also intensity.

Grazing management and the density of animals affects the grazers impact on soil carbon dynamics. The long-term carbon storage could be influenced by animals, but, depending on the grazing practice, it might lead to sequestering or release of SOC (Schmitz et al., 2014). One might assume that a higher intensity and density of animals impacts SOC greater through different influences than lower intensities. In the study conducted over 7 years on grassland in Norway, Martinsen et al. (2011) found that C-stocks, when corrected by mass, were different with grazing intensity. As stated by Martinsen et al. (2011) high densities might generate a greater loss of soil C and/or less biomass input than low densities. A meta-analysis conducted by Byrnes et al. (2018) also found differences between grazing practices. Among the differences they found that rotational grazing had a significantly higher SOC and CN than continuous grazing plus reduced bulk density (BD) (Byrnes et al., 2018). In addition, they found that study duration was important for determination of the soil responses to continuous grazing vs. no grazing (Byrnes et al., 2018). Management of pastures and the intensity of grazing effects soil properties as SOC, CN-ratio and BD.

In addition to remove aboveground biomass grazers returns nutrients and biomass via manure and urine. The amount of nutrients is dependent on the diet, and the amount returned is generally about 75% N, 80% P and 90% K of the ingested matter (Weil et al., 2017). This might cause an increase in the turnover of nutrients and decomposition of the organic materials. In a study conducted in Sweden Bolinder et al. (2010) found that by adding manure in addition to crop rotations the SOC-stocks increased over a period of 50 years. In this study the manure was added, the field was not grazed. Animal manure have higher concentrations of nutrients than the above- and belowground dead plant materials (Taboada et al., 2011). As for phosphorous, it is mainly returned to soil in inorganic forms, and for added urine half the nitrogen is rapidly hydrolyzed to ammonium and might be lost as gas (Taboada et al., 2011). In addition to manure influence, Sun et al. (2017) found that grazing stimulates plants to release a flush of labile C into the rhizosphere. This release enhanced soil N mineralization in addition to increase the plant uptake of nutrients (Sun et al., 2017).

Martinsen et al. (2012) tested the effects of grazing on bioavailable N and found that grazing effects differently by altitude and grazing densities, hence a significantly greater rate of potential N mineralization in high density sites compared to both low density and no grazing. Piñeiro et al. (2010) reviewed the current literature on grazing effects on SOC and found that the CN ratio of the soil organic matter either increased or remained unchanged with grazing as well as effects on the bulk density of the soil as either an increase or with no changes. The increase of CN ratio was suggested by Piñeiro et al. (2010) to be caused by grazers increasing N limitation in grasslands, although only increasing in the more labile part of the soil organic material.

In contrast, Byrnes et al. (2018) found in a meta-analysis conducted on 64 studies on how grazing impacts soil health indicators that grazing significantly reduced SOC, CN and total Nitrogen (TN) when compared to no grazing controls. The study also found an increased bulk density of the soil. The difference between the studies is the place of study, Piñeiro et al. (2010) conducted the study on grasslands, while the study of Byrnes et al. (2018) were conducted on studies from all over the world, not restricted to grasslands. In addition, Byrnes et al. (2018) found differences in the CN-ratio between grazing management strategies. Generally, the CN decreased, although with moderate grazing the CN increased significantly while light and heavy grazing led to a significantly decrease in CN (Byrnes et al., 2018). Byrnes et al. (2018) explain this to potentially be due to greater rates of decomposition or reduced fresh plant material input during heavy grazing.

Another example of studies conducted on grazing and their effects were conducted in Norway by excluding Cervid in a Boreal Forest. Kolstad et al. (2017) created 15 study sites in recently clear-cut boreal forests in Trøndelag, central Norway where some plots were fenced off resulting in non-accessibility for the cervids, like moose. After eight years they found a significant reduce in soil temperature and bulk density and increase in the soil organic depth and the biomass composition above ground (Kolstad et al., 2017). In contrast, the exclusion did not show any affect the soil C or N stocks, the concentrations of C and N, or the CN ratio in any layers of the soil (Kolstad et al., 2017).

In addition to grazing affecting vegetation, nutrients from high quality litter, high bioturbation and increased decomposition of organic material (Rasse et al., 2019), grazing effects might also be dependent on climate and location. McSherry et. al. (McSherry & Ritchie, 2013) preformed a multifactorial meta-analysis of grazer effects on SOC density and found that grazing effects are influenced by precipitation and soil texture. They found that an increase in precipitation decreased the grazing effect when the soil contained of finer textured soil, thus increased the effect of grazing in soil types of sandy soils (McSherry & Ritchie, 2013). This might suggest that grazing effects differ by climate and soil type in addition to above ground vegetation dynamics. The conclusion of the meta-analysis was that precipitation and soil type, especially their interaction, explained a large proportion of the variation of grazer effect (McSherry & Ritchie, 2013). Piñeiro et al. (2010) also found a relationship between grazing effects on SOC and precipitation, that is the effects of root contents were depended on precipitation.

As put by Schmitz et al. (2014) further evaluations of animal effects are needed to understand their effect on carbon dynamics. In addition to understand the dynamics, this can contribute to greater sustainable use and production both locally and regionally (Schmitz et al., 2014).

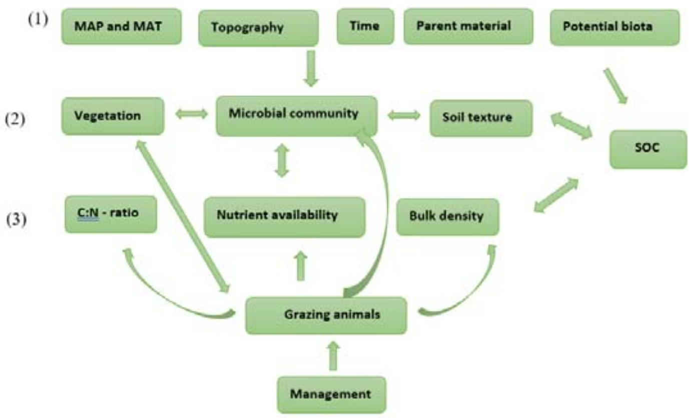

Figure 2: Simplified model of the grazing effects and the relationships to exterior and inherent factors in the soil. The figure is simplified to three levels, and the impact among levels on presented as an arrow pointing in the impact level. The three level is as follows; (1) exterior factors and long-term controls; mean annual precipitation (MAP), mean annual temperature (MAT), time, parent material and potential biota. (2) Inherent factors; vegetation, microbial community and soil texture. (3) Indirect controls on inherent factors; CN-ratio, nutrient availability and bulk density. All three levels affect the SOC in the soil. Grazing effects factors in level (2) and (3) as future influence between levels therefore SOC additionally. Figure freely after (Piñeiro et al., 2010).

1.5 Outfield grazing in Norway

From 1949 to 1999, grazing in Norway changed from being dominated by livestock to being equally grazed between wild herbivore and livestock (Austrheim et al., 2011). The ecological effects of this shifts are poorly examined, simultaneous knowing that many red-listed species in Norway have their habitats in semi-natural areas (Austrheim et al., 2011). According to a report carried out by Rekdal et.al (Rekdal & Angeloff, 2021) only 45% of outfields suitable for outfield grazing are utilized, hence 55% of the areas remain unexploited.

As briefly discussed, SOM is partly dependent of the climate, specifically temperature and moisture. Norway belongs to the world boreal region. Naturally, in an elongated country like Norway there are local differences in climate. The soils in Norway will, under a small resolution map of the global soil regions, fall under the categories Spodosols as well as a modest proportion under the Inceptisols category (Weil et al., 2017). The soil orders containing the highest amount of carbon are soils belonging to the orders Histosols, Inceptisols and Gelisols (Weil et al., 2017).

Only 4% of Norwegian soils classify as deep organic soil, 73% classify as "other mineral soil", 16 % as mineral soil with a surface layer rich in humus and the remaining 7 % classify as shallow organic soil (4%) (Roar Lågbu, 2018). Even though the percentage of organic soil are low, they store more than 30 % of the national soil C stocks, and Norway has approximately 0.18% of all global carbon stocks (Bartlett et al., 2020). The areas in Norway that sequester the most carbon on an annual basis are forests and low-mid alpine zones (Bartlett et al., 2020).

1.6 Presentation of the project

This thesis is a part of the project "Animal health and pasture carbon dynamics in sustainability assessment of ruminant production systems (SUSCOW)". The project is led by The Norwegian University of Life Science and has many participants, such as the Norwegian Institute for Bioeconomics (NIBIO), Norwegian University of Science and Technology (NTNU), the Swedish University of Agricultural Sciences (SLU), Queen`s University Belfast (QUBIS), TINE SA, Animalia - Sustainability, environment and climate, Nortura SA, TYR, Geno SA and the Agriculture Climate company SA (ANIMALIA, 2021).

The main goal is as stated in the project description and is" to provide scientific based documentation showing the importance of health status in dairy and beef cattle production on GHG-emissions intensities and other impact categories"(SUSCOW, 2022). This means that the aim of the project is partly related to carbon sequestration in pastures and partly increased animal productivity and health (SUSCOW, 2022). This thesis is a part of the work package 3 (WP3) regarding carbon sequestration in pastures and the need for increased knowledge of how grazing affect pastures, particularly in regards to outfields.

In the project 12 farmers agreed to allow access to their farms for soil sampling in their pastures. The farmers agreed to continue with this new project as a continuation from an earlier project called OPTIBIFF. The farms included in the project are located between Sirdal in the south of Norway and Salangen, Troms in the north. In this thesis five of these locations were selected to represent a paired plot of two sites, grazed and non-grazed, with similar conditions.

1.7 Relevance of project

As a part of the Norwegian strategy to reach the UN's sustainable goals, the work of providing and facilitating a good scientific knowledge base is called for to make a base for decisions (Moderniseringsdepartementet, 2021). Rasse et al. (2019) emphasise the need for a greater understanding of the mechanisms and processes that controls the carbon capture, decomposition, and storage in Norwegian systems. In the report, it is indicated that studies performed on outfield systems are ambiguous with regard to grazing on soil carbon (Rasse et al., 2019).

Bartlett et al. (2020) writes on the report “Carbon storage in Norwegian ecosystems” about the same demand for knowledge. First, it is pointed out that the mapping of habitat types in Norway is low in accuracy and therefore tend to prevent accurate area estimates based on these maps. Secondly, it is noted that the carbon stocks are mainly based on studies performed outside of Norway that might not be transferable to Norwegian conditions. According to Svendgård-Stokke et al. (2019), the soil mapping in Norway traditionally only has been carried out on cultivated land, and the mapping of the cultivated land only approx. 53% of the area is covered by 2019. In addition to the lack of data it is also pointed out the existing knowledge gap in understanding the relationship between biological diversity and carbon capture (Bartlett et al., 2020).

1.8 Aim and Hypotheses

The aim of this thesis is to determine levels of SOC in the upper 30 cm of the soil in outfields at five different locations with varying climate and edaphic conditions in mid-Norway. The effects of grazing on build-up of SOC and relevant soil properties will be assessed for every location. Accordingly, I hypothesised that:

H1) Grazing sites have a higher labile SOC stock than non-grazed sites.

H2) There is a higher SOC stock in locations with a higher MAT and MAP. Hence, geography is related to grazing effects.

H3) Fine textured soils have higher SOC stocks.

H4) CN-ratio has a positive effect on the SOC stock.

H5) Grazing sites have a higher nutrient availability than non-grazed sites.

H6) Grazing sites have a lower thickness of the organic layer.

H7) Grazing sites have a higher bulk density than non-grazed sites.

2 Study Locations

2.1 General description

The fieldwork was executed around on numerous locations in Norway. Within the project there are 12 locations sampled in total, of which five are analysed and will be descried in this thesis. They are as follows location 9. Rena, location 11. Tynset, 12. Leksvik, 13. Korgen and 14. Dønna as listed in table 1. Given in the table is the belonging of each location regarding municipality and county as well as the coordinates and altitude for sampling site. Plotted coordinates for each location are shown in a map over Norway, in figure 3.

Table 1: Summary of location properties. Overview of location numbering, location name, placement in terms of name of municipality and county in addition to coordinates and altitude and mean annual precipitation (MAP) and mean annual temperature (MAT) described in this thesis.

Nr.	Location	Municipality	County	Coordinates	Altitude [m]	MAP [mm]**	MAT [°C]**
9	Rena	Åmot and Stor-Elvdal	Innlandet	33 V, E 309363, N 6802262*	255*	771.8	3.15
11	Tynset	Tynset	Innlandet	32 V, E 599400, N 6902993	846-875	622.4	0.65
12	Leksvik	Indre Fosen	Trøndelag	32 V, E 579611, N 7064458	124-133	841.5	6.1
13	Korgen	Hemnes	Nordland	33 V, E 451799, N 7321078	335-398	1716.3	3.5
14	Dønna	Dønna	Nordland	33 V, E 391829, N 7335097	6-23	3054.7	6.26

*Exact GPS-data missing
**Information collected from the Norwegian centre for climate services' database, period 1991-2021 (some year data missing, see appendix 15).

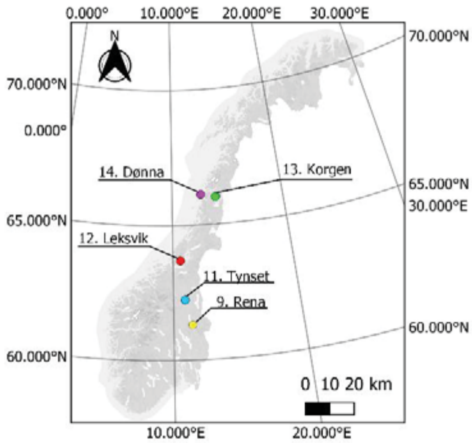

Figure 3: Locations; Rena, Tynset, Leksvik, Korgen and Dønna. GPS coordinates plotted in QGIS and the underlaying map is collected from the database statskart.no.

2.2 Location description

The five mentioned locations will be described regarding registered parameters in field, and information collected from different databases in addition to work excecated by an earlier project on the same locations. The vegetation at the locations was described by the botanists Rekdal (2018). All grazed sites were utilized by suckler cow, and variations in breed, count and duration of grazing periods is also obtained from same publication. Neither of sites were fertilized by mineral fertilisers (Farmers, 2022).

Geo-referencing was performed at every site and plot. The coordinates were plotted into the program QGIS and arranged into maps retrieved from the website statskart.no.

2.2.1 Rena

The farm is owned by Anne Dieset and are located on Deset between the two rivers Glomma and Rena in Åmot and Stor-Elvdal municipality in Innlandet County, see figure 4. The livestock who utilize the pasture is of the breed Hereford counting 109 individuals (Rekdal, 2018). The animals are realized into the outfield pastures around the end of May and retrieved in autumn in the middle of September (Rekdal, 2018). The outfield pasture fits under the vegetation zone "Southern boreal zone", and the vegetation section "Slightly continental section" (Moen et al., 1998), see table 2 for a summary of the properties of the location. Mean annual precipitation (MAP) over the period 1991-2021 were 771.8 mm, and mean annual temperature (MAT) 3.15 °C, collected from the Norwegian database for weather statistics (Norway, 2022). Overall the underlaying bedrock in the area consists of is sandstone and granite, sedimentary bedrock of glacial deposits as Moelvtillitt and conglomerate (NGU, 2022). In the area there is deposits from both river and glacier deposition (NGU, 2022).

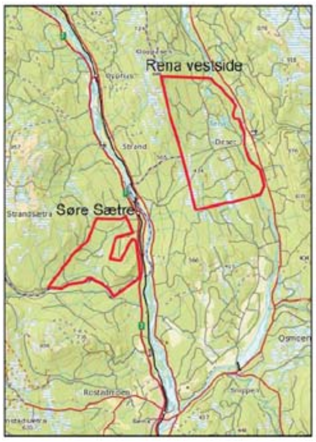

Figure 4: Topographic map showing the grazing areas (Rekdal, 2018).

Species observed at the site were amongst others northern wolf's-bane, wood cranesbill, Lady fern, alpine sow-thistle, lady's mantle, raspberry and many more (Rekdal, 2018). The pasture is characterized by Rekdal (2018) as good to very good. The vegetation type "meadow spruce woodland" consists of three other vegetation types; "Low-herb woodland", "Tall-fern woodland" and "Tall-herb, birch and spruce woodland" (Rekdal, 2021). Observed plant species in this pasture amongst others common bent and wavy hair-grass (Rekdal, 2018). Picture of the grazed site is shown in figure 5, and in figure 6 the grazed site.

Figure 5: Picture taken on the non-grazed site in Rena. Picture taken by Vegard Martinsen.

Figure 6: Picture taken on the grazed site in Rena. Picture taken by Vegard Martinsen.

Table 2: Grazer and count of animals, vegetation zone, vegetation section, vegetation type, quality of pasture and underlying bedrock for location Rena.

LOCATION 9, RENA							
Grazer	**Grazer density**	**Grazing period**	**Vegetation zone**	**Vegetation section**	**Vegetation type**	**Quality of pasture**	**Underlying bedrock**
109 animals of Hereford cows	2.3 animals / km^2	End of May - middle of September	Southern boreal zone (Moen et al., 1998)	Slightly continental section (Moen et al., 1998)	"Low-herb woodland", "Tall-fern woodland" and "Tall-herb, birch and spruce woodland"	Good - very good	Sandstone and granite, sedimentary bedrock of glacial deposits as Moelvtillitt and conglomerate*

*Information collected from NGU's database (NGU, 2022)

2.3.2 Tynset

The farm is owned by Morten Storeng and the pasture is in the municipality of Tynset in Innlandet County, see figure 8. In figure 7 the coordinates are plotted for both the grazed site and the non-grazed site. The pasture sampled is grazed by 15 Charolais cows from the beginning of July to the middle of August (Rekdal, 2018). By Rekdal (2018) it is categorized as a good to very good pasture, see table 3 for a summary of the properties of the location.

The underlaying bedrock in the area consists of quartzite with feldspar, slate of quartz, and partly with calcite and diabase (Rekdal, 2018). The outfield pasture lays in the vegetation zone "middle boreal zone" and in the vegetation section "Slightly continental section" (Moen et al., 1998). Mean annual precipitation over the period 1991-2021 662.4 mm, and mean annual temperature 0.65 °C, collected from the Norwegian database for weather statistics (Norway, 2022).

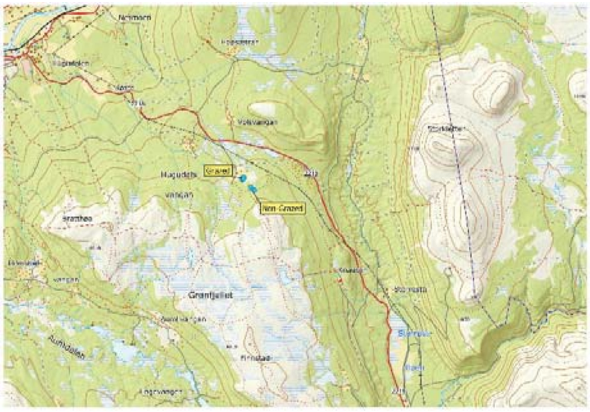

Figure 7: Plotted coordinates in the program QGIS and arranged into maps retrieved from the website statskart.no. The yellow tags points at the separate sites where plots were sampled.

Figure 8: Orthophoto over grazing area with rough vegetation types distribution (Rekdal, 2018).

The vegetation in the pasture is classified by Rekdal (2018) to contain a small portion of "Alpine lady-fern", then the rest in divided into "Bilberry-Birch woodland" estimated to cover nearly half of the pasture and the rest is "Meadow-Birch woodland". The figure 9 is a picture taken at the non-grazed site, and the figure 10 the grazed site.

Figure 9: Picture taken on the non-grazed site in Tynset.

Figure 10: Picture taken on the grazed site in Tynset.

The soil in the area sampled is mostly glacial/till deposits with varying thickness of cover from thin to places with greater amount, and continuous to incoherent (NGU, 2022).

Table 3: Grazer and count of animals, vegetation zone, vegetation section, vegetation type, quality of pasture and underlying bedrock for location Tynset.

LOCATION 11, TYNSET							
Grazer	**Grazer density**	**Grazing period**	**Vegetation zone**	**Vegetation section**	**Vegetation type**	**Quality of pasture**	**Underlying bedrock**
15 animals of Charolais Cows (Rekdal, 2018) 350 dekar	42.9 animals / km^2	Beginning of July - middle of August	middle boreal zone (Moen et al., 1998)	Slightly continental section	"Alpine lady-fern", "Bilberry-Birch woodland", "Meadow-Birch woodland".	Good - very good pasture	Quartzite with feldspar, slate of quartz, and partly with calcite and diabase (Rekdal, 2018).

2.3.3 Leksvik

The pasture belongs to the Hovland farm and are in Indre Fosen municipality in Trøndelag county. The pasture is marked at the map in figure 12, and in figure 11 the sampled location is marked for the grazed and the non-grazed site. In the outfield pasture 15 Aberdeen Angus cows utilize the pasture from the middle of May until the start of September (Rekdal, 2018), see table 4 for a summary of the properties of the location.

The outfield pasture falls in "middle boreal zone" vegetation zone, and slightly oceanic section (Moen et al., 1998). Mean annual precipitation over the period 1991-2021 841.5 mm, and mean annual temperature 6.1 °C, collected from the Norwegian database for weather statistics (Norway, 2022).

Figure 11: Plotted coordinates in the program QGIS and arranged into maps retrieved from the website statskart.no. The yellow tags points at the separate sites where plots were sampled.

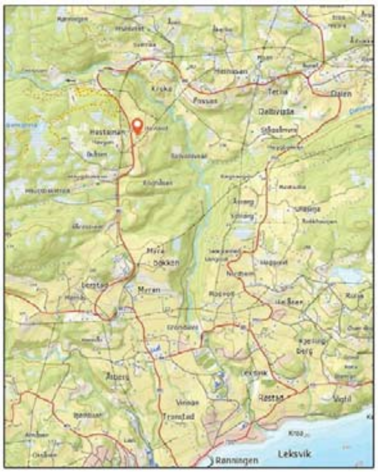

Figure 12: Topographic map showing the pasture (Rekdal, 2018).

Rekdal (2018) characterize the pasture as good and the main vegetation type as "Bilberry-Birch woodland", with features of "Meadow-Spruce woodland". The figure 13 and 14 is taken at the sites of the vegetation of the non-grazed site (figure 13) and of the grazed site (figure 14).


Figure 13: Picture taken on the non-grazed site in Leksvik.


Figure 14: Picture taken on the grazed site in Leksvik.

The underlaying bedrock in the area consisting of Garnet-mica schist to gneiss partly with hornblende and rusty colours caused by pyrite (NGU, 2022). The soil mainly consists of limnic deposits (NGU, 2022).

Table 4: Grazer and count of animals, vegetation zone, vegetation section, vegetation type, quality of pasture and underlying bedrock for location Leksvik.

LOCATION 12, LEKSVIK							
Grazer	**Grazing density**	**Grazing periode**	**Vegetation zone**	**Vegetation section**	**Vegetation type**	**Quality of pasture**	**Underlying bedrock**
15 Aberdeen Angus cow (Rekdal, 2018)	21.4 animals / km^2	Middle of May - the start of September	middle boreal zone (Moen et al., 1998)	Slightly oceanic section (Moen et al., 1998)	“Bilberry-Birch woodland”, with features of “Meadow-Spruce woodland”	Good	Garnet-mica schist to gneiss partly with hornblende and rusty colours caused by pyrite*

*Information collected from NGU’s database (NGU, 2022)

2.3.4 Korgen

The pasture is located in Hemnes Municipality and Nordland County, see figure 15 and 16. In the area approximately 60 cows of the breed Aberdeen Angus utilize the premises from the middle of June to the middle of September (Rekdal, 2018). The outfield pasture falls under the “northern boreal zone” vegetation zone and vegetation section “Slightly oceanic section” (Moen et al., 1998). Mean annual precipitation over the period 1991-2021 1716.3 mm, and mean annual temperature 3.5 °C, collected from the Norwegian database for weather statistics (Norway, 2022). In the area the underlaying bedrock is calcite marble (NGU, 2022), see table 5 for a summary of the properties of the location.

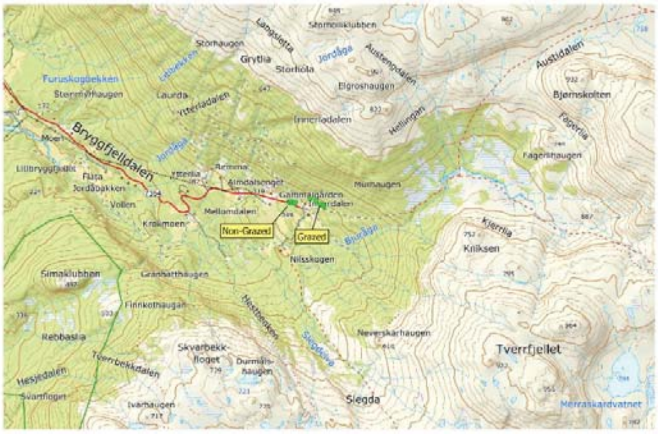

Figure 15: Plotted coordinates in the program QGIS and arranged into maps retrieved from the website statskart.no. The yellow tags points at the separate sites where plots were sampled.

Figure 16: Topographic map showing the pasture (Rekdal, 2018).

Rekdal (2018) characterize the vegetation type as "Meadow-Birch woodland", and the pasture as very good to good. For a visual overview of the vegetation of the non-grazed site see figure 17, and for the grazed site see figure 18.

Figure 17: Picture taken on the non-grazed site in Korgen.

Figure 18: Picture taken on the grazed site in Korgen.

Over the underlaying bedrock there is glacial deposits varying from great thickness to lower and incoherent (NGU, 2022).

Table 5: Grazer and count of animals, vegetation zone, vegetation section, vegetation type, quality of pasture and underlying bedrock for location Korgen.

LOCATION 13, KORGEN							
Grazer	**Grazing density**	**Grazing periode**	**Vegetation zone**	**Vegetation section**	**Quality of pasture**	**Vegetation type**	**Underlying bedrock**
60 cows of Aberdeen Angus	20 animals / km^2	Middle of June - middle of September	Northern boreal zone	Slightly oceanic section	very good - good	"Meadow-Birch woodland"	Calcite marble (NGU, 2022)

*Information collected from NGU's database (NGU, 2022)

2.3.5 Dønna

The pasture sampled are owned by Jørn Høberg and Eva Knarten Høberg. The farm belongs the municipality with the same name, Dønna, and Nordland County. A map of the pasture see figure 20. In the figure 19 the sampled sites grazed and non-grazed is marked at the map. The pasture is utilized from mid-June until the middle of September (Rekdal, 2018). The herd consists of around 60 animals of the breed Hereford (Rekdal, 2018), see table 6 for a summary of the properties of the location.

The island Dønna has two vegetation zones and the border between the two zones lays approximately where the samples were taken. The two vegetation zones are "middle boreal zone" and "southern boreal zone" (Moen et al., 1998). The same division of the island applies to vegetation section, half of the island, the west side, "Humid sub-section" and the other half "Markedly oceanic section" (Moen et al., 1998). Mean annual precipitation over the period 1991-2021 3053.7 mm, and mean annual temperature 6.26 °C, collected from Norway's database for weather statistics (Norway, 2022).

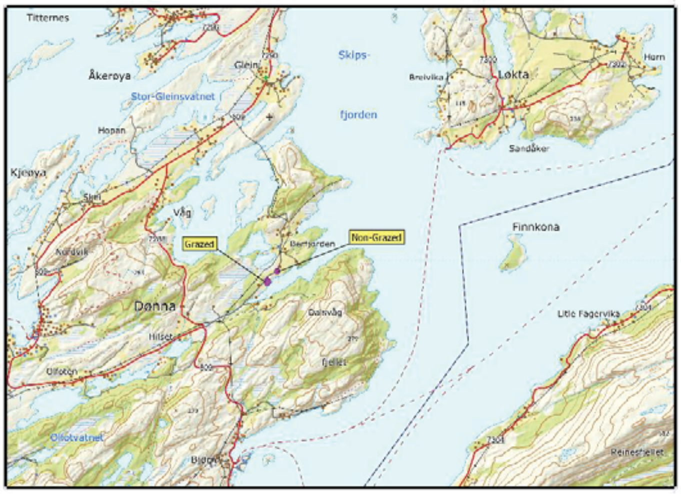

Figure 19: Plotted coordinates in the program QGIS and arranged into maps retrieved from the website statskart.no. The yellow tags points at the separate sites where plots were sampled.

Figure 20: Orthophoto showing pasture. The farm is located by arrow to the right (Rekdal, 2018).

Rekdal (2018) categorizes the vegetation as "Meadow-Birch woodland" in the sub-type "Low-herb woodland" in addition the type "Bilberry-Birch woodland" and the pasture quality as good. Visual overview of the vegetation at the non-grazed site is given in figure 21, and in figure 22 the grazed site.

Figure 21: Picture taken on the non-grazed site in Dønna.

Figure 22: Picture taken on the grazed site in Dønna.

In the area the underlaying bedrock is calcite marble, thus partly with thin layers of amphibolite or/in addition to Mica schist (NGU, 2022). The overlaying soil are composted of marine and beach deposits with varying depths, also some sand and stone/coarse fragments (NGU, 2022).

Table 6: Grazer and count of animals, vegetation zone, vegetation section, vegetation type, quality of pasture and underlying bedrock for location Dønna.

LOCATION 14, DØNNA							
Grazer	**Grazing density**	**Grazing periode**	**Vegetation zone**	**Vegetation section**	**Vegetation type**	**Quality of pasture**	**Underlying bedrock**
60 animals of Hereford (Rekdal, 2018)	18.2 animals / km^2	Mid-June - middle of September	"middle boreal zone" / "southern boreal zone" (Moen et al., 1998)	"Humid sub-section" / "Markedly oceanic section" (Moen et al., 1998)	"Meadow-Birch woodland" and "Bilberry-Birch woodland"	Good - less good	Calcite marble thin layers of amphibolite or/in addition to Mica schist*

*Information collected from NGU's database (NGU, 2022)

3. Method

3.1 Soil sampling

The soil samples were collected 21-28/7 and 6-9/9 in 2022. All samples were collected in collaboration between three scientists: Vegard Martinsen, Line Tau Strand and Jan Mulder from NMBU and me.

At each location two sets of samples with five plots each were collected. The two sets were divided, one in a grazed pasture and the other set of samples from a comparable but non-grazed area. The two sites, referred to as grazed and non-grazed, were compared on several characteristics as similar plant community composition, parent material, litter coverage, frequency of visible stones and boulders and most importantly the plants appropriateness for grazing hence the quality of the pasture. In addition, the soil was classified and registered in field at each site. The sampling process started with determination based on visual inspection and information about grazing frequency obtained from farmers. Soil sampling was performed in a similar method at both sites, allowing for a paired comparison between grazed and non-grazed outfields. The farms involved in the project are on a voluntary basis, therefore locations are not entirely randomly selected.

At each site, five plots (each ~1m^2) within an area of approximately 15 m^2 (deviations might occur) were randomly selected. At each of the five plots, five sub-plots were selected for soil sampling. One sub-plot in the center of each plot was selected for bulk density (BD) determination and four adjacent sub-plots were selected to collect soil for chemical analysis, see figure 23. All sub-plots were sampled down to a 30 cm depth using (1) a split-tube sampler, a corer with an inner diameter of 4.8 cm and full length of 45 cm for BD determination and (2) a smaller metal ring sampler in addition to an auger for the adjacent sub-plots. If the depth was less than 30 cm this was recorded. The organic layer with variable depth was separated from the mineral soil in each soil core and the mineral soil divided into three layers by depth; 0-10 cm mineral soil, 10-20 cm mineral soil and 20-30 cm mineral soil. Samples from the four sub-plots sampled for chemical analysis were pooled per depth, resulting in one composite sample per depth from each of the five plots. Sub-plots for BD determination and chemical analysis gave three or four samples, depending on whether it existed an organic layer. After the soil sampling the soil were collected in airtight plastic bags and shipped to Ås where they were stored in a refrigerator over the summer.

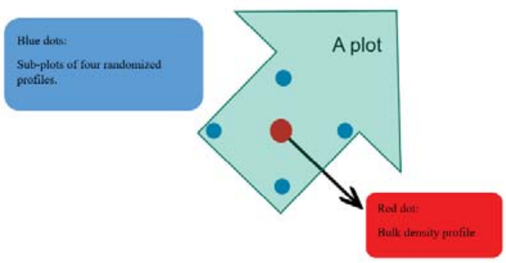

Figure 23: Figure of the setup of a sampling plot. The blue dots represent the four randomized profiles (sub-plots), and the red dot the bulk density sample.

3.2 Sample Preparation

Soil samples were stored in a refrigerator at 4°C, since drying was not possible right after collection. When dried in late summer the samples were placed in a drying cabinet for 2-4 days at 40 – 55 °C. The weight of all dried soil samples was recorded before and after sieving through a 2 mm sieve. Components with diameter > 2 mm were separated from the rest of the sample. The soil volume and weights before and after sieving were used to calculate natural bulk density (using weight before sieving) and fine-earth bulk density (using weight after sieving), see chapter 3.4.1. After calculation of BD, BD samples and the pooled samples from the adjacent sub-plots were mixed and thoroughly homogenized per depth and plot prior to further analysis. This means that after the pre-treatment the sample numbering referrers to the whole plot as a composite or bulked sample.

A small portion of every sample were ground to a fine powder. This was done using a Agat mortar. Every sample were grounded for four minutes and collected as a separate sample. This portion of the sample was now ground to a fine powder (<0.15 mm) for future analyses on total N and C. Between each crushing the Agat mortar were cleaned using a vacuum cleaner, brush and some paper towels.

3.3 Soil analyses

Analyses were performed in collaboration between me and the staff at the laboratory on NMBU. The analysis was performed on all plots, however for some analysis only selected layers in the plot were analyzed. Some analysis could not be performed on all desired samples because of size on sample. For a total overview of number of preformed sample analysis see appendix 1.

3.3.1 pH

On every sample there was performed a measurement of the pH. This was done in accordance with the method described by Krogstad (1992). The soil samples were carefully measured in soil spoons with known volume and placed into plastic beakers. Soil samples was diluted with deionized water in the ratio soil : water, in size 1 : 2.5, carefully shaken until all of the soil were mixed with water. Then the samples were left over night to achieve equilibrium. The next morning the plastic beakers got a new round of shaking and left for 10 minutes so that the bigger soil particles could settle. After these preparations the pH could be measured. A PHM210, standard pH meter, was used to perform the measurements. For calibration of the pH meter two standard buffers were used, one with pH 4 and for the other one pH 6.87. When preforming the actual measurements, it was always paid attention to the electrode, firstly that it did not come in direct contact with the soil, and carefully rinsed between measurements. Overview of count of samples, see appendix 1.2.

3.3.2 Dry matter

The method used for dry matter and loss on ignition are described by Krogstad (1992). Firstly, the used crucibles were weight and the results journaled. Thereafter, a small portion of each soil sample were weight and journaled into individually crucibles. The crucibles were put into a heating cabinet overnight and dried at 105 °C. The next morning the samples were weighed, and the dry matter was calculated using the following equation.

Equation 1:

$$Dry\ matter\ [\%] = \frac{(Dried\ soil\ included\ crucible\ [g]) - (Crucible\ [g])}{Soil\ before\ drying\ [g]} * 100$$

3.3.3 Loss on ignition (LOI)

The analysis of LOI continues right were the dry matter analysis ends. The dried soil is still placed in the same crucibles. These are now placed into a furnace oven, the heat was set to 550 °C and left overnight. The next morning the samples were taken out and weighed. The LOI_{corr} were calculated using equation 2. The factor used in the formula is based on the clay content of the sample. After conducting the grain distribution of the soil samples, the factor based on the clay content were subtracted from the LOI. The factor number is collected from Krogstad's method description (Krogstad, 1992), and implemented because clay chemically bind water that do not evaporates until 150 °C is reached (Krogstad, 1992). See appendix 1.3 for an overview of count of samples.

Equation 2:

$$LOI_{\ (corr)}[\%] = [\frac{(Dried\ soil\ included\ crucible\ [g]) - (Soil\ after\ included\ crucible[g])}{Soil\ before\ drying\ [g]} * 100] - \text{Factor}$$

3.3.4 Total Carbon (TotC) & Nitrogen (TotN)

The method used for analyzing for total carbon proposed by Allison and described in Nelson and Sommers (1983). Approximately 200 mg of the soil powder were packed into foil made of tin and analyzed by the instrument Leco CHN628. In the instrument the samples were exposed to high temperature, 1050 °C, thus undergoes a complete combustion. This means that all the carbon is oxidized to CO_2, then the gas is measured using infrared light (IR cell) (Nelson & Sommers, 1983).

For determination of the total amount of nitrogen in the samples the Dumas method were used (Bremner & Mulvaney, 1983). The same principle and soil powder as for total carbon, except the reaction in the instrument differs. In the case of nitrogen, the nitric oxide compounds (NO_X) are reduced to nitrogen gas (N_2) by using copper. Concentration of nitrogen gas are read by a thermal conductivity cell (TC cell) on the Leco CHN628 (Bremner & Mulvaney, 1983). The detection limit for C and N is 0.05%. See appendix 1.4 for an overview of count of samples. Sample count for both TOT-C and TOT-N, see appendix 1.4.

3.3.5 Total inorganic carbon (TotIC)

This analysis follows the same procedure as the analysis for Tot C. What separates these two analyses is the soil sample used. The purpose for this analysis is to find the portion of C that is inorganic. Therefore, only soil that measured a pH > 6.5 were selected. Samples in this category see appendix 1.5. The samples that met this criterion were collected after LOI analysis and run in the analysis instrument Leco CHN628. For this analysis it is assumed that the organic part of C disappeared during the period in the furnace oven.

The analysis was made on the assumption that the LOI process burn away the organic carbon, the resulting values of this analyze rresent the inorganic carbon (IC) content. By subtracting the TotIC from TotC the result is assumed to be the TotOC, see chapter 3.4.2.

3.3.6 Plant available macro-nutrients measured in ammonium lactate (AL-method)

The method used in this thesis are performed in accordance to method in Krogstad (1992) and are based on Egnérs AL-method. This method analyzes for the nutrients that is easily soluble, often also referred to as plant available. To extract these nutrients an extraction solution made of ammonium lactate (0.1 mol/l) and acetic acid (0.4 mol/l) and the pH of this mix are at 3.75 (Krogstad, 1992). 2.00 g of soil were weighted in glass bottles and added 40 ml ready-mixed solution. These glass bottles were laid lengthwise in a shaker. The shaker was set at 100 back- and forth movements a minute and left for 90 minutes. Meanwhile a setup of funnels and plastic bottles were prepared and paper filters with pore size <2 µm (Particle retention) were placed in all the funnels. After 90 minutes the filtration of the liquid started. The finished filtrated extract was analyzed in an IPC instrument. This analysis was performed on the organic layers and layer 0-10 cm, not the deeper layers, see appendix 1.6.

3.3.7 Hot water extractable carbon (HWEC)

The HWEC analysis performed in accordance with method described by Dong et al. (2021). Briefly, 4.5 g of dried soil were mixed with 45 mL deionized water. Because of the light properties of organic material in addition to a minor sample size some of the samples of the organic layer had a decreased in weight, hence the ratio soil : water was kept. The analyze performed after weighing were as following, adding deionized water, thereafter, shaking of the tubes for approximately 1 minute before set in a bath of hot water. The hot water held a temperature of 80 °C, and the tubes remained in the water for 16 hours. Then, all samples were centrifuged at a force of 4500 RPM for 10 minutes. Thereafter the solution was filtered using a plastic syringe to push the solution through a 0.45 µm filter. To complete the analysis the samples were analyzed by using a TOC-V SPN, Shimadzu instrument. This instrument heats the filtrate to 680 °C and the CO_2 gas is detected by an infrared detector. Sample count for HWEC analysis, see appendix 1.7.

3.3.8 Particle size distribution

In this thesis the method used are based on monochromatic laser radiation and the reflection from the different fractions of the soil. The different fractions in the soil sample reflects the electromagnetic radiation with different deflection. In the analysis the “LS 13 320 Laser Diffraction Particle Size Analyzer” were used. Before using the apparatus, 10.00 g of each soil sample of the 20-30 cm layer were weight, for count of samples see appendix 1.8. The samples were pre-treated with hydrogen peroxide 33% with 20 ml in each sample. Then the samples were heated to 90 °C until the reaction declined. Thereafter, 10 ml hydrochloric acid were added with water. This was left over night and the day after the water was removed. The samples were added 0.05 M $Na_4P_2O_7 * H_2O$, applied ultrasound for 3 minutes and stirred by a magnetic stirrer at 1500 rpm until the precipitate were dissolved. From this 10-20 ml of a representative portion of the sample were analyzed by the laser and repeated four times. The angle of the reflected rays is registered by up to 130 detectors, and the data are then interpreted as a fraction size and quantity (Brendryen, 2013). The analysis was conducted with the apparatus setting "Fraunerhofer". The fraction size is determined by the instrument based on the fraction reflection, therefore dependent on the shape of the particles. The apparatus calibrated based on spherical grain shape, therefore Brendryen (2013) points out that in this method the clay fraction tends to be underestimated in comparison to the sedimentation principle based on Stokes law.

3.4 Calculations

3.4.1 Bulk density calculations

For determination of bulk density the "undisturbed (intact) core method" were used (FAO, 2019). Since the fine earth >2 mm was used, the bulk density referred to in this thesis are fine earth bulk density (BD_{fine}). The BD_{fine} was calculated in accordance with the following equation 3.

Equation 3:

$$BD\left[\frac{g}{cm^3}\right] = \frac{Weight\ of\ fine\ earth\ [g]}{Area\ of\ the\ cross\ section, metal\ core\ (\pi r^2)[cm^2] * depth\ of\ layer\ [cm]}$$

3.4.2 Soil organic Carbon

Based on the assumption that organic fraction could be calculated by retracting the inorganic fraction from the total element organic concentration can be calculated. This was calculated using the equations 4-7. For samples with pH < 6.5 there is assumed that TOT-C equals TOT-OC, see table in appendix 1.5.

Equation 4:

$$\text{Weight TOT} - \text{E [g]} = \frac{\text{Weight dry soil [g]}}{[\frac{\text{TOT} - \text{E[\%]}}{100}]}$$

Equation 5:

$$\text{Weight TOT} - \text{IE [g]} = \frac{\text{Weight LOI soil [g]}}{[\frac{\text{TOTIE[\%]}}{100}]}$$

Equation 6:

$$Weight\ TOT - OC\ [g] = \text{TOT} - \text{C [g]} - \text{TOT} - \text{IC [g]}$$

Equation 7:

$$TOT - OC\ [\%] = \left[\frac{Weight\ OC\ [g]}{Weight\ dry\ soil\ [g]}\right] * 100$$

3.4.3 Soil organic carbon and nitrogen stocks

The soil organic of element (E) were calculated based on volume, hence the bulk densities and depth of layers. Therefore, the stocks are mass per area in unit (kg m^{-2}), hence always given simultaneously with specified layer depth. This was completed applying the same procedure for both soil organic carbon and nitrogen stocks (SOC, SON), hence inserted desired element-concentration into equation 8. The organic fraction of elements is calculated using formulas in chapter 3.4.2. In addition, the SOC- and SON-stock were calculated for the entire profile, hence from the organic-layer down to 30 cm depth of mineral layer. This was done by summarizing the result for each layer until the sum of the entire profile.

Equation 8:

$$E_{(fine\_earth)}\ stocks\ \left(\frac{kg}{m^2}\right) = [Bulk\ density\ _{(fine_{earth})}\left(\frac{g}{cm^3}\right) \times E - consentration\,\frac{g}{100g} \times Soil\ depth\ (cm)] \times (10\,\frac{\frac{kg}{m^2}}{\frac{g}{cm^2}})$$

3.4.4 Ratio of Carbon/Nitrogen (CN)

The ratio between Carbon and Nitrogen were calculated using equation 9. In this equation the organic fraction of the element was used, see chapter 3.4.2.

Equation 9:

$$C\!:\!N - ratio = \left[\frac{TOT-OC\ [\%]}{TOT-ON\ [\%]}\right]$$

3.4.5 Nutrient stocks

Elements of nutrient (Ca, K, Mg and P) stocks were calculated based on volume, hence the bulk densities and depth of layers, equation 10. Therefore, the stocks are given in mass per area simulant as with specified layer which gives the stocks the unit (g m^{-2}).

Equation 10:

$$E_{(fine\_earth)}\ stocks\ \left(\frac{g}{m^2}\right) = [Bulk\ density\ _{(fine_{earth})}\left(\frac{g}{cm^3}\right) \times E - consentration\,\frac{mg}{kg} \times Soil\ depth\ (cm)] \times (10)$$

3.5 Statistical Analyses

Two-way Analysis of Variance (two-way ANOVA) with locations (five levels) and grazing (two levels) as categorical variables was used to assess differences in %SOC, BD, pH, SOC-stock, HWEC-stock, SON stocks, CN-ratio for each of the four soil layers separately. A whole profile comparison was additionally implemented for SOC-stock and HWEC-stock. Regarding the nutrients no more than the organic layer and mineral 1 layer (0-10 cm) are used, but for Calcium stocks, Potassium stocks, Magnesium stocks and Phosphorus stocks. For thickness of organic layer only organic layer were tested, not the mineral layers.

The treatment (Gr/NG) and factor (average of CN, average of the sum of silt and clay, MAP and MAT) was used to assess difference in SOC-stock for the whole profile. When testing sum of silt and clay the organic layer were left out of the test.

Following a model reduction using backwards stepwise elimination of non-significant terms, differences between treatments were assessed by means of pairwise comparisons using t-tests with adjustment for multiplicity (α=0.05). Comparisons of means with adjustment of p-values for multiple comparisons were conducted using the R extension package lsmeans (Russell, 2016).

Linear regression was used for exploring relationships between LOI and %SOC. The statistical software "R", version 2021.09.1 (R-Core-Team, 2022) was used for all statistical analysis.

4. Results

4.1 Location description and soil characteristics

4.1.1 General location description and visual findings

All through fieldwork visual registrations were made. The results from these findings will be listed by location in addition in the table 7.

Rena

The frequency of visible stones and boulders were registered as equally at both sites, hence 25% of visible stones and boulders. The soil sampled were classified in field as a Cambisol.

At location Rena the vegetation was dominated by gras and cleared forest of Spruce. The main gras species registered were Matgrass (nardus stricta) and tufted hairgrass. Other plant species seen were wild raspberry and tormentil. The grazed site was visibly embossed by grazers. At the site there was stumps in addition to replanted Spruce.

Tynset

Vegetation observed at the non-grazed site can be described as a forest consisting mainly of Birch, but also sections of coniferous trees as Pine, Norwegian spruce and Juniperus communis. Herbs observed at the ground as bottom vegetation were amongst other species wood cranesbill, arctic starflower, meadow buttercup, some moss, blueberries, tussock grass.

At the grazed site the forest tended to be a bit more open because of less density of trees, thus composition of tree and herb species remained the same.

The frequency of visible stones and boulders were registered as equally at both sites, 10-15% of visible stones and 0-2% of seen boulders. The soil at the site were classified in field as a Cambisol.

Leksvik

In Leksvik at the grazed site species as tussock grass, meadow buttercup, blueberries, raspberries and different mosses and ferns were registered. Also, at the pasture the spruce plantation had been cleared to a greater extent than at the non-grazed site. At the non-grazed site, there were also seen some specimens of Birch. The vegetation at both sites were quite similar, thus in the non-grazed site the wavy hair-grass bloomed making the assumption that the site had not been grazed certain.

The soil was classified in field as a Cambisol. No observations were made of stones and boulders in the visual registration.

Korgen

The soil was classified in field as a Cambisol. On the grazed site the frequency of visible stones was estimated to approximately 10%, thus not observed any boulders. At the non-grazed site, the ground was covered in high herbs which made the visual estimation somewhat challenging, thus both visible stones and boulders were set to be between 0-2%.

At the grazed site the birch appeared as the most frequent tree species, thus occasionally elements of the tree species Spruce. The site appeared lush with a lot of herbs like wood cranesbill, meadow buttercup and northern wolf's-bane.

The non-grazed site also had a great variety in large herbs, some of the species seen were mead wort, northern wolf's-bane, wood cranesbill, Bird's Foot -Trefoil and different fern species. The composition of trees was quite comparable to the grazed site, although some Willows were also registered.

Dønna

For location Dønna the soil was classified in field as a Glaysol. The frequency of boulders was estimated for both sites to be 0-2%. Visible stones were estimated on grazed site to 5%, thus for the non-grazed site to 2-5%.

At the grazed site the area had Birch and Juniperus, also planted with Sitka spruce (Picea sitchensis). Less herbs seen, mostly grasses.

At the non-grazed site, the variety in herbs was a bit greater, registered species was wood cranesbill, mead wort, meadow buttercup, dandelion and wood horsetail. The most common tree at the site were Birch and goat willow.

Table 7: The table contains a summary of the visual finding for all locations.

Location	***Boulders [%]***		***Stones [%]***		***Soil type***	***Key species***	
	Gr	**NG**	**Gr**	**NG**		**Gr**	**NG**
Rena	25	25	25	25	Cambisol	Visibly embossed by grazers, similar species	Cleared forest of Spruce, Matgrass, tufted hairgrass, wild raspberry, tormentil
Tynset	0-2	0-2	10-15	10-15	Cambisol	Less tree density, similar species	Birch, Pine, Norwegian spruce, Juniperus communis, wood cranesbill, arctic starflower, meadow buttercup, some moss, blueberries, tussock grass
Leksvik	0	0	0	0	Cambisol	Cleared forest, some Birch. Tussock grass, meadow buttercup, blueberries, raspberries, mosses, ferns	Wavy hair-grass blooming
Korgen	0	0-2	10	0-2	Cambisol	Birch, some Spruce, lush with cranesbill, meadow buttercup and northern wolf's-bane	Willows in addition to Birch, large herbs
Dønna	0-2	0-2	5	2-5	Glaysol	Birch, Juniperus, Sitka, mostly grasses	Birch and goat willow, greater variety in herbs

4.1.2 Particle size distribution

The grain distribution determines the soil texture type. In the figure 24 below the distributions are averaged by location, site and plots (n=5). The result from this analysis was used to determine soil texture type.

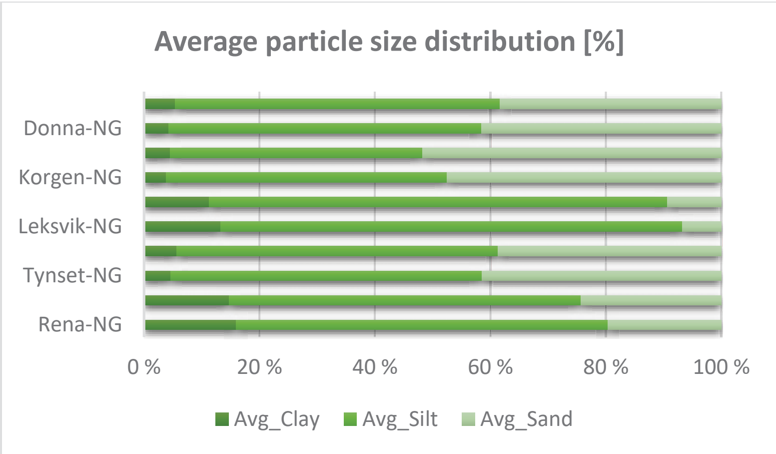

Figure 24: Average particle size distribution in percent [%] in layer 20-30 cm of all profiles (n=5) sorted by site (grazed and non-grazed). The bars illustrate the distribution of each location and their sites. The dark green colour represents the clay fraction [< 0.002 mm], the medium green the silt fraction [0.002-0.06 mm] and the light green colour the sand fraction [0.06-2 mm].

4.1.3 Soil type based on soil texture

Soil type based on texture refers to the mechanical composition, hence not on the geologically formation. The Norwegian soil texture triangle were utilized, hence the soil types are defined after the Norwegian classification and translated to English. Even though the soil texture types are translated they are not based on USDA classification etc. The soil types of each location and site are listed in table 8 and are based on the average grain distribution of mineral layer 20-30 cm of each location and site.

For location Rena, Korgen and Dønna the soil types are equal in both sites (Gr, NG). In location Tynset the two sites were given different soil types since the non-grazed site contained a small proportion more sand relative to both clay and silt fraction. Additionally, location Leksvik differ by site, containing a bit more clay and less sand at the non-grazed site.

Table 8: Soil type based on soil texture for each location with both sites, grazed and non-grazed. The soil types are given in both English and Norwegian.

	Treatment	
	Gr	**NG**
Location	**Soil type based on soil texture**	
Rena	Silty loam (Siltig lettleire)	Silty loam (Siltig lettleire)
Tynset	Loamy sand (Siltig sand)	Sandy loam (Sandig silt)
Leksvik	(Silt)	Silty loam (Siltig lettleire)
Korgen	Loamy sand (Siltig sand)	Loamy sand (Siltig sand)
Dønna	Sandy loam (Sandig silt)	Sandy loam (Sandig silt)

4.1.4 pH

For each location, site and layer the average were calculated. The result is shown in figure 25 displaying some general differences between sites at each location. Leksvik location has a low variation in measurements of pH compared to the other locations. Location Korgen also display variations in results, thus higher in the non-grazed plots than the grazed ones. At this site there were only one plot containing an organic layer, hence no box displayed in the figure.

The pH-values in all layers are not significantly (p>0.05) associated with treatment (Gr/NG), see appendix 4.3. On the other hand, the pH-values are significantly different between locations in all layers.

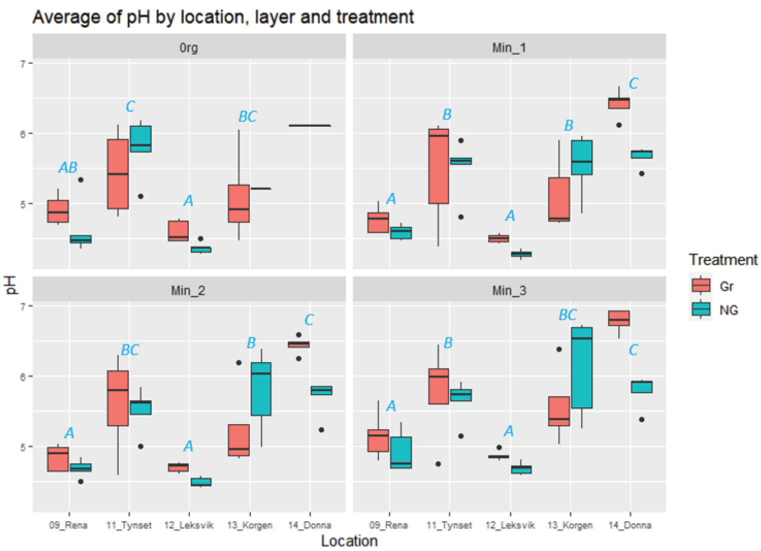

Figure 25: Average pH of layer by treatment and location. The locations are grouped, and the name is found on the x-axis. The layers are grouped under frame found on top, respectively organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm). The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.2. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxplot represents the median of the category, and the boxplots frames samples from lower quartile (median - 25%) to upper quartile (+ 25%). The whiskers present an additional +/- 25 %. Uppercase italic blue letters indicate a significant difference between locations (*A, B, AB*). Groups with distinct letters are significantly different, see appendix 4.3.

4.1.5 C concentration [%] in profile and distribution between organic and inorganic

Analysis of total-C were determined on all samples. Additionally, samples measured pH >6.5 were analyzed for total-IC, see chapter 3.4.2. The distribution of carbon between the fractions organic and inorganic are shown in figure 26. As the figure shows the only locations that contained inorganic carbon is Dønna and Korgen.

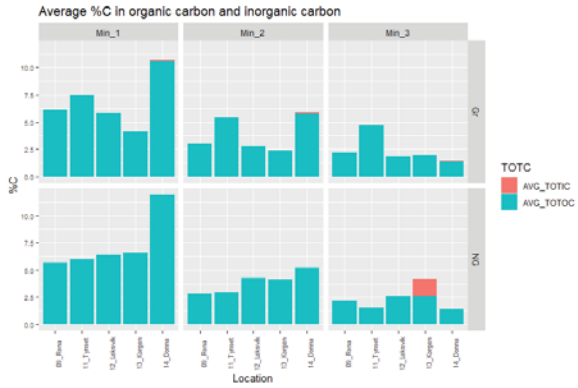

Figure 26: Average precent of carbon, divided into inorganic (red) fraction and organic (blue) fraction. The bars show the average in samples in the same category of layer, treatment and location. The locations are grouped, and the name is found on the x-axis. Layers are grouped by frame on top, respectively mineral later 0-10 cm (Min_1), mineral layer 10-20 cm (Min_2) and mineral layer 20-30 cm (Min_3). The organic layer is not shown in the figure. Number of samples in each category displayed in the figure, see appendix 1.4 and 1.5.

4.2 Differences between location and grazing in selected soil properties

4.2.1 Average thickness of organic layer

The average of the thickness of the organic layer is shown in figure 27. The soil at location Dønna did not contain an organic layer, therefore displayed without bars. As shown in the figure the average thickness of the organic layer in Leksvik is thicker than all other locations.

The treatment (Gr/NG) is not significantly ($p=0.0634$) associated with different thickness of the organic layer. A significant ($p= 4.13e-11$) difference between locations were found, see appendix 4.5. Rena, Tynset and Korgen belongs to group A and Leksvik group B.

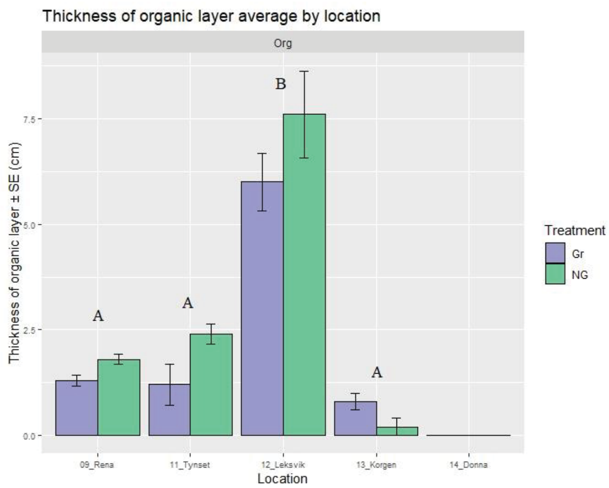

Figure 27: Average thickness of the organic layer [cm] ± standard error (SE) by treatment and location. The bars illustrate the thickness of the organic layer sorted by sites, grazed (blue) and non-grazed (green). The results are averaged by plots (n=5), no organic layer was counted as a result. Dønna lacked organic layer. Capital letter indicates the difference between location (A, B). Groups with distinct letters are significantly different.

4.2.2 Bulk density of the fine earth

The results of the calculations of the fine-earth bulk densities (BD) are shown in figure 28. In general, the BD increases with depth at all locations.

By testing all locations combined there was found a significant relationship between treatment and BD in the top two layers; organic layer (p=0.025677) and mineral 0-10 cm (p= 0.0165), hence difference between sites. In addition, there is a significant (p<0.05) relationship between location and BD in every layer, see appendix 4.4 and table in appendix 5.

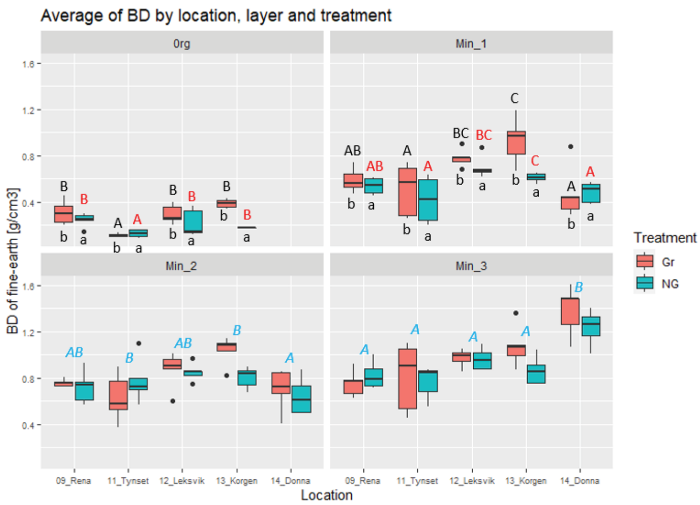

Figure 28: Average BD of layer by treatment and location. The locations are grouped, the name is found on the x-axis. The layers are grouped under frame found on top, respectively organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm). The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.1. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxplot represents the median of the category, and the boxplots frames samples from lower quartile (median - 25%) to upper quartile (+ 25%). The whiskers present an additional +/- 25 %. In addition, lower case letters by the average value represents a difference between treatments (Gr/NG) within each location and the letter the difference between category (a, b, ab, c). Uppercase italic blue letters indicate a significant difference between locations (*A, B, AB*). Uppercase letters in black indicates differences between locations of the grazed outfields (A, B, C, AB, BC), and uppercase red letters indicate differences between locations for the non-grazed outfields (A, B, C, AB, BC). Different letters indicate differences at a level of significance p<0.05.

4.2.3 %SOC concentration by layers

The figure 29 illustrate the average SOC concentration in percent [%]. As the figure shows the organic layers displays the greatest variation between samples in the same category and concentrations. There was not found a significant relationship between treatment and SOC-concentration in any layers (p<0.05). Difference between locations is significant for the organic layer (p= 3.93e-06) and the mineral 1 (0-10 cm) layer (p= 4.85e-05), see appendix 4.6 and table in appendix 5.

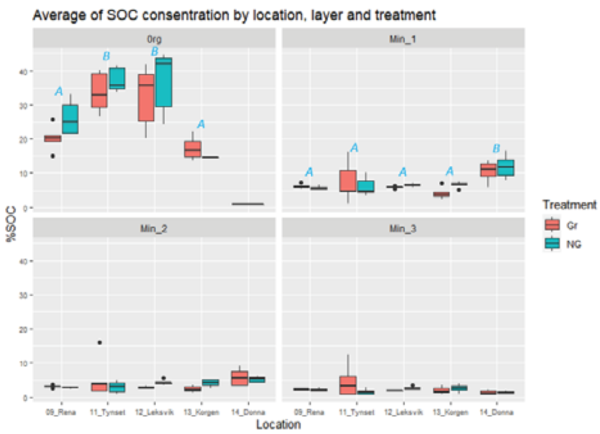

Figure 29: Average concentration of SOC in percent [%] of each layer by treatment and location. The locations are grouped, and the name is found on the x axis. The layers are grouped under frame found on top, respectively organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm). The colour on boxes determines the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.4. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxplot represents the median of the category, and the boxplots frames samples from lower quartile (median - 25%) to upper quartile (+ 25%). The whiskers present an additional +/- 25 %. Uppercase italic blue letters indicates a significant difference between locations (*A, B, AB*). Different letters indicate differences at a level of significance p<0.05.

4.2.4 Soil organic Nitrogen (SON) stock by layer

In figure 30 the average SON stock by category is plotted, see appendix 6. The category consists of location, layer and site (treatment, Gr/NG). The organic layer in Leksvik differ from the other locations by having a much higher SON stock. As the standard error bars shows, there is also the greatest variation between samples.

Generally, there was not found a significant (p>0.05) relationship between treatment (Gr/NG) and SON-stock in any layer. Although, there was a significant difference between locations in the organic layer (p= 2.2e-09), mineral 1 (0-10 cm) layer (p= 3.75e-08) and mineral 2 (10-20 cm) layer (p= 0.00365). In the mineral 3 (20-30 cm) layer the difference between locations is not significant.

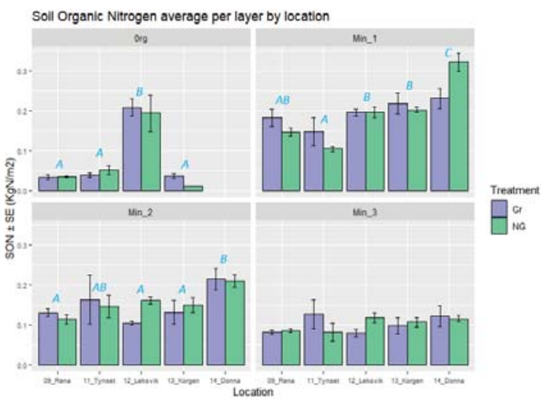

Figure 30: Average SON stock [kgC/m2] ± standard error (SE) by category of location, layer and site (treatment, Gr/NG). Grazed (Gr) sites display as a blue colour, non-grazed (NG) sites as green. Both sites stacked besides each other to their location belongings. The locations are grouped, and the name is found on the x-axis. Layers are divided by frame on top, respectively organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm) given in the frame titles. Number of samples in every category, see table in appendix 15. In addition, uppercase italic blue letters indicate a significant difference between locations within each layer (*A, B, AB*). Different letters indicate differences at a level of significance p<0.05. For mineral_3 20-30 cm there was not no significant difference.

4.2.5 Carbon:Nitrogen (CN) ratio by layer

The ratio of CN for of each layer by treatment and location is shown in figure 31, also see appendix 7. All locations and sites carry the same pattern of having the highest ratio in the organic layer, then decrease with depth. Korgen in site grazed is the only exception, hence increases by depth at the grazed site.

When tested all locations collectively the organic layers were significant (p=1.27e-05) between sites, indicating a relationship between treatment and CN-ratio. The mineral layers (mineral 1 0-10 cm, mineral 2 10-20 cm and mineral 3 20-30 cm) not found to significantly differs. All layers found significantly different between locations (p<0.05), see appendix 4.12. The organic layer also showed a significant (p=0.0103) value that indicate that the relationship between treatment and CN-ratio depends on location.

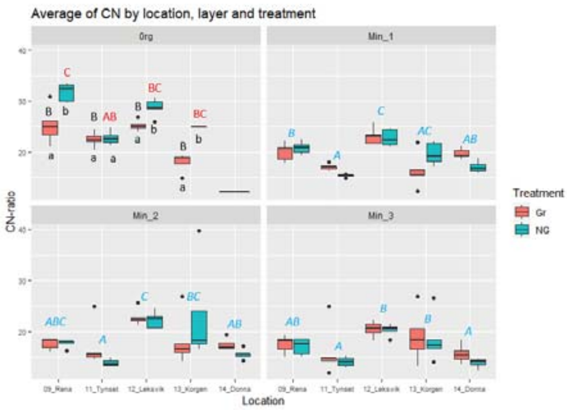

Figure 31: Average C:N ratio of each layer by treatment and location. The locations are grouped, and the name is found on the x-axis. The layers are grouped under frame found on top, respectively organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm). The colour on boxes determines the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 15. The boxplots display the maximum and minimum by fully drawn line and outliers is shown with a dot. Horizontal line inside the boxplot represents the median of the category. In addition, lower case letters by the average value represents a significant difference between treatments (Gr/NG) within each location and the letter the difference between category (a, b, ab, c). Uppercase italic blue letters indicate a significant difference between locations (*A, B, AB*). Uppercase letters in black indicates differences between locations of the grazed outfields (A, B, C, AB, BC), and uppercase red letters indicate differences between locations for the non-grazed outfields (A, B, C, AB, BC). Different letters indicate differences at a level of significance p<0.05.

4.3 Variations in soil organic carbon (SOC) stocks by location and grazing

4.3.1 Soil organic carbon stock in profile

In figure 32 the average of SOC-stock in [Kg/m^2] for the whole profile, sorted by treatment and location are plotted, for average numbers see appendix 6. There was not found a significant difference between sites (NG/Gr) for the SOC-stock in the whole profiles, thus a significant difference between locations (p=2.4e-10), see appendix 4.1.

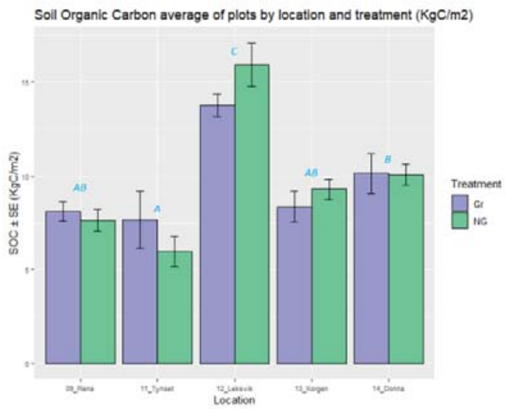

Figure 32: Average SOC stock [kgC/m2] ± standard error (SE) of whole profile classified by treatment and location. Grazed (Gr) sites display as a blue colour, non-grazed (NG) sites as green. Both sites stacked besides each other to their location belongings. Number of samples for every bar; n=5. In addition, uppercase italic blue letters indicate a significant difference between locations independent of site (Gr/NG) (*A, B, AB*). Different letters indicate differences at a level of significance p<0.05.

4.3.2 Soil organic carbon stock by treatment and layer

In figure 33 the average SOC-stocks by layer, location and site (treatment, Gr/NG) are shown, see appendix 6. The difference between sites (treatment Gr/NG) is not significant (p>0.05) for any of the layers. On the contrary there is a significant difference between the locations in the organic layer (p= 1.73e-09), the mineral 1 (0-10 cm) layer (p= 2.47e-09) and mineral 2 (10-20 cm) layer (p= 0.0177). The deepest mineral layer is not significantly different between locations, see appendix 4.1.

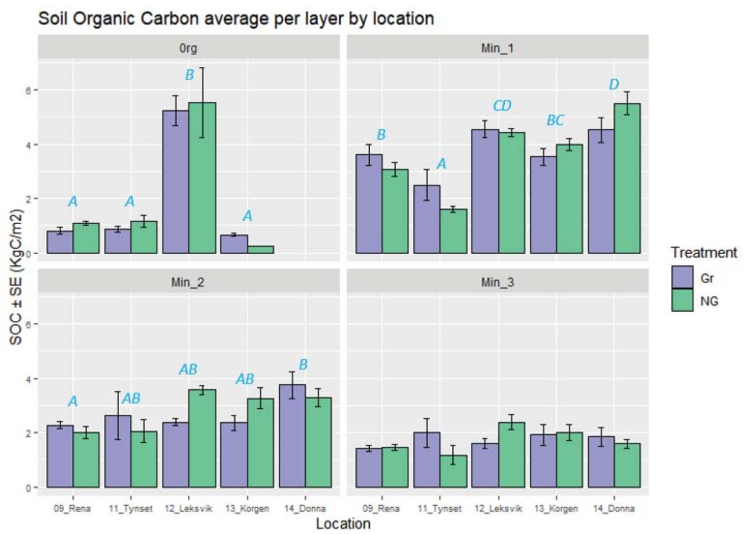

Figure 33: Average SOC stock [kgC/m2] ± standard error (SE) by category of location, layer and site (treatment, Gr/NG). Grazed (Gr) sites display as a blue colour, non-grazed (NG) sites as green. Both sites stacked besides each other to their location belongings. The locations are grouped, and the name is found on the x-axis. Layers are divided into organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm) given in the frame titles. Number of samples in every category, see table in appendix 15. In addition, uppercase italic blue letters indicate a significant difference between locations within each layer (*A, B, AB*). Different letters indicate differences at a level of significance p<0.05.

4.3.3 Soil organic carbon stock distribution in soil profiles

In figure 34 the distribution of the SOC stocks in the profile is shown. For numeric presentation of numbers, see appendix 2.3.

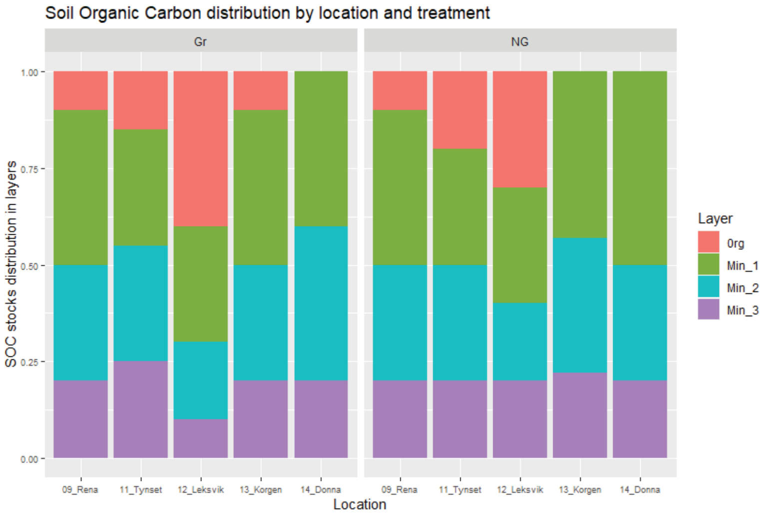

Figure 34: Average SOC stock distribution in profile [%] by location and treatment. The profile consists of an average of 5 plots in each category of location and site. The profile is divided into the organic layer (red), mineral layer 0-10 cm (green), mineral layer 10-20 cm (blue) and mineral layer 20-30 cm (purple). The location name is given on the x-axis and the heading frame the treatment, hence grazed and non-grazed (Gr/NG). Number of samples (n) in each category, see appendix 15.

4.3.4 HWEC-stock (Labile SOC-stock) average of profile

The HWEC-stocks are viewed as the carbon fraction is soil that is more sensitive to management change therefore can be used as a measure of dynamics in SOC (Dong et al., 2021).

In figure 35 the average of whole profile (all layers) separated by treatment and location are shown. None of the locations is showing the greatest HWEC-stock at the grazed site, hence the HWEC fraction is higher in the non-grazed sites. By comparing the whole profile a significantly ($p= 0.000559$) difference between the sites, that is treatment (Gr/NG). By comparing locations there was also found a significantly ($p< 2e-16$) difference, see appendix 4.2. In addition, there was found a significant interaction between location and treatment (Gr/NG), which indicates that the relationship between location and HWEC-stocks depends on whether the area is grazed or not.

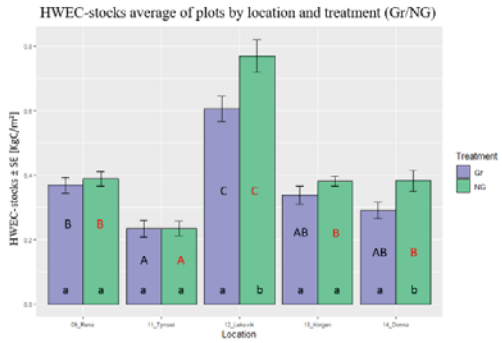

Figure 35: Average HWEC-stock [kgC/m2] ± standard error (SE) by plots classified by treatment and location. Grazed (Gr) sites display as a blue colour, non-grazed (NG) sites as green. Both sites stacked besides each other to their location belongings. Number of samples for each category, n=5. In addition, lower case letters by the average value represents a significant difference between treatments (Gr/NG) within each location and the letter the difference between category (a, b, ab, c). Uppercase letters in black indicates differences between locations of the grazed outfields (A, B, C, AB, BC), and uppercase red letters indicate differences between locations for the non-grazed outfields (A, B, C, AB, BC). Different letters indicate differences at a level of significance p<0.05.

4.3.5 Hot water extractable carbon (HWEC) stock by treatment and layer

In figure 36 the HWEC-stocks average by category is shown, for numeric display see appendix 6. The category consists of location, layer and site (treatment, Gr/NG). There was not found a significant (p>0.05) difference in HWEC-stocks between sites (Gr/NG) in the organic layers. In contrast all mineral layers are significantly (p<0.05) different between sites (Gr/NG), see appendix 4.2.

Comparing locations, the content of HWEC-stock in the organic layers is significantly (p= 1.53e-08) different. The mineral 2 (10-20 cm) also show a significantly (p= 0.036095) difference between locations. The mineral 1 (0-10 cm) and mineral 3 (20-30 cm) not significant (p>0.05) between locations. Additionally, for the mineral 2 (10-20 cm) a significant (p= 0.033852) interaction between site (treatment, Gr/NG) and location, hence meaning that the relationship between site and HWEC-stock depends on the location, see appendix 4.2.

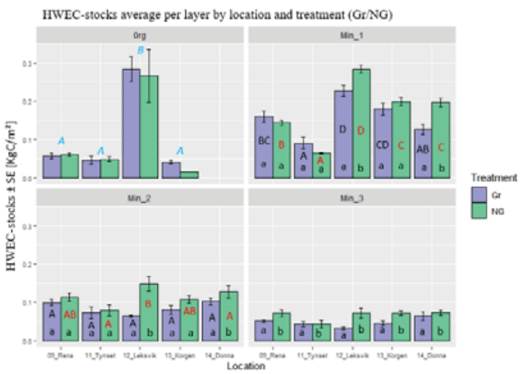

Figure 36: Average HWEC-stock [kgC/m2] ± standard error (SE) by category of location, layer and site (treatment, Gr/NG). Grazed (Gr) sites display as a blue colour, non-grazed (NG) sites as green. Both sites stacked besides each other to their location belongings. The locations are grouped, and the name is found on the x axis. Layers are divided into organic layer, min_1 (0-10 cm), min_2 (10-20 cm) and min_3 (20-30 cm) given in the frame titles. Number of samples in every category, see table in appendix 15. In addition, lower case letters by the average value represents a significant difference between treatments (Gr/NG) within each location and the letter the difference between category (a, b, ab, c). Uppercase italic blue letters indicate a significant difference between locations (*A, B, AB*). Uppercase letters in black indicates differences between locations of the grazed outfields (A, B, C, AB, BC), and uppercase red letters indicate differences between locations for the non-grazed outfields (A, B, C, AB, BC). Different letters indicate differences at a level of significance p<0.05.

4.3.6 Hot water extractable carbon (HWEC) stock distribution in soil profiles

In figure 37 the average distribution of the HWEC-stocks in profiles is shown, for numeric presentation see appendix 2.2.

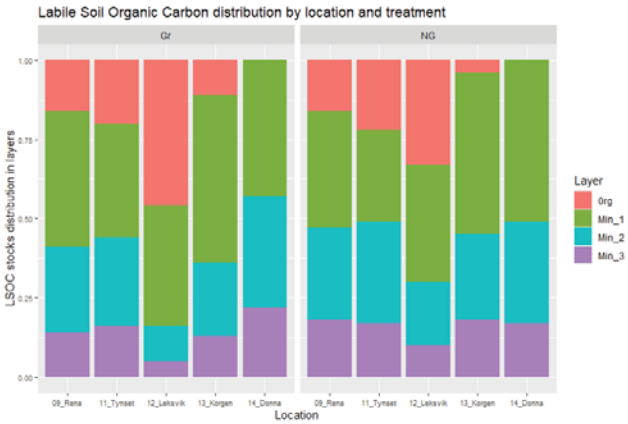

Figure 37: Average HWEC-stock distribution in profile [%] by location and treatment. The profile consists of 5 plots in each category of location and site. The profile is divided into the organic layer (red), mineral layer 0-10 cm (green), mineral layer 10-20 cm (blue) and mineral layer 20-30 cm (purple). The location is given on the x-axis and the heading frame the treatment, hence grazed and non-grazed (Gr/NG). Number of samples n in each category, see appendix 15.

4.4 Makro nutrients

4.4.1 Calcium (Ca) stocks

In figure 38 the average Ca-stocks is shown. As shown in the figure, only organic layer and mineral 1 (0-10 cm) were analyzed. Overall, there was not found a significant ($p>0.05$) relationship between treatment (Gr/NG) and Ca-stock in neither of the layers Thus, there is a significant ($p<0.05$) difference between the Ca-stock in locations independent of sites (Gr/NG), see appendix 4.8.

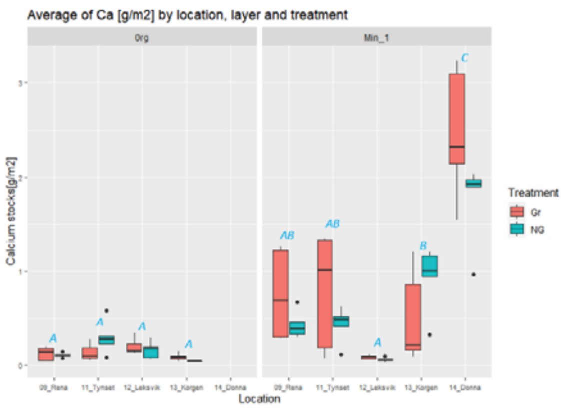

Figure 38: Average Ca-stocks of layer by treatment and location. The locations are grouped, the name is found on the x-axis. The layers are grouped under frame found on top, respectively organic layer and min_1 (0-10 cm) The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.6. Notice that location Dønna do not contain an organic layer, and that Korgen, non-grazed site only contain one sample. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxes represents the median of the category. In addition, uppercase italic blue letters indicate a significant difference between locations within each layer (*A, B, AB*). Different letters indicate differences at a level of significance $p<0.05$.

4.4.2 Potassium (K) stocks

In figure 39 the average K-stocks is shown. Overall, there was not found a significant ($p>0.05$) relationship between treatment (Gr/NG) and K-stock in neither of the layers. On the contrary, the relationship between K-stock and location is significant ($p>0.05$) for both the organic layer and the mineral 1 (0-10 cm) layer, see appendix 4.10.

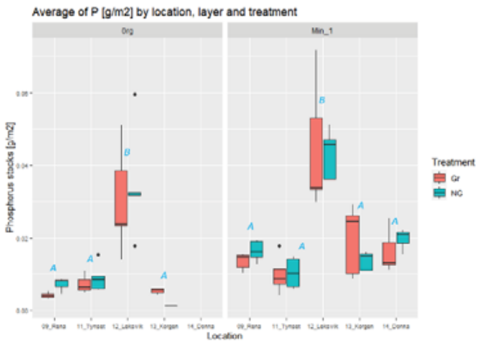

Figure 39: Average K-stocks of layer by treatment and location. The locations are grouped, the name is found on the x axis. The layers are grouped under frame found on top, respectively organic layer and min_1 (0-10 cm) The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.6. Notice that location Dønna do not contain a organic layer, and that Korgen, non-grazed site only contain one sample. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxes represents the median of the category. In addition, uppercase italic blue letters indicate a significant difference between locations within each layer (*A, B, AB*). Different letters indicate differences at a level of significance $p<0.05$.

4.4.3 Magnesium (Mg) stocks

In figure 40 the average Mg-stocks is shown. Overall, there was not found a significant ($p= 0.947$) relationship between treatment (Gr/NG) and Mg-stock in the organic layer. On the contrary, the sites were significantly ($p= 0.00458$) different in the mineral 1 (0-10 cm) layer. For both layers the difference between locations were significant ($p<0.05$), see appendix 4.9.

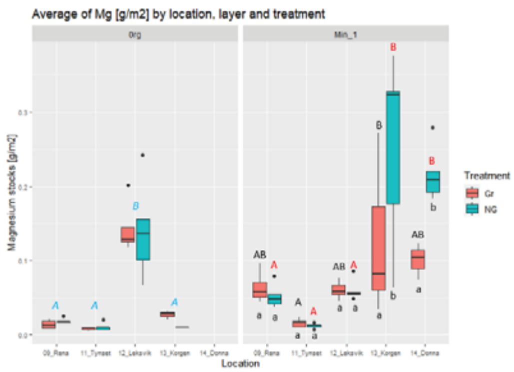

Figure 40: Average Mg-stocks of layer by treatment and location. The locations are grouped, the name is found on the x axis. The layers are grouped under frame found on top, respectively organic layer and min_1 (0-10 cm) The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.6. Notice that location Dønna do not contain a organic layer, and that Korgen, non-grazed site only contain one sample. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxes represents the median of the category. In addition, lower case letters by the average value represents a significant difference between treatments (Gr/NG) within each location and the letter the difference between category (a, b, ab, c). Uppercase italic blue letters indicate a significant difference between locations (*A, B, AB*). Uppercase letters in black indicates differences between locations of the grazed outfields (A, B, C, AB, BC), and uppercase red letters indicate differences between locations for the non-grazed outfields (A, B, C, AB, BC). Different letters indicate differences at a level of significance $p<0.05$.

4.4.4 Phosphorus (P) stocks

In figure 41 the average P-stocks is shown. Overall, there was not found a significant relationship between treatment (Gr/NG) and P-stock in neither of the layers. In contrast, there was a significant difference between locations in both organic layer (p= 1.58e-07) and the mineral 1 (0-10 cm) layer (p= 6.68e-13), see appendix 4.11.

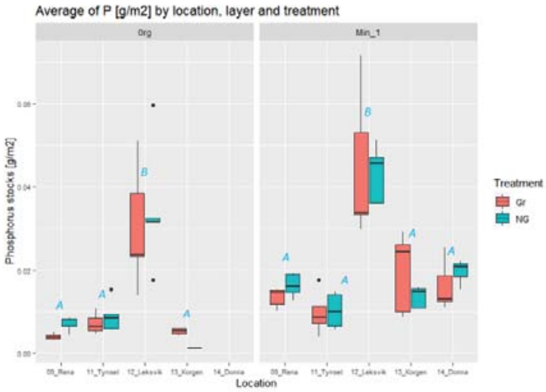

Figure 41: Average P-stocks of layer by treatment and location. The locations are grouped, the name is found on the x axis. The layers are grouped under frame found on top, respectively organic layer and min_1 (0-10 cm) The colour on boxes determine the treatment, grazed (red) and non-grazed (blue). Number of samples in each category displayed in the figure, see appendix 1.6. Notice that location Dønna do not contain a organic layer, and that Korgen, non-grazed site only contain one sample. The boxplots display the maximum and minimum by fully drawn line ad outliers is shown with a dot. Horizontal line inside the boxes represents the median of the category. In addition, uppercase italic blue letters indicate a significant difference between locations within each layer (*A, B, AB*). Different letters indicate differences at a level of significance p<0.05.

4.5 Relationships and interactions between factors

4.5.1 Relationship between Soil organic carbon concentration (%SOC) and loss on ignition (LOI)

In the figure 42 the correlation between %SOC and LOI is plotted for all samples divided only by location. As the figure shows the relationship between these two variables is strong from lowest in Tynset (r^2=0.89) highest in Leksvik and Rena (r^2=1).

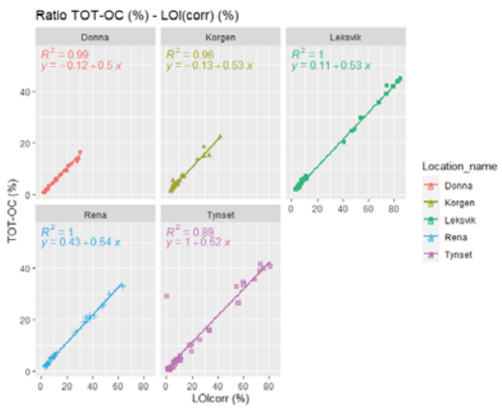

Figure 42: Correlation coefficient and linear relationship between TOT-OC and $LOI_{(corr)}$ for all samples by location. Rena n=40, Tynset n=40, Leksvik n=40, Korgen n=35, Dønna n=30.

4.5.2 Distribution between hot water extractable carbon (HWEC) and soil organic carbon

In the figure 43 the SOC-stock fractions are shown. As the figure shows the labile fraction, HWEC-stock, are respectively low.

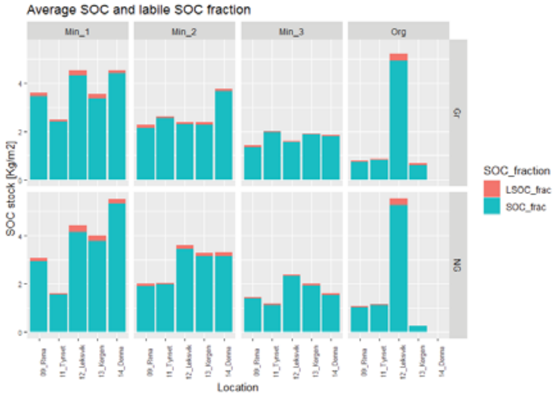

Figure 43: Division of average SOC stock, divided into labile fraction (red) and SOC (blue) fraction. The bars show the average in samples in the same category of layer, treatment and location. The locations are grouped, and the name is found on the x axis. Layers are grouped by frame, hence mineral later 0-10 cm (min_1), mineral layer 10-20 cm (Min_2) and mineral layer 20-30 cm (Min_3). Number of samples in each category displayed in the figure, see appendix 15.

4.5.3 Relationship between C:N ratio and soil organic carbon (SOC)

In the figure 44 below the linear relationship between the CN-ratio and SOC shown. The CN-ratio was not found associated with significant ($p=0.228$) different SOC-stock, see table 9.

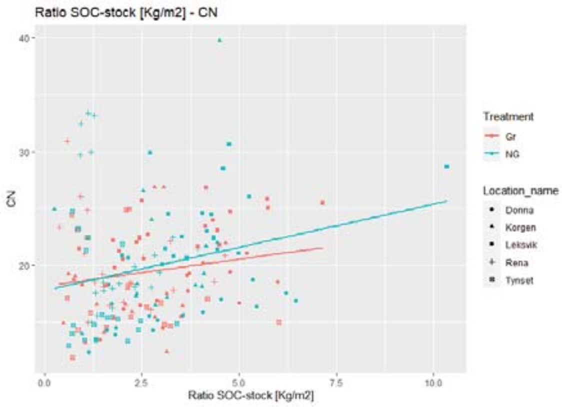

Figure 44: Linear relationship between the average CN and average SOC stock [kgC/m2]. The red line represents the grazed (Gr) sites and the blue the non-grazed (NG) sites. The symbols represent the locations.

4.5.4 Relationship between silt and clay fractions and soil organic carbon (SOC)

In the figure 45 below the linear relationship between the sum of the silt and clay fraction and SOC-stock is shown. In this figure the organic layer is not present. The average of silt and clay fraction found not significantly (p=0.702) associated with significant different SOC-stock, see table 9.

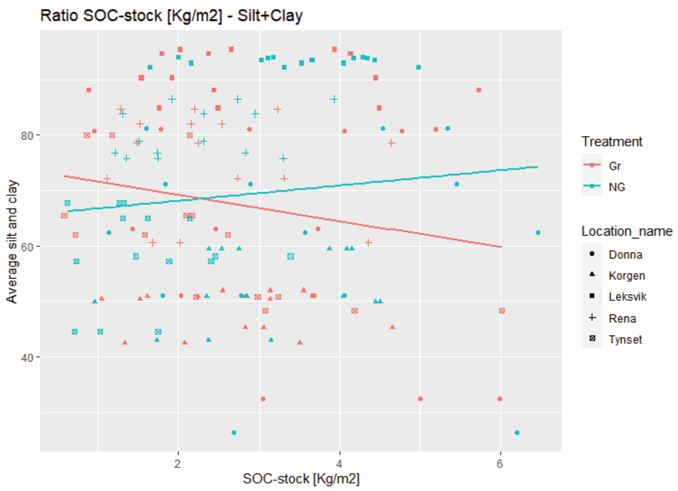

Figure 45: Linear relationship between the average silt and clay fraction and average SOC stock [kgC/m2]. The red line represents the grazed (Gr) sites and the blue the non-grazed (NG) sites. The symbols represent the locations. The organic layer of the profile is not included.

4.5.5 Relationship between climatic factors and SOC

In the figure 46 below the linear relationship between the MAT and SOC is shown. And in the figure 47 relationship between the MAP and SOC is shown.

MAT was found significantly (p=0.00759) associated with SOC, thus indicating that the temperature is associated with significant different SOC. The MAP was not found significantly (p=0.848) associated with SOC.

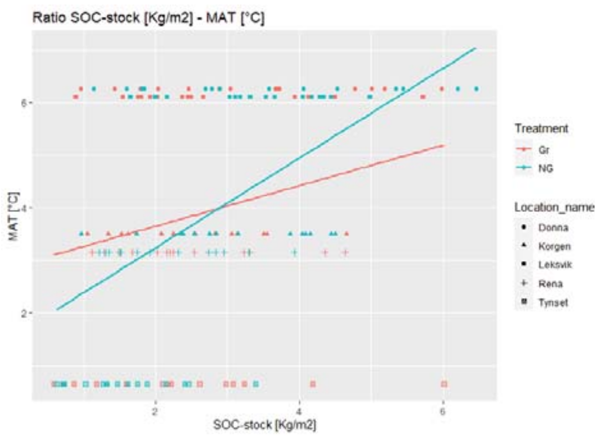

Figure 46: Linear relationship between the MAT [°C] and average SOC stock [kgC/m2] divided by treatment. The red line represents the grazed (Gr) sites and the blue the non-grazed (NG) sites. The symbols represent the locations.

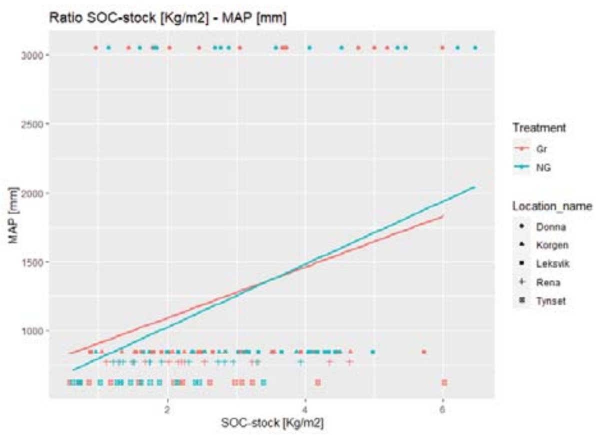

Figure 47: Linear relationship between the MAP [mm] and average SOC stock [kgC/m2] divided by treatment. The red line represents the grazed (Gr) sites and the blue the non-grazed (NG) sites. The symbols represent the locations.

4.5.6 Summary relationship between factor and soil organic carbon (SOC)

The association between SOC-stocks and four factors; CN-ratio, fine texture soil (sum silt and clay), climatic factor simplified to mean annual precipitation (MAP) and mean annual temperature (MAT) were tested. In addition, the effect of treatment (Gr/NG) and the relationship to the four factors were tested. Only MAT found to significantly effect SOC-stock, see result is listed in table 9. For all factors except of the fine texture the whole profile was tested, for the fine texture fraction the SOC-stock of the organic layer were excluded.

Table 9: In this table the results from the two-way anova test between the level of factors; average of CN, average of the sum of silt and clay, MAP and MAT is associated with significant different average of SOC-stock in the whole profile. Similarly, if treatment (Gr/NG) is associated with significant different average of SOC-stock. In addition, if there is a relationship between the factor and SOC-stock depends on the treatment (Gr/NG).

Factor	*C:N*	*Sum silt and Clay*	*MAP*	*MAT*
Levels of factor is associated with SOC	Not significant (p= 0.228)	Not significant (p=0.702)	Not significant (p=0.848)	Significant (p=0.00759)
Treatment (Gr/NG) ***is associated with SOC***	Not significant (p= 0.897)	Not significant (p=0.821)	Not significant (p=0.939)	Not significant (p=0.9018)
Interaction between factor and SOC depends on *Treatment (Gr/NG)*	-	-	-	-

4.6 Summary of grazing effects

In table 10 a summary of grazing effects on all tested soil properties are given. As seen in the table below grazing was found to have a significant effect on Mg-stock, HWEC-stock, CN and BD.

Table 10: Summary of the significant effects of grazing for all locations by layers, or/eighter whole profile. Difference in factor between sites (Gr/NG) is represented with a delta sign, Δ. The factors are listed in the top row, and a positive significant effect marked "increases", negative significant effect "decreases" and no significant difference "n.s.e." (no significant effect).

Grazing effects on different soil properties

Factor Layer/ profile	**Δ%SOC**	**ΔCa**	**ΔK**	**ΔMg**	**ΔP**	**ΔSOC**	**ΔHWEC**	**ΔSON**	**ΔC:N**	**ΔBD**	**ΔThickness of O-layer**	**ΔpH**
Org.	n.s.e.	n.s.e.	n.s.e.	n.s.e.	n.s.e.	n.s.e.	n.s.e.	n.s.e.	Decreases	Increases	n.s.e.	n.s.e.
0-10 cm	n.s.e.	n.s.e.	n.s.e.	Decreases	n.s.e.	n.s.e.	Decreases	n.s.e.	n.s.e.	Increases	-	n.s.e.
10-20 cm	n.s.e.	-	-	-	-	n.s.e.	Decreases	n.s.e.	n.s.e.	n.s.e.	-	n.s.e.
20-30 cm	n.s.e.	-	-	-	-	n.s.e.	Decreases	n.s.e.	n.s.e.	n.s.e.	-	n.s.e.
Whole profile	-	-	-	-	-	n.s.e.	Decreases	n.s.e.	-	-	-	-

5. Discussion

5.1 Grazing effects on Soil Organic Carbon

The first objective in this thesis was to test if grazing influenced the carbon in soil. By comparing sites, layer by layer, for all locations there was no significant increase or decrease to indicate an association between grazing treatment and SOC-stocks. By examine the mean values of the SOC-stock the organic layer has a higher SOC-stock in the non-grazed sites. Note that Korgen is an exception. The non-grazed site contained only one soil profile with an organic layer, causing a result that might not be representative for the site.

The SOC-stock is a measure of all organic carbon in the soil, both the labile and the stabile. The stabilized carbon can stay for relatively long periods, centuries or even millennia (Weil et al., 2017). Therefore, it might be that the grazing utilization effect has not become applicable yet. Other studies performed in Norway on effects of excluding grazing animals shows similar results. After 12 years of sheep exclusion from a heavy used area in Setesdal in Norway Speed et al. (2014) found that the SOC-stock increased, although to significantly. In a boreal forest clear-cut sites in Central Norway Kolstad et al. (2017) found no significant difference after excluding moose for 8 years. The time period the sites in this thesis have been utilized as pasture is not known. As stated by Byrnes et al. (2018) study duration is important when determining the soil responses to grazing.

Neither the SOC concentration nor the thickness of the organic layer gave a significant response to grazing. The distribution of SOC stock in the profile, figure 34, shows that only Leksvik holds the greatest amount of the SOC in the organic layer. Although not significant, the thickness of the organic layer had a higher mean value in the grazed sites for Rena, Tynset and Leksvik. The same were observed in the study of effects on excluding moose, that is an increase in organic soil without grazing (Kolstad et al., 2017). Kolstad et al. (2017) additionally found an association between increase in organic soil and increase of C and N, therefore suggested that soil depth and nutrient stocks have a plausible causal relationship. Indeed, also found in this thesis results, that is the organic layer has a higher mean value of SOC concentration in the non-grazed sites than in the grazed sites.

When comparing the sites content of the average of HWEC-stocks in the whole profile the difference was significant, hence grazing was found to significantly decreased the HWEC-stock in every mineral layer. The animals remove organic materials when grazing from the organic layer, plus returns some of the carbon with the feces. A decrease in the labile SOC (in this case especially POC) was also observed by Martinsen et al. (2011) in a long-term study in Hol in Norway, hence concluded as a result of reduced organic matter input.

Grazing also stimulates plants and vegetation diversity (Austrheim et al., 2014; McSherry & Ritchie, 2013; Schmitz et al., 2018). Grazing enhances a flush release of labile C into the rhizosphere, which can lead to both soil N mineralization and nutrient plant uptake (Sun et al., 2017). This might relocate carbon from aboveground to beneath ground. A part of the HWEC is root exudates (Bu et al., 2011), which is also influenced by grazing (Piñeiro et al., 2010).

McSherry and Ritchie (2013) showed that grazing effects on vegetation may also differ depending on grass type. A simple species registration on sites were preformed and no obvious difference found in vegetation. In this thesis grazing was not found to significant influence the thickness of organic layer, although a higher mean value for non-grazed sites compared to grazed sites. This in combination with the significant decline in HWEC-stocks makes it unlikely that a relocation of carbon appears. Rather more likely that grazer removal of above-ground vegetation causes the HWEC-stock decrease.

By looking at the locations individually only Leksvik and Dønna embodies a significant difference in mineral 0-10 cm and mineral 10-20 cm. These locations have the highest MATs compared to the other locations. Finding literature on the relationship between temperature and effects of grazing resulted unsuccessfully, although an increase in carbon turnover with decreasing temperature of the upper 20 cm of the soil were shown in a ^{14}C analysis by Trumbore et al. (1996). A relationship between precipitation and grazing effects has been published (McSherry & Ritchie, 2013, Piñeiro et al., 2010). The effect of temperature might be supported by the fact that all locations were found significantly influenced by grazing in the deepest mineral layer (20-30 cm), where it is conceivable that ambient temperature has less effect.

The HWEC-stock was found by Ghani et.al (Ghani et al., 2003) to be a measurement in soil on an early indication of organic matter loss. If this is the case in these locations is unknown, hence the SOC-stock, SOC concentration or the thickness of the organic layer was not significantly different between sites.

5.1.1 Climatic effects

The second objective of this thesis was to test if SOC-stock is related to climate, simplified to MAT and MAP, and if the geography is also related to the grazing effects. There was not found a significant difference of SOC-stock between sites, on the contrary a significant difference between locations. Again, location Leksvik significantly differ from all other locations. Tynset and Dønna differs significantly from each other, although not from the other locations with Leksvik as an exception.

When testing if the climate (MAP and MAT) is associated with significant effect on SOC-stock only MAT gave a significant response. Since the grazing effect already was proven not significant on SOC-stock a test on interaction between MAT and treatment (Gr/NG) was irrelevant, meaning that for all locations grazing effect was not found climate dependent.

Since location Leksvik differed significantly from all the other locations in SOC-stock amount, the MAT might be a part of the explanation. The MAT in Leksvik is not the highest compared to the other locations, although the summer temperatures for this area typically is higher than for the other locations plus a longer growing season.

Many other studies found that in fact the grazing effects is climate dependent, especially the precipitation. An example is the review of Piñeiro et al. (2010) who found that root content, as one of the primary controls of SOC formation, were higher under grazing with eighter low or high precipitation, thus lower under grazing and intermediate precipitation. In this thesis the precipitation was not found associated with SOC-stocks.

Since HWEC-stock is a part of the total SOC-stock, HWEC-stock might also be affected by the climate, hence MAT. Tynset has the lowest temperature out of all locations simultaneous as the lowest HWEC-stock. In Leksvik the MAT is the second highest, although the highest HWEC-stock of all locations. Therefore, it is likely that temperature is an important factor, however not the only determining factor.

As mentioned, the thickness of organic layer was not significantly different between sites (Gr/NG). On the contrary, there was a significant difference between locations. Location Leksvik differs significantly from the other locations. By comparing the climatic factors as precipitation and temperature Leksvik's MAT is the second highest out of all locations, but in the middle of the locations MAP. Generally higher temperature accelerates all biochemically processes (Weil et al., 2017). On the contrary, Dønna, who receives the most precipitation during a mean year plus the highest MAT, lacked an organic layer.

5.1.2 Parent material

The third hypothesis is related to the parent material, simplified to the texture of the soil, and if soils consisting of greater amounts of fine texture have higher SOC-stocks than the coarser soils. Therefore, the average of the sum of silt and clay was tested as a factor related to SOC-stock. Note that in this test the SOC-stock in the organic layer was excluded. This relationship was found not significant; meaning that the average of silt and clay fraction were found not associated with significant different SOC-stock. This finding contradicts to other studies performed on silt and clay, e.g. Hassink (1997) who found a close correlation between C (and N) and the fine texture fraction.

The soil texture in Leksvik differs from all other locations by having a low share of the sand fraction. Therefore, it was thought plausible that the high fraction of silt and clay in Leksvik is one of the reasons this location has a significant greater SOC-stock to all other locations. On the other hand, by looking at the distribution of SOC in the whole profile, see figure 34, a considerably amount of the SOC is found in the organic layer assumed to lack mineral fractions.

In compliance, Tynset and Dønna differ significantly in SOC-stock (figure 32), hence the particle size distribution resembles each other (figure 24). By looking at each layer individually, the significant difference does not apply in mineral 2 (10-20 cm) and mineral 3 (20-30 cm). As concluded in a study by Meyer et al. (2017) the soil C cannot be assigned to a specific size fraction.

5.1.3 Effects on grazing management

Another reason for the significantly difference in HWEC-stocks between sites might be related to management of the pasture. Information on how long these areas is utilized as a pasture is unknown. Since treatment (Gr/NG) was not found to significantly effect SOC-stocks, only HWEC-stocks will be discussed.

When testing grazing effect on HWEC-stocks, each location separately, only Leksvik and Dønna were found to significantly differ between sites in mineral 1 and 2 layers. An additional explanation to MAT might be the management of the pasture. Several studies have found grazing intensity to be major regulator of the grazing effects on SOC (Byrnes et al., 2018; Martinsen et al., 2012; Schmitz et al., 2014).

Leksvik and Dønna has comparable grazing density, respectively 21.4 animals / km^2 and 18.2 animals / km^2. Grazing density in Korgen, 20 animals / km^2, also resembles Leksvik and Dønna. The locations Rena and Tynset both differs, respectively 2.3 animals / km^2 and 42.86 animals / km^2. Hence, the significantly difference between locations seems unaffected by the density of animals. The locations are utilized over different periods; Tynset for approximately 1.5 moths, Dønna and Korgen for approximately 3 months and Rena and Leksvik approximately for 3.5 months. Since Leksvik and Dønna holds medium grazing density and some of the highest utilizing periods it might be that the grazing management is a part of the explanation to why exactly these locations significantly differ in HWEC-stock between sites.

5.2 Grazing effects on soil characteristics

5.2.1 Bulk density

A significant difference in BD between sites in the two top layers (the organic layer, mineral 0-10 cm) were found, hence all locations had a significant difference. Note that location Dønna is an exception, the mineral 1 layer has a higher bulke density at the non-grazed site.

This finding is in accordance with other studies (Byrnes et al., 2018; Martinsen et al., 2012; Piñeiro et al., 2010) on the effects of grazing, hence the soil samples were taken in areas frequently used by the grazing animals.

5.2.2 Nitrogen and C:N-ratio

The fourth hypothesis of this thesis is related to the CN-ratio, and if the CN-ratio influence the SOC stock. A test was conducted to test if CN was associated with the SOC-stock. No significant result to indicate that this was the case. The CN effect on HWEC-stock specifically was not tested. The grazing treatment was found to significantly effect the CN-ratio for the organic layer, but interaction between CN and grazing on SOC-stock was not found significant. Nor was grazing found to significantly affect the SON-stocks, that is no significant difference between sites.

However, when looking at all locations assembled the C:N ratio in the organic layer was found to significantly decrease with grazing. A decreasing CN ratio could be created by eighter a higher nitrogen input or a lower carbon input, or a change in decomposition or the form. The SON-stocks were not significantly different between sites, nor was SOC-stocks. The HWEC-stock was significantly different between sites, although not in the organic layer. Since the CN ratio is decreasing simultaneous as the HWEC-stock it is most likely due to less carbon input from above and belowground as an effect of grazing. This may be a sign that a decline of microbial biomass pool (Ghani et al., 2003) are taking place. As showed by Bhattacharyya et al. (2022) the "SOM and SOC deposition, decomposition, transformation and stabilization are fully reliant on the microbial composition".

By looking at locations individually, every location except Tynset and Dønna (lacked organic layer) had a significantly change in HWEC-stock from grazing. Location Tynset differs from the other locations by having a high density of animals, e.g., a doubling of density compared to Korgen and Dønna. According to findings by Byrnes et al. (2018) CN significantly decreased under light and heavy grazing. This was explained by higher decomposition rates or reduced fresh plant input. Since Tynset has the highest grazing intensity compared to the other locations, although might have expected a decrease this was not found. By looking at the CN ratio results in the other layers of the profile in Tynset all of them holds a lower mean value in the non-grazed site, although not significant. Piñeiro et al. (2010) found the CN ratio to frequently increase under grazing, however only in the more labile part of the soil. In the paper this is suggested explained by potential N limitations for SOM formation under grazing. The SON-stock in Tynset has a lower mean value at the non-grazed sites than at grazed sites for all mineral layers. This might suggest that N is limited in Tynset, and an increase in CN may occur in the future.

5.3 Grazing effects on nutrient availability

Another hypothesis in this thesis was that grazing sites have a higher nutrient availability than non-grazed sites. This partly because animals manure contains nutrients (Bolinder et al., 2010), but also because grazers may increase the nutrient cycling (Rasse et al., 2019).

The Mg-stock was the only nutrient found significantly different between sites, in mineral 1 layer (0-10 cm). Grazing significantly decreased the amount of plant available Mg.

By interpreting locations separately only Korgen and Dønna has a significantly different Mg-stock between sites, in the mineral 1 layer (0-10 cm). Note that only the organic layer and the mineral 1 layer was analysed. Both locations share the same underlaying bedrock causing samples in the mineral layers to entail relatively high pH-values. This might explain availability difference between location but fails to explain the difference between sites. No literature was found on grazing effects on Mg-stocks.

For plant available K, Ca and P grazing seemed to be irrelevant, hence there were no significant difference between sites. Generally about 75% N, 80% P and 90% K of the ingested matter is returned by grazers (Weil et al., 2017). If a pasture is only used by grazing animals, given that plant materials is not removed otherwise, the grazing animals typically recycle back most of the nutrients removed when they eat (Weil et al., 2017). As pointed out by Taboada et al. (2011) a study of nutrient dynamics is difficult in pastures since the area might contain spatial heterogeneity and therefore also a high spatial variability. Therefore, results might have been otherwise by sampling in other area.

The availability of nutrients is pH dependent in soil. In this thesis grazing was not found to significantly effect pH. Chaneton et al. (1996) found in a study of how nitrogen and phosphorus cycled in grazed and ungrazed plots in in a temperate subhumid grassland in Argentina that grazing strongly affected the location of nutrients within vegetation, that is below vs. above-ground. In the study the amount of available N and P in soil was not affected, on the contrary the cycling rate of P were affected (Chaneton et al., 1996). In this thesis there is not conducted any samples on vegetation or plants, therefore this effect is not examined. Hence, grazing influence on the P cycling cannot be excluded.

6. Conclusion

Grazing was found to significantly increase bulk density in the organic layer and the mineral 1 layer (0-10 cm) in addition to significantly decrease the HWEC-stock in all mineral layers. The SOC concentration and SOC-stock was not found significantly affected by grazing. Nor was the thickness of the organic layer significantly affected by grazing. The distribution of SOC stock, figure 34, shows that only Leksvik holds the greatest amount of the SOC in the organic layer. Although, the organic layer has the highest mean values of SOC-stocks when compared to the other layers.

The decrease in the HWEC-stock is suggested caused by removal of organic matter by grazers. The basis for this assumption is partly the combination of the significant decline in HWEC-stocks and difference in mean values of the thickness or organic layer (not significant). In addition, the CN ratio was found to significantly decrease under grazing. The form and behaviour of the SOM and SOC is fully reliant on microbial mass (Bhattacharyya et al., 2022), and a decrease of the HWEC might therefor be a sign that a decline of microbial biomass pool (Ghani et al., 2003) are taking place. Although, the CN ratio was not found to significantly affect the SOC-stock. A test on HWEC-stock alone was not completed.

Management of pastures might be influencing the HWEC-stock. Leksvik and Dønna was the only locations with significant difference in HWEC-stock in the mineral 1 and mineral 2 layers. These locations had medium grazing density and some of the highest utilizing periods. Therefore, grazing management might be a part of the explanation to why exactly these locations significantly differ in HWEC-stock between sites.

Amongst the tested factors related to geography and effect on the SOC-stock, only MAT were found significant. Precipitation and content of fine texture quantity were not found to significantly effect SOC-stocks. Therefore, geography was found somewhat related to the SOC-stock.

Only Mg-stock had a significant difference between sites. No plausible explanation for this significant result was found. The other macronutrient stock found not significant different between sites.

7. References

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8. Appendix

Appendix 1: Total overview of number of samples and preformed analysis

Appendix 1.1: Table of number of samples of BD

NUMBER OF SAMPLES (N) - BD

LOCATION	Rena		Tynset		Leksvik		Korgen		Dønna	
TREATMENT	Gr	NG	Gr	NG	Gr	NG	Gr	NG	Gr	NG
LAYER / TOTAL	20	20	18	20	20	20	19	16	15	14
O-LAYER	5	5	3*	5	5	5	4*	1*	0*	0*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	5	5	5	5	5	5	5	5	5	5
20-30	5	5	5	5	5	5	5	5	5	4

***NO SAMPLE LACKED OF BD**

Appendix 1.2: Table of number of samples of pH

NUMBER OF SAMPLES (N) - PH

LOCATION	Rena		Tynset		Leksvik		Korgen		Dønna	
TREATMENT	Gr	NG	Gr	NG	Gr	NG	Gr	NG	Gr	NG
LAYER / TOTAL	20	20	19	20	20	20	19	16	15	15
O-LAYER	5	5	4*	5	5	5	4*	1*	0*	1*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	5	5	5	5	5	5	5	5	5	5
20-30	5	5	5	5	5	5	5	5	5	4

***SAMPLE SIZE TOO SMALL/LACKED FOR ANALYSIS OF PH**

Appendix 1.3: Table of number of samples of LOI

NUMBER OF SAMPLES (N) - DRY MATTER AND LOI

LOCATION	Rena		Tynset		Leksvik		Korgen		Dønna	
TREATMENT	Gr	NG	Gr	NG	Gr	NG	Gr	NG	Gr	NG
LAYER / TOTAL	20	20	19	20	20	20	19	16	15	15
O-LAYER	5	5	4*	5	5	5	4*	1*	0*	1*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	5	5	5	5	5	5	5	5	5	5
20-30	5	5	5	5	5	5	5	5	5	4

***SAMPLE SIZE TOO SMALL/LACKED FOR ANALYSIS OF DRY MATTER AND LOI**

Appendix 1.4: Table of number of samples of TOTC and TOTN

NUMBER OF SAMPLES (N) - TOTAL CARBON AND NITROGEN

LOCATION	Rena		Tynset		Leksvik		Korgen		Dønna	
TREATMENT	Gr	NG	Gr	NG	Gr	NG	Gr	NG	Gr	NG
LAYER / TOTAL	20	20	20	20	20	20	19	16	15	15
O-LAYER	5	5	5	5	5	5	4*	1*	0*	1*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	5	5	5	5	5	5	5	5	5	5
20-30	5	5	5	5	5	5	5	5	5	4

***SAMPLE SIZE TOO SMALL/LACKED FOR ANALYSIS OF TOT-C AND TOT-N**

Appendix 1.5: Table of number of samples of TOTIC and TOTIN

NUMBER OF SAMPLES (N) - TOTAL INORGANIC CARBON AND NITROGEN

LOCATION	Rena		Tynset		Leksvik		Korgen		Dønna	
TREATMENT	Gr	NG	Gr	NG	Gr	NG	Gr	NG	Gr	NG

LAYER / TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**11**	**0**
O-LAYER	**	**	**	**	**	**	**	**	**	**
0-10	**	**	**	**	**	**	**	**	3	**
10-20	**	**	**	**	**	**	**	**	3	**
20-30	**	**	**	**	**	**	**	3	5	**

****ANALYSIS NOT RELEVANT FOR THIS LAYER FOR ANALYSIS OF TOT-IC AND TOT-IN**

Appendix 1.6: Table of number of samples of macro nutrients

NUMBER OF SAMPLES (N) – MAKRO NUTRIENTS

LOCATION	**Rena**		**Tynset**		**Leksvik**		**Korgen**		**Dønna**	
TREATMENT	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**
LAYER / TOTAL	**10**	**10**	**10**	**10**	**10**	**10**	**9**	**6**	**5**	**5**
O-LAYER	5	5	5	5	5	5	4*	1*	0*	0*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	**	**	**	**	**	**	**	**	**	**
20-30	**	**	**	**	**	**	**	**	**	**

***SAMPLE SIZE TOO SMALL/LACKED FOR ANALYSIS OF AL**
****ANALYSIS NOT RELEVANT FOR THIS LAYER**

Appendix 1.7: Table of number of samples of HWEC

NUMBER OF SAMPLES (N) - HWEC

LOCATION	**Rena**		**Tynset**		**Leksvik**		**Korgen**		**Dønna**	
TREATMENT	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**
LAYER / TOTAL	**20**	**20**	**19**	**20**	**20**	**20**	**19**	**16**	**15**	**15**
O-LAYER	5	5	4*	5	5	5	4*	1*	0*	1*
0-10	5	5	5	5	5	5	5	5	5	5
10-20	5	5	5	5	5	5	5	5	5	5
20-30	5	5	5	5	5	5	5	5	5	4*

***SAMPLE SIZE TOO SMALL/LACKED FOR ANALYSIS OF HWEC**

Appendix 1.8: Table of number of samples of particle size distribution

NUMBER OF SAMPLES (N) - PARTICLE SIZE DISTRIBUTION

LOCATION	**Rena**		**Tynset**		**Leksvik**		**Korgen**		**Dønna**	
TREATMENT	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**
LAYER / TOTAL	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
O-LAYER	**	**	**	**	**	**	**	**	**	**
0-10	**	**	**	**	**	**	**	**	**	**
10-20	**	**	**	**	**	**	**	**	**	**
20-30	5	5	5	5	5	5	5	5	5	5

****ANALYSIS NOT RELEVANT FOR THIS LAYER**

Appendix 2: Distribution of stocks in profile

Appendix 2.1: Average SOC stock distribution in profile [%] by location and treatment. The profile consists of 5 plots in each category of location and site. The profile is divided into the organic layer, mineral layer 0-10 cm, mineral layer 10-20 cm and mineral layer 20-30 cm. The table is divided into two parts, first part shows the grazed (Gr) sites, seconds part is showing the non-grazed (NG) site.

SOC STOCK DISTRIBUTION IN PROFILE - GR [%]

LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**
SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	10	10	38	8	-
0-10	44	32	33	42	45
10-20	28	32	17	28	37
20-30	18	26	12	22	18

SOC STOCK DISTRIBUTION IN PROFILE - NG [%]

LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**

SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	15	20	33	2	-
0-10	40	28	28	42	54
10-20	26	33	23	35	31
20-30	19	19	16	21	15

Appendix 2.2: Average labile SOC stock distribution in profile [%] by location and treatment. The profile consists of 5 plots in each category of location and site. The profile is divided into the organic layer, mineral layer 0-10 cm, mineral layer 10-20 cm and mineral layer 20-30 cm. The table is divided into two parts, first part shows the grazed (Gr) sites, seconds part is showing the non-grazed (NG) site.

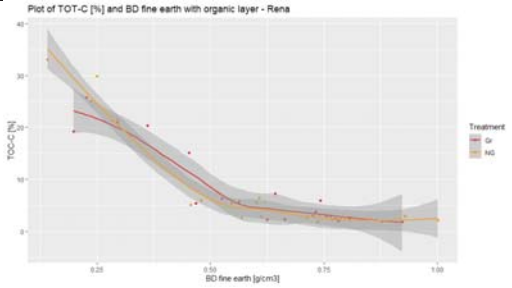
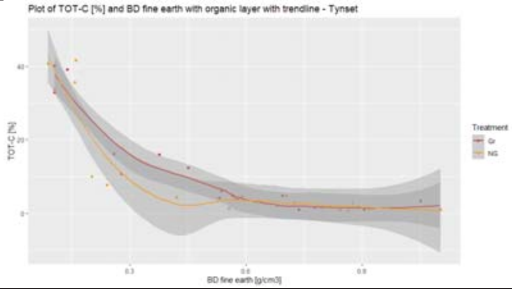
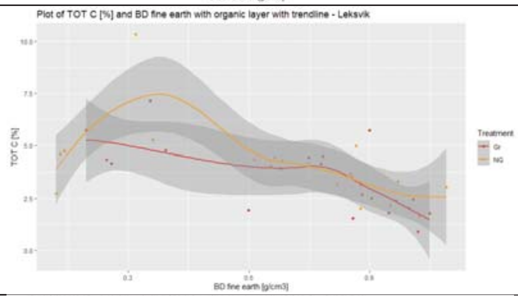
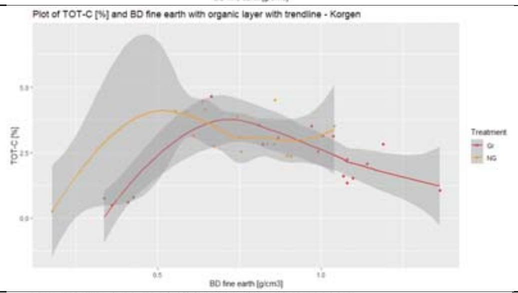
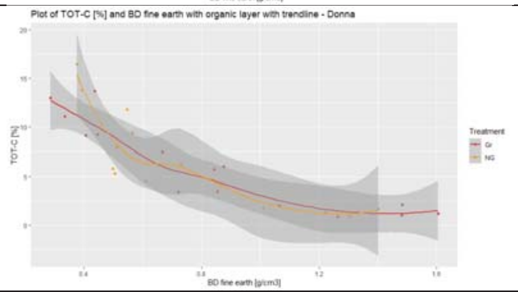
LABILE SOC STOCK DISTRIBUTION IN PROFILE - GR [%]					
LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**
SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	43	36	46	53	-
0-10	27	28	38	23	43
10-20	14	16	11	13	35
20-30	16	20	5	11	22
LABILE SOC STOCK DISTRIBUTION IN PROFILE - NG [%]					
LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**
SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	37	29	33	51	-
0-10	29	32	37	27	51
10-20	18	17	20	18	32
20-30	16	22	10	4	17

Appendix 2.3: Average SON stock distribution in profile [%] by location and treatment. The profile consists of 5 plots in each category of location and site. The profile is divided into the organic layer, mineral layer 0-10 cm, mineral layer 10-20 cm and mineral layer 20-30 cm. The table is divided into two parts, first part shows the grazed (Gr) sites, seconds part is showing the non-grazed (NG) site.

SON STOCK DISTRIBUTION IN PROFILE - GR [%]					
LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**
SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	7	12	35	7	-
0-10	42	30	34	46	41
10-20	31	32	18	27	38
20-30	20	26	13	20	21
SON STOCK DISTRIBUTION IN PROFILE - NG [%]					
LOCATION	**Rena**	**Tynset**	**Leksvik**	**Korgen**	**Dønna**
SOIL TYPE	Cambisol	Cambisol	Cambisol	Cambisol	Regosol
LAYER					
O-LAYER	9	14	28	2	-
0-10	38	29	30	44	51
10-20	30	37	24	32	32
20-30	23	20	18	22	17

Appendix 3: TOT-C% and BD

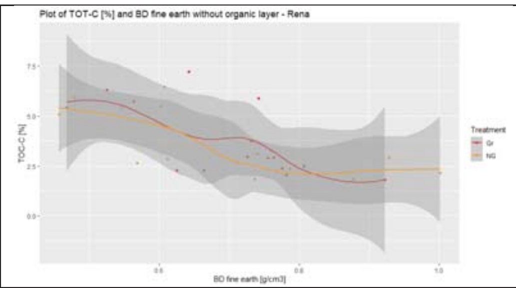
Appendix 3.1: TOT-C% and BD with organic layer

<u>Location 9. Rena</u>	
<u>Location 11. Tynset</u>	
<u>Location 12. Leksvik</u>	
<u>Location 13. Korgen</u>	
<u>Location 14. Dønna</u>	

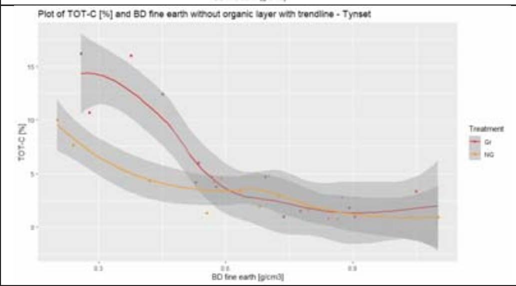
Appendix 3.2: TOT-C% and BD without organic layer

Plot of TOT-C [%] and BD_{fine_earth} without organic layer

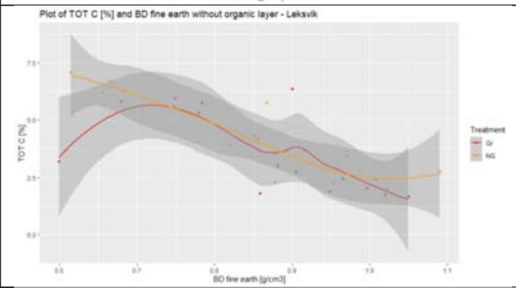
Location 9. Rena



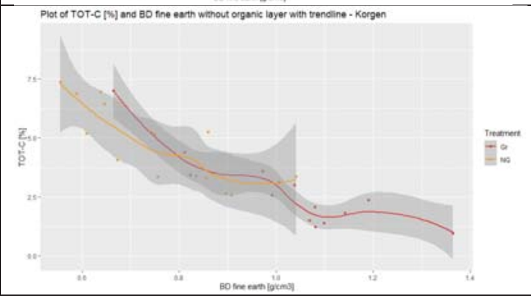
Location 11. Tynset



Location 12. Leksvik



Location 13. Korgen



Appendix 4: Significance testing results

Appendix 4.1: Significance results of SOC-stocks

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
Factor	**SOC stock [kgC/m2]**	**SOC stock [kgC/m2]**	**SOC stock [kgC/m2]**
Layer			
Org.	**Not significant (p= 0.62)**	**Significant (p= 1.73e-09)**	**-**
0-10 cm	**Not significant (p= 0.888)**	**Significant (p= 2.47e-09)**	**-**
10-20 cm	**Not significant (p= 0.5650)**	**Significant (p= 0.0177)**	**-**
20-30 cm	**Not significant (p= 0.879)**	**Not significant (p = 0.354)**	**-**

Grouping of significant difference between SOC-stocks in location
Organic layer

```
Location_name lsmean    SE df  lower.CL upper.CL .group
Korgen         0.582 0.532 29  -0.8319     2.00  a
Rena           0.945 0.377 29  -0.0548     1.94  a
Tynset         1.048 0.421 29  -0.0703     2.17  a
Leksvik        5.380 0.377 29   4.3803     6.38   b
```

Mineral 1

```
Location_name lsmean    SE df lower.CL upper.CL .group
Tynset          2.05 0.259 45     1.35     2.74  a
Rena            3.34 0.259 45     2.65     4.03   b
Korgen          3.76 0.259 45     3.06     4.45   bc
Leksvik         4.49 0.259 45     3.79     5.18    cd
Donna           5.01 0.259 45     4.32     5.71     d
```

Mineral 2

```
Location_name lsmean    SE df lower.CL upper.CL .group
Rena            2.14 0.299 45     1.34     2.94  a
Tynset          2.35 0.299 45     1.55     3.15  ab
Korgen          2.82 0.299 45     2.02     3.62  ab
Leksvik         2.98 0.299 45     2.18     3.78  ab
Donna           3.53 0.299 45     2.73     4.33   b
```

Mineral 3

Not relevant

Whole profile

```
Location_name lsmean    SE df lower.CL upper.CL .group
Tynset          6.82 0.628 44     5.13     8.50  a
Rena            7.86 0.628 44     6.18     9.55  ab
Korgen          8.82 0.628 44     7.14    10.51  ab
Donna          10.24 0.662 44     8.46    12.01   b
Leksvik        14.84 0.628 44    13.16    16.53    c
```

Appendix 4.2: Significance results HWEC-stocks

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
Factor	**Labile SOC stock [kgC/m2]**	**Labile SOC stock [kgC/m2]**	**Labile SOC stock [kgC/m2]**
Layer			
Org.	**Not significant (p=0.823)**	**Significant (p= 1.53e-08)**	**-**
0-10 cm	**Significant (p= 0.006840)**	**Not significant (p= 1.72e-15)**	**-**
10-20 cm	**Significant (p= 0.000248)**	**Significant (p= 0.036095)**	**Significant (p= 0.033852)**
20-30 cm	**Significant (p= 0.00353)**	**Not significant (p=0.06947)**	**-**
Profile	**Significant (p= 0.000559)**	**Significant (p< 2e-16)**	**Significant (p= 0.045132)**

Grouping of significant difference between labile SOC-stocks in location

Organic layer

```
Location_name lsmean     SE df  lower.CL upper.CL .group
Korgen        0.0380 0.0294 29 -0.04001    0.116  a
Tynset        0.0488 0.0232 29 -0.01292    0.110  a
Rena          0.0580 0.0208 29  0.00284    0.113  a
Leksvik       0.2740 0.0208 29  0.21884    0.329   b
```

Mineral_1

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.088 0.0124 40   0.0545   0.1215  a
 Donna          0.124 0.0124 40   0.0905   0.1575  ab
 Rena           0.160 0.0124 40   0.1265   0.1935   bc
 Korgen         0.176 0.0124 40   0.1425   0.2095    cd
 Leksvik        0.226 0.0124 40   0.1925   0.2595     d

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.066 0.0124 40   0.0325   0.0995  a
 Rena           0.142 0.0124 40   0.1085   0.1755   b
 Donna          0.196 0.0124 40   0.1625   0.2295    c
 Korgen         0.200 0.0124 40   0.1665   0.2335    c
 Leksvik        0.282 0.0124 40   0.2485   0.3155     d
```

Mineral_2

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Leksvik        0.064 0.0129 40   0.0292   0.0988  a
 Tynset         0.072 0.0129 40   0.0372   0.1068  a
 Korgen         0.078 0.0129 40   0.0432   0.1128  a
 Rena           0.100 0.0129 40   0.0652   0.1348  a
 Donna          0.102 0.0129 40   0.0672   0.1368  a

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.080 0.0129 40   0.0452   0.1148  a
 Korgen         0.108 0.0129 40   0.0732   0.1428  ab
 Rena           0.114 0.0129 40   0.0792   0.1488  ab
 Donna          0.128 0.0129 40   0.0932   0.1628  ab
 Leksvik        0.150 0.0129 40   0.1152   0.1848   b
```

Mineral_3

Not relevant

Whole profile

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.232 0.0293 39    0.153    0.311  a
 Donna          0.290 0.0293 39    0.211    0.369  ab
 Korgen         0.336 0.0293 39    0.257    0.415  ab
 Rena           0.368 0.0293 39    0.289    0.447   b
 Leksvik        0.606 0.0293 39    0.527    0.685    c

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.236 0.0293 39    0.157    0.315  a
 Korgen         0.382 0.0293 39    0.303    0.461   b
 Rena           0.390 0.0293 39    0.311    0.469   b
 Donna          0.412 0.0328 39    0.324    0.501   b
 Leksvik        0.770 0.0293 39    0.691    0.849    c
```

Grouping of significant difference between labile SOC in sites (Treatment Gr/NG)

Organic layer

Not relevant

Mineral 1

```
Location_name = Donna:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.124 0.0124 40   0.0951   0.1529  a
 NG         0.196 0.0124 40   0.1671   0.2249   b

Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.176 0.0124 40   0.1471   0.2049  a
 NG         0.200 0.0124 40   0.1711   0.2289  a

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.226 0.0124 40   0.1971   0.2549  a
 NG         0.282 0.0124 40   0.2531   0.3109   b

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.142 0.0124 40   0.1131   0.1709  a
 Gr         0.160 0.0124 40   0.1311   0.1889  a

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.066 0.0124 40   0.0371   0.0949  a
 Gr         0.088 0.0124 40   0.0591   0.1169  a
```

Mineral 2

```
Location_name = Donna:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.102 0.0129 40    0.072    0.132  a
 NG         0.128 0.0129 40    0.098    0.158  a

Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.078 0.0129 40    0.048    0.108  a
 NG         0.108 0.0129 40    0.078    0.138  a

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.064 0.0129 40    0.034    0.094  a
 NG         0.150 0.0129 40    0.120    0.180   b

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.100 0.0129 40    0.070    0.130  a
 NG         0.114 0.0129 40    0.084    0.144  a

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.072 0.0129 40    0.042    0.102  a
 NG         0.080 0.0129 40    0.050    0.110  a
```

Mineral 3

```
Location_name = Donna:
 Treatment lsmean      SE df lower.CL upper.CL .group
 Gr        0.0587 0.00666 43   0.0433   0.0742  a
 NG        0.0766 0.00689 43   0.0606   0.0926   b

Location_name = Korgen:
 Treatment lsmean      SE df lower.CL upper.CL .group
 Gr        0.0491 0.00648 43   0.0341   0.0641  a
 NG        0.0669 0.00648 43   0.0519   0.0819   b

Location_name = Leksvik:
 Treatment lsmean      SE df lower.CL upper.CL .group
 Gr        0.0431 0.00648 43   0.0281   0.0581  a
 NG        0.0609 0.00648 43   0.0459   0.0759   b

Location_name = Rena:
 Treatment lsmean      SE df lower.CL upper.CL .group
 Gr        0.0531 0.00648 43   0.0381   0.0681  a
 NG        0.0709 0.00648 43   0.0559   0.0859   b

Location_name = Tynset:
 Treatment lsmean      SE df lower.CL upper.CL .group
 Gr        0.0341 0.00648 43   0.0191   0.0491  a
 NG        0.0519 0.00648 43   0.0369   0.0669   b
```

Whole profile

```
Location_name = Donna:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.290 0.0293 39    0.222    0.358  a
 NG         0.412 0.0328 39    0.336    0.489   b

Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.336 0.0293 39    0.268    0.404  a
 NG         0.382 0.0293 39    0.314    0.450  a

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.606 0.0293 39    0.538    0.674  a
 NG         0.770 0.0293 39    0.702    0.838   b

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.368 0.0293 39    0.300    0.436  a
 NG         0.390 0.0293 39    0.322    0.458  a

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr         0.232 0.0293 39    0.164    0.300  a
 NG         0.236 0.0293 39    0.168    0.304  a
```

Appendix 4.3: Significance results of treatment and location on pH

	Treatment (Gr/NG)	*Location*
Factor	**pH**	**pH**
Layer		
Org.	**Not significant (p=0.736)**	**Significant (p= 7.34e-06)**
0-10 cm	**Not significant (p= 0.214)**	**Significant (p= 3.23e-11)**
10-20 cm	**Not significant (p=0.289)**	**Significant (p= 5.76e-10)**
20-30 cm	**Not significant (p=0.205)**	**Significant (p = 9.6e-09)**

Grouping of pH - location

Organic layer

```
Location_name lsmean    SE df lower.CL upper.CL .group
Leksvik         4.47 0.129 30     4.13     4.82  a
Rena            4.76 0.129 30     4.42     5.10  ab
Korgen          5.11 0.182 30     4.63     5.59   bc
Tynset          5.63 0.136 30     5.27     5.99    c
```

Mineral 1

```
Location_name lsmean   SE df lower.CL upper.CL .group
Leksvik         4.38 0.13 45     4.03     4.73  a
Rena            4.67 0.13 45     4.33     5.02  a
Korgen          5.32 0.13 45     4.97     5.67   b
Tynset          5.50 0.13 45     5.15     5.84   b
Donna           6.04 0.13 45     5.69     6.39    c
```

Mineral 2

```
Location_name lsmean    SE df lower.CL upper.CL .group
Leksvik         4.59 0.133 45     4.23     4.94  a
Rena            4.76 0.133 45     4.40     5.11  a
Korgen          5.52 0.133 45     5.16     5.88   b
Tynset          5.56 0.133 45     5.21     5.92   bc
Donna           6.07 0.133 45     5.71     6.43    c
```

Mineral 3

```
Location_name lsmean    SE df lower.CL upper.CL .group
Leksvik         4.77 0.148 44     4.37     5.17  a
Rena            5.03 0.148 44     4.63     5.43  a
Tynset          5.71 0.148 44     5.32     6.11   b
Korgen          5.86 0.148 44     5.46     6.25   bc
Donna           6.34 0.156 44     5.92     6.76    c
```

Appendix 4.4: Significance results of treatment and location on BD

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
	BD	**BD**	**BD**
Layer			
Org.	**Significant (p=0.025677)**	**Significant (p=0.000165)**	**Not significant (p=0.238275)**
0-10 cm	**Significant (p= 0.0165)**	**Significant (p= 3.52e-05)**	**Not significant (p=0.1654)**
10-20 cm	**Not significant (p= 0.37268)**	**Significant (p= 0.0028)**	**-**
20-30 cm	**Not significant (p=0.164)**	**Significant (p= 5.61e-08)**	**-**

Grouping of significant difference between BD in sites (Treatment Gr/NG)

Organic layer

```
Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.292 0.0415 28   0.1940    0.390  a
 Gr         0.357 0.0353 28   0.2736    0.440   b

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.219 0.0284 28   0.1524    0.287  a
 Gr         0.285 0.0284 28   0.2175    0.352   b

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.241 0.0284 28   0.1744    0.309  a
 Gr         0.307 0.0284 28   0.2395    0.374   b

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.101 0.0295 28   0.0309    0.170  a
 Gr         0.166 0.0327 28   0.0884    0.243   b
```

Mineral 1

```
Location_name = Donna:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.425 0.0537 44    0.301    0.550  a
 Gr         0.535 0.0537 44    0.410    0.659   b

Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.714 0.0537 44    0.590    0.839  a
 Gr         0.824 0.0537 44    0.699    0.948   b

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.681 0.0537 44    0.557    0.806  a
 Gr         0.791 0.0537 44    0.666    0.915   b

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.509 0.0537 44    0.385    0.634  a
 Gr         0.619 0.0537 44    0.494    0.743   b

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG         0.407 0.0537 44    0.283    0.532  a
 Gr         0.517 0.0537 44    0.392    0.641   b
```

Mineral 2

Not relevant

Mineral 3

Not relevant

Grouping of significant difference between BD between location

Organic layer

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.166 0.0327 28   0.0786    0.253  a
 Leksvik        0.285 0.0284 28   0.2090    0.360   b
 Rena           0.307 0.0284 28   0.2310    0.382   b
 Korgen         0.357 0.0353 28   0.2630    0.451   b

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.101 0.0295 28   0.0221    0.179  a
 Leksvik        0.219 0.0284 28   0.1440    0.295   b
 Rena           0.241 0.0284 28   0.1660    0.317   b
 Korgen         0.292 0.0415 28   0.1816    0.402   b
```

Mineral 1

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.517 0.0537 44    0.373    0.661  a
 Donna          0.535 0.0537 44    0.391    0.679  a
 Rena           0.619 0.0537 44    0.475    0.763  ab
 Leksvik        0.791 0.0537 44    0.647    0.935   bc
 Korgen         0.824 0.0537 44    0.680    0.968    c

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.407 0.0537 44    0.263    0.551  a
 Donna          0.425 0.0537 44    0.281    0.569  a
 Rena           0.509 0.0537 44    0.365    0.653  ab
 Leksvik        0.681 0.0537 44    0.537    0.825   bc
 Korgen         0.714 0.0537 44    0.570    0.858    c
```

Mineral 2

```
 Location_name lsmean     SE df lower.CL upper.CL .group
 Donna          0.671 0.0486 45    0.541    0.801  a
 Tynset         0.705 0.0486 45    0.575    0.835  a
 Rena           0.741 0.0486 45    0.611    0.871  ab
 Leksvik        0.860 0.0486 45    0.730    0.990  ab
 Korgen         0.919 0.0486 45    0.789    1.049   b
```

Mineral 3

```
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.786 0.0528 44    0.644    0.928  a
 Rena           0.789 0.0528 44    0.647    0.931  a
 Korgen         0.969 0.0528 44    0.827    1.111  a
 Leksvik        0.970 0.0528 44    0.828    1.112  a
 Donna          1.314 0.0557 44    1.165    1.464   b
```

Appendix 4.5: Significance results of treatment and location on thickness of organic layer and interaction between treatment and placement of location

	Treatment (Gr/NG)	*Location*
Factor	**Thickness of o-layer**	**Thickness of o-layer**
Layer		
Org.	**Not significant (p=0.0634)**	**Significant (p= 4.13e-11)**
0-10 cm	**-**	**-**
10-20 cm	-	-
20-30 cm	-	-

Grouping of significant difference between thickness of organic layer

```
Location_name lsmean    SE df lower.CL upper.CL .group
Korgen          1.00 0.524 29   -0.391     2.39  a
Rena            1.55 0.371 29    0.566     2.53  a
Tynset          2.25 0.414 29    1.150     3.35  a
Leksvik         6.80 0.371 29    5.816     7.78   b
```

Appendix 4.6: Significance results of treatment on SOC% and interaction between treatment and placement of location

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
Factor	**%SOC**	**%SOC**	**%SOC**
Layer			
Org.	**Not significant (p=0.708)**	**Significant (p= 3.93e-06)**	**-**
0-10 cm	**Not significant (p= 0.506)**	**Significant (p= 4.85e-05)**	**-**
10-20 cm	**Not significant (p= 0.969)**	**Not significant (p= 0.0958)**	**-**
20-30 cm	**Not significant (p=0.472)**	**Not significant (p = 0.339)**	**-**

Grouping of significant difference between %SOC in location

Organic layer

```
Location_name lsmean    SE df lower.CL upper.CL .group
Korgen          16.8 2.86 31     9.26     24.4  a
Rena            23.2 2.02 31    17.90     28.6  a
Leksvik         34.6 2.02 31    29.25     39.9   b
Tynset          35.5 2.02 31    30.11     40.8   b
```

Mineral_1

```
Location_name lsmean    SE df lower.CL upper.CL .group
Korgen          5.33 0.824 45    3.12     7.54  a
Rena            5.89 0.824 45    3.67     8.10  a
Leksvik         6.11 0.824 45    3.90     8.32  a
Tynset          6.73 0.824 45    4.52     8.94  a
Donna          11.21 0.824 45    9.00    13.42   b
```

Mineral_2 – Not significant

Mineral_3 – Not significant

Appendix 4.7: Significance results of treatment on SON and interaction between treatment and placement of location

Location	*Treatment (Gr/NG)*	*Location*	*Interaction treatment/ Location*
Factor	**SON**	**SON**	**SON**
Locations			
Layer			
Org.	**Not significant (p= 0.825)**	**Significant (p= 2.2e-09)**	**-**
0-10 cm	**Not significant (p= 0.83)**	**Significant (p= 3.75e-08)**	**-**
10-20 cm	**Not significant (p= 0.72346)**	**Significant (p= 0.00365)**	**-**
20-30 cm	**Not significant (p= 0.997)**	**Not significant (p = 0.178)**	**-**

Grouping of significant difference between locations in SON-stocks
Organic layer

```
Treatment = Gr:
 Location_name lsmean     SE df  lower.CL upper.CL .group
 Korgen        0.0307 0.0201 28 -0.022761   0.0842  a
 Rena          0.0358 0.0162 28 -0.007192   0.0788  a
 Tynset        0.0497 0.0186 28  0.000229   0.0992  a
 Leksvik       0.2018 0.0162 28  0.158808   0.2448   b

Treatment = NG:
 Location_name lsmean     SE df  lower.CL upper.CL .group
 Korgen        0.0271 0.0236 28 -0.035710   0.0900  a
 Rena          0.0322 0.0162 28 -0.010775   0.0752  a
 Tynset        0.0462 0.0168 28  0.001465   0.0908  a
 Leksvik       0.1982 0.0162 28  0.155225   0.2412   b
```

Mineral 1

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.126 0.0159 44   0.0838    0.169  a
 Rena           0.166 0.0159 44   0.1238    0.209  ab
 Leksvik        0.198 0.0159 44   0.1558    0.241   b
 Korgen         0.210 0.0159 44   0.1678    0.253   b
 Donna          0.282 0.0159 44   0.2398    0.325    c

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Tynset         0.124 0.0159 44   0.0810    0.166  a
 Rena           0.164 0.0159 44   0.1210    0.206  ab
 Leksvik        0.196 0.0159 44   0.1530    0.238   b
 Korgen         0.208 0.0159 44   0.1650    0.250   b
 Donna          0.280 0.0159 44   0.2370    0.322    c
```

Mineral 2

```
Treatment = Gr:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Rena           0.120 0.0193 44   0.0685    0.172  a
 Leksvik        0.131 0.0193 44   0.0795    0.183  a
 Korgen         0.138 0.0193 44   0.0865    0.190  a
 Tynset         0.152 0.0193 44   0.1005    0.204  ab
 Donna          0.214 0.0193 44   0.1625    0.266   b

Treatment = NG:
 Location_name lsmean     SE df lower.CL upper.CL .group
 Rena           0.126 0.0193 44   0.0741    0.177  a
 Leksvik        0.137 0.0193 44   0.0851    0.188  a
 Korgen         0.144 0.0193 44   0.0921    0.195  a
 Tynset         0.158 0.0193 44   0.1061    0.209  ab
 Donna          0.220 0.0193 44   0.1681    0.271   b
```

Mineral 3
Not relevant

Appendix 4.8: Significance results of treatment on Ca-stocks and interaction between treatment and placement of location

	Treatment (Gr/NG)	***Location***	***Interaction treatment/ Location***
Factor	**Ca-stocks**	**Ca-stocks**	**Ca-stocks**
Layer			
Org.	**Not significant (p= 0.6328)**	**Significant (p= 0.0322)**	**-**
0-10 cm	**Not significant (p= 0.121)**	**Significant (p= 7.54e-12)**	**-**

Grouping of significant difference between locations in Ca-stocks
Organic layer

```
Location_name lsmean     SE df lower.CL upper.CL .group
Korgen        0.0835 0.0476 28  -0.0431    0.210  a
Rena          0.1139 0.0327 28   0.0269    0.201  a
Leksvik       0.1793 0.0327 28   0.0922    0.266  a
Tynset        0.2341 0.0369 28   0.1360    0.332  a
```

Mineral 1

```
Location_name  lsmean    SE df lower.CL upper.CL .group
Leksvik        0.1715 0.154 44  -0.2422    0.585  a
Rena           0.6893 0.154 44   0.2756    1.103  ab
Tynset         0.7092 0.154 44   0.2955    1.123  ab
Korgen         0.8169 0.154 44   0.4032    1.231   b
Donna          2.2125 0.154 44   1.7989    2.626    c
```

Appendix 4.9: Significance results of treatment on Mg-stocks and interaction between treatment and placement of location

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
Factor	**Mg-stocks**	**Mg-stocks**	**Mg-stocks**
Layer			
Org.	**Not significant (p= 0.947)**	**Significant (p= 2.6e-11)**	**-**
0-10 cm	**Significant (p= 0.00458)**	**Significant (p= 9.27e-09)**	**Significant (p=0.00584)**

Grouping of significant difference between locations in Mg-stocks

Organic layer

```
Location_name  lsmean      SE df lower.CL upper.CL .group
Tynset        0.00995 0.00990 29 -0.01633   0.0362  a
Rena          0.01655 0.00885 29 -0.00695   0.0401  a
Korgen        0.02385 0.01252 29 -0.00939   0.0571  a
Leksvik       0.14206 0.00885 29  0.11856   0.1656   b
```

Mineral 1

```
Treatment = Gr:
 Location_name lsmean     SE df  lower.CL upper.CL .group
 Tynset        0.0165 0.0241 40 -0.048603   0.0816  a
 Leksvik       0.0605 0.0241 40 -0.004632   0.1256  ab
 Rena          0.0642 0.0241 40 -0.000906   0.1293  ab
 Donna         0.1007 0.0241 40  0.035632   0.1658  ab
 Korgen        0.1242 0.0241 40  0.059055   0.1893   b

Treatment = NG:
 Location_name lsmean     SE df  lower.CL upper.CL .group
 Tynset        0.0123 0.0241 40 -0.052835   0.0774  a
 Rena          0.0523 0.0241 40 -0.012784   0.1174  a
 Leksvik       0.0606 0.0241 40 -0.004513   0.1257  a
 Donna         0.2169 0.0241 40  0.151817   0.2820   b
 Korgen        0.2533 0.0241 40  0.188228   0.3184   b
```

Grouping of significant difference between sites **in Mg-stocks**

Organic layer

Not relevant

Mineral 1

```
Location_name = Donna:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr        0.1007 0.0241 40  0.04464   0.1568  a
 NG        0.2169 0.0241 40  0.16082   0.2730   b

Location_name = Korgen:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr        0.1242 0.0241 40  0.06806   0.1803  a
 NG        0.2533 0.0241 40  0.19723   0.3094   b

Location_name = Leksvik:
 Treatment lsmean     SE df lower.CL upper.CL .group
 Gr        0.0605 0.0241 40  0.00437   0.1166  a
 NG        0.0606 0.0241 40  0.00449   0.1167  a

Location_name = Rena:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG        0.0523 0.0241 40 -0.00378   0.1084  a
 Gr        0.0642 0.0241 40  0.00810   0.1203  a

Location_name = Tynset:
 Treatment lsmean     SE df lower.CL upper.CL .group
 NG        0.0123 0.0241 40 -0.04383   0.0684  a
 Gr        0.0165 0.0241 40 -0.03960   0.0726  a
```

Appendix 4.10: Significance results of treatment on K-stocks and interaction between treatment and placement of location

	Treatment (Gr/NG)	*Location*	*Interaction treatment/ Location*
Factor	**K-stocks**	**K-stocks**	**K-stocks**
Layer			
Org.	**Not significant (p= 0.703)**	**Significant (p= 6.83e-10)**	**-**
0-10 cm	**Not significant (p= 0.5702)**	**Significant (p= 0.00286)**	**-**

Grouping of significant difference between locations in K-stocks

Organic layer

```
Location_name lsmean      SE df lower.CL upper.CL .group
Korgen        0.0143 0.00675 29 -0.00358   0.0322  a
Tynset        0.0265 0.00533 29  0.01237   0.0407  a
Rena          0.0346 0.00477 29  0.02193   0.0473  a
Leksvik       0.0850 0.00477 29  0.07231   0.0976   b
```

Mineral 1

```
Location_name lsmean    SE df lower.CL upper.CL .group
Tynset        0.0351 0.007 44   0.0164   0.0539  a
Donna         0.0477 0.007 44   0.0289   0.0665  ab
Korgen        0.0624 0.007 44   0.0436   0.0812   b
Rena          0.0659 0.007 44   0.0471   0.0847   b
Leksvik       0.0669 0.007 44   0.0481   0.0857   b
```

Appendix 4.11: Significance results of treatment on P-stocks and interaction between treatment and placement of location

	Treatment (Gr/NG)	***Location***	***Interaction treatment/ Location***
Factor	**P-stocks**	**P-stocks**	**P-stocks**
Layer			
Org.	**Not significant (p= 0.433)**	**Significant (p= 1.58e-07)**	**-**
0-10 cm	**Not significant (p= 0.978)**	**Significant (p= 6.68e-13)**	**-**

Grouping of significant difference between locations in P-stocks

Organic layer

```
Location_name  lsmean      SE df  lower.CL upper.CL .group
Korgen        0.00450 0.00376 28 -0.005510   0.0145  a
Rena          0.00573 0.00280 28 -0.001734   0.0132  a
Tynset        0.00836 0.00297 28  0.000444   0.0163  a
Leksvik       0.03234 0.00266 28  0.025259   0.0394   b
```

Mineral 1

```
 Location_name  lsmean      SE df lower.CL upper.CL .group
 Tynset        0.00979 0.00335 40 0.000752   0.0188  a
 Rena          0.01350 0.00335 40 0.004462   0.0225  a
 Donna         0.01618 0.00335 40 0.007142   0.0252  a
 Korgen        0.01968 0.00335 40 0.010642   0.0287  a
 Leksvik       0.04431 0.00335 40 0.035275   0.0533   b

Treatment = NG:
 Location_name  lsmean      SE df lower.CL upper.CL .group
 Tynset        0.01028 0.00335 40 0.001248   0.0193  a
 Korgen        0.01361 0.00335 40 0.004577   0.0227  a
 Rena          0.01631 0.00335 40 0.007269   0.0253  a
 Donna         0.01966 0.00335 40 0.010621   0.0287  a
 Leksvik       0.04331 0.00335 40 0.034274   0.0523   b
```

Appendix 4.12: Significance results of treatment on CN-ratio and interaction between treatment and placement of location

	Treatment (Gr/NG)	***Location***	***Interaction treatment/ Location***
Factor	**CN**	**CN**	**CN**
Layer			
Org.	**Significant (p= 1.27e-05)**	**Significant (p= 8.82e-09)**	**Significant (p= 0.0103)**
0-10 cm	**Not significant (p= 0.853)**	**Significant (p= 9.6e-09)**	**-**
10-20 cm	**Not significant (p= 0.89002)**	**Significant (p= 0.000904)**	**-**
20-30 cm	**Not significant (p= 0.240182)**	**Significant (p = 3e-04)**	**-**

Grouping of significant difference between locations in CN

Organic layer

```
 Location_name lsmean    SE df lower.CL upper.CL .group
 Korgen          17.9 1.020 27     15.2     20.7  a
 Tynset          22.5 0.912 27     20.0     24.9   b
 Leksvik         25.2 0.912 27     22.8     27.6   b
 Rena            25.2 0.912 27     22.8     27.7   b

Treatment = NG:
 Location_name lsmean    SE df lower.CL upper.CL .group
 Tynset          22.7 0.912 27     20.3     25.2  a
 Korgen          24.9 2.040 27     19.5     30.3  ab
 Leksvik         28.7 0.912 27     26.3     31.2   bc
 Rena            31.7 0.912 27     29.3     34.2    c
```

Mineral 1

```
 Location_name lsmean    SE df lower.CL upper.CL .group
 Tynset          16.2 0.625 44     14.5     17.9  a
 Korgen          18.0 0.625 44     16.3     19.7  ab
 Donna           18.4 0.625 44     16.7     20.0  ab
 Rena            20.4 0.625 44     18.8     22.1   b
 Leksvik         22.9 0.625 44     21.3     24.6    c
```

Mineral 2

<pre>Location_name lsmean   SE df lower.CL upper.CL .group
Tynset   15.5 1.24 45   12.2   18.9 a
Donna   16.5 1.24 45   13.2   19.8 ab
Rena   17.6 1.24 45   14.3   21.0 abc
Korgen   20.7 1.24 45   17.4   24.0   bc
Leksvik   22.6 1.24 45   19.2   25.9   c</pre>

Mineral 3

<pre>Location_name lsmean   SE df lower.CL upper.CL .group
Donna   14.8 0.967 44   12.2   17.4 a
Tynset   15.1 0.917 44   12.6   17.6 a
Rena   17.2 0.917 44   14.8   19.7 ab
Korgen   18.8 0.917 44   16.4   21.3   b
Leksvik   20.3 0.917 44   17.9   22.8   b</pre>

Grouping of significant difference between sites in CN
Organic layer

<pre>Location_name = Korgen:
 Treatment lsmean   SE df lower.CL upper.CL .group
 Gr   17.9 1.020 27   15.5   20.4 a
 NG   24.9 2.040 27   20.1   29.7   b
 	
Location_name = Leksvik:
 Treatment lsmean   SE df lower.CL upper.CL .group
 Gr   25.2 0.912 27   23.0   27.4 a
 NG   28.7 0.912 27   26.6   30.9   b
 	
Location_name = Rena:
 Treatment lsmean   SE df lower.CL upper.CL .group
 Gr   25.2 0.912 27   23.1   27.4 a
 NG   31.7 0.912 27   29.6   33.9   b
 	
Location_name = Tynset:
 Treatment lsmean   SE df lower.CL upper.CL .group
 Gr   22.5 0.912 27   20.3   24.6 a
 NG   22.7 0.912 27   20.6   24.9 a</pre>

Mineral 1
Not relevant
Mineral 2
Not relevant
Mineral 3
Not relevant

Appendix 5: Average of pH, soil depth, BD, %SOC and %SIC

Appendix 5.1: The table contains a summary of average of pH, soil depth, BD, %SOC and %SIC for layers and plots for all locations and treatments.

Location	*Soil type based on soil texture*		*Average pH ± SE*		*Average soil depth ± SE [cm]*		*Average $BD_{fineearth}$ ± SE [g/cm^3]*		*Average %SOC ± SE [%]*		*Average %SIC ± SE [%]*	
	Gr	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**
Rena												
Org.			4.9 ± 0.096	4.62 ± 0.18	1.3 ± 0.122	1.8 ± 0.122	0.31 ± 0.046	0.24 ± 0.027	20.28 ± 1.717	26.2 ± 2.295		
0-10 cm			4.77 ± 0.085	4.58 ± 0.046	10 ± 0	10 ± 0	0.59 ± 0.048	0.54 ± 0.031	6.11 ± 0.312	5.66 ± 0.243		
10-20 cm			4.83 ± 0.082	4.68 ± 0.055	10 ± 0	10 ± 0	0.76 ± 0.014	0.72 ± 0.063	3.01 ± 0.201	2.77 ± 0.147		
20-30 cm	Silty loam	Silty loam	5.15 ± 0.148	4.91 ± 0.134	8.8 ± 0.583	8.3 ± 0.7	0.75 ± 0.052	0.82 ± 0.053	2.17 ± 0.105	2.17 ± 0.163		
Tynset												
Org.			5.43 ± 0.325	5.79 ± 0.192	2 ± 0	2.4 ± 0.245	0.12 ± 0.011	0.13 ± 0.014	33.6 ± 2.645	37.3 ± 1.628		
0-10 cm			5.49 ± 0.347	5.5 ± 0.184	8.8 ± 0.49	7.6 ± 0.245	0.51 ± 0.101	0.42 ± 0.088	7.46 ± 2.682	5.99 ± 1.227		
10-20 cm			5.61 ± 0.305	5.51 ± 0.142	10 ± 0	10 ± 0	0.63 ± 0.091	0.78 ± 0.089	5.45 ± 2.689	2.91 ± 0.736		

20-30 cm	Loamy sand	Sandy loam	5.78 ± 0.289	5.65 ± 0.134	7.7 ± 0.97	10 ± 0	0.81 ± 0.133	0.76 ± 0.063	4.73 ± 2.135	1.52 ± 0.385		
Leksvik												
Org.			4.59 ± 0.068	4.36 ± 0.037	6 ± 0.689	7.6 ± 1.03	0.29 ± 0.036	0.21 ± 0.052	32.34 ± 4.129	36.84 ± 4.16		
0-10 cm			4.49 ± 0.028	4.27 ± 0.025	10 ± 0	10 ± 0	0.78 ± 0.036	0.7 ± 0.044	5.83 ± 0.169	6.4 ± 0.224		
10-20 cm			4.69 ± 0.032	4.48 ± 0.031	10 ± 0	10 ± 0	0.87 ± 0.072	0.85 ± 0.036	2.78 ± 0.153	4.26 ± 0.363		
20-30 cm	Silt	Silty loam	4.86 ± 0.033	4.68 ± 0.039	9 ± 1	9.6 ± 0.4	0.97 ± 0.034	0.96 ± 0.042	1.83 ± 0.061	2.58 ± 0.272		
Korgen												
Org.			5.09 ± 0.34	5.2 ± 0	1 ± 0	1	0.38 ± 0.021	0.18	17.35 ± 1.914	14.7		
0-10 cm			5.1 ± 0.232	5.54 ± 0.199	10 ± 0	10 ± 0	0.93 ± 0.089	0.61 ± 0.017	4.1 ± 0.795	6.56 ± 0.379		
10-20 cm			5.23 ± 0.255	5.81 ± 0.259	10 ± 0	10 ± 0	1.04 ± 0.056	0.8 ± 0.041	2.35 ± 0.382	4.12 ± 0.505		
20-30 cm	Loamy sand	Loamy sand	5.56 ± 0.235	6.15 ± 0.313	9.6 ± 0.4	9.6 ± 0.4	1.08 ± 0.082	0.86 ± 0.054	1.96 ± 0.476	2.57 ± 0.528		1.64 ± 0.404
Dønna												
Org.			-	-	-	-	-	-	-	0.85	-	-
0-10 cm			6.42± 0.09	5.66 ± 0.064	10 ± 0	10 ± 0	0.48 ± 0.104	0.48 ± 0.039	10.53 ± 1.393	11.9 ± 1.524	0.14 ± 0.04	
10-20 cm			6.45 ± 0.055	5.7 ± 0.116	10 ± 0	10 ± 0	0.7 ± 0.081	0.64 ± 0.07	5.8 ± 1.12	5.2 ± 0.385	0.09 ± 0.01	
20-30 cm	Sandy loam	Sandy loam	6.78 ± 0.074	5.79 ± 0.136	10 ± 0	9.5 ± 0.5	1.38 ± 0.93	1.23 ± 0.083	1.36 ± 0.261	1.40 ± 0.203	0.06 ± 0.008	

Appendix 6: Average of SOC- and labile SOC-stock

Appendix 6: The table contains a summary of average of SOC- and labile SOC-stock for all layers every location and both treatments (Gr/NG).

Location	***SOC stock ± SE [kg/m²]***		***Labile SOC-stocks ± SE [kg/m²]***	
	Gr	**NG**	**Gr**	**NG**
Rena				
Org.	0.805 ± 0.138	1.087 ± 0.072	0.058 ± 0.007	0.061 ± 0.004
0-10 cm	3.615 ± 0.387	3.066 ± 0.268	0.159 ± 0.016	0.143 ± 0.006
10-20 cm	2.271 ± 0.122	2.009 ± 0.225	0.1 ± 0.007	0.113 ± 0.011
20-30 cm	1.418 ± 0.098	1.459 ± 0.124	0.052 ± 0.004	0.071 ± 0.009
Tynset				
Org.	0.872 ± 0.113	1.155 ± 0.223	0.046 ± 0.011	0.049 ± 0.006
0-10 cm	2.5 ± 0.587	1.598 ± 0.107	0.09 ± 0.016	0.064 ± 0.002
10-20 cm	2.635 ± 0.867	2.055 ± 0.419	0.073 ± 0.016	0.079 ± 0.015
20-30 cm	1.999 ± 0.530	1.167 ± 0.345	0.043 ± 0.008	0.043 ± 0.010
Leksvik				
Org.	5.229 ± 0.553	5.532 ± 1.278	0.282 ± 0.033	0.266 ± 0.069
0-10 cm	4.548 ± 0.311	4.422 ± 0.154	0.228 ± 0.014	0.283 ± 0.010
10-20 cm	2.38 ± 0.124	3.575 ± 0.173	0.064 ± 0.003	0.148 ± 0.019
20-30 cm	1.605 ± 0.194	2.391 ± 0.290	0.032 ± 0.003	0.072 ± 0.013
Korgen				
Org.	0.661 ± 0.068	0.260 ± 0	0.041 ± 0.005	0.016 ± 0
0-10 cm	3.538 ± 0.309	3.975 ± 0.218	0.179 ± 0.016	0.199 ± 0.011
10-20 cm	2.364 ± 0.284	3.271 ± 0.396	0.08 ± 0.012	0.108 ± 0.011
20-30 cm	1.922 ± 0.379	1.995 ± 0.292	0.045 ± 0.006	0.072 ± 0.005
Dønna				
Org.	-	-	-	-
0-10 cm	4.523 ± 0.457	5.502 ± 0.419	0.125 ± 0.012	0.197 ± 0.011
10-20 cm	3.76 ± 0.502	3.292 ± 0.346	0.102 ± 0.009	0.128 ± 0.016
20-30 cm	1.85 ± 0.349	1.597 ± 0.161	0.064 ± 0.011	0.073 ± 0.006

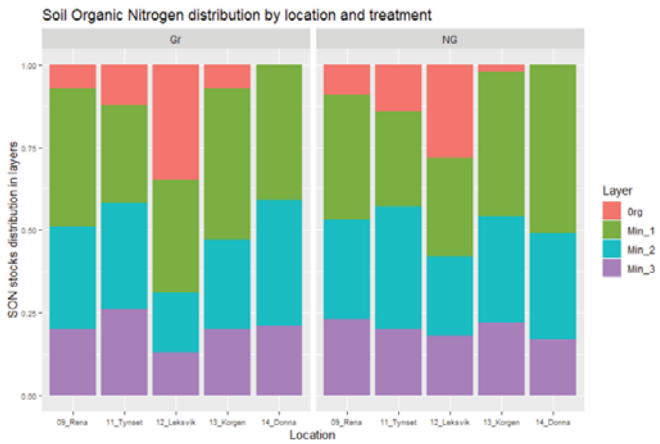
Appendix 7: Average ± SE of CN-ratio, SON-, Ca-, K-, Mg- and P-stocks

Appendix 7: The table contains a summary of average ± SE of CN-ratio, SON-, Ca-, K-, Mg- and P-stocks for all layers at every location and sites (Gr/NG)

Location	***SON stock** ± SE [kg/m²]*		***Ca-stocks** ± SE [g/m²]*		***K-stocks** ± SE [g/m²]*		***Mg-stocks** ± SE [g/m²]*		***P-stocks** ± SE [g/m²]*		***C:N** ± SE*	
	Gr	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**	**Gr**	**NG**
Rena												
Org.	0.033 ± 0.007	0.034 ± 0.002	0.12 ± 0.032	0.108 ± 0.012	0.032 ± 0.003	0.037 ± 0.003	0.014 ± 0.002	0.019 ± 0.002	0.004 ± 0	0.016 ± 0.001	25.25 ± 1.648	25.25 ± 0.794
0-10 cm	0.182 ± 0.021	0.147 ± 0.011	0.749 ± 0.213	0.43 ± 0.066	0.07 ± 0.009	0.058 ± 0.007	0.064 ± 0.009	0.052 ± 0.007	0.013 ± 0.001	0.007 ± 0.001	20.02 ± 0.79	20.83 ± 0.554
10-20 cm	0.13 ± 0.01	0.114 ± 0.012									17.62 ± 0.492	17.63 ± 0.353
20-30 cm	0.081 ± 0.006	0.086 ± 0.005									17.45 ± 0.765	17.00 ± 0.736
Tynset												
Org.	0.038 ± 0.006	0.052 ± 0.011	0.119 ± 0.069	0.180 ± 0.081	0.021 ± 0.003	0.03 ± 0.005	0.008 ± 0.001	0.011 ± 0.003	0.007 ± 0.002	0.009 ± 0.002	22.48 ± 0.663	22.73 ± 0.595
0-10 cm	0.147 ± 0.035	0.104 ± 0.007	0.615 ± 0.275	0.191 ± 0.085	0.038 ± 0.009	0.029 ± 0.004	0.017 ± 0.003	0.012 ± 0.001	0.01 ± 0.002	0.01 ± 0.002	17.06 ± 0.29	15.32 ± 0.142
10-20 cm	0.163 ± 0.061	0.146 ± 0.027									17.16 ± 1.963	13.89 ± 0.302
20-30 cm	0.127 ± 0.036	0.082 ± 0.022									16.11 ± 2.251	14.07 ± 0.407
Leksvik												
Org.	0.208 ± 0.022	0.194 ± 0.045	0.198 ± 0.039	0.161 ± 0.041	0.086 ± 0.011	0.084 ± 0.012	0.144 ± 0.015	0.141 ± 0.030	0.03 ± 0.007	0.035 ± 0.007	25.19 ± 0.471	28.73 ± 0.784
0-10 cm	0.196 ± 0.008	0.196 ± 0.013	0.086 ± 0.011	0.058 ± 0.012	0.078 ± 0.014	0.053 ± 0.004	0.06 ± 0.005	0.061 ± 0.006	0.044 ± 0.008	0.043 ± 0.003	23.15 ± 0.755	22.76 ± 0.736
10-20 cm	0.104 ± 0.005	0.161 ± 0.009									22.83 ± 0.751	22.28 ± 0.727
20-30 cm	0.079 ± 0.010	0.118 ± 0.013									20.43 ± 0.689	20.25 ± 0.784
Korgen												
Org.	0.037 ± 0.002	-	0.087 ± 0.021	-	0.016 ± 0.001	-	0.027 ± 0.003	-	0.005 ± 0	-	17.98 ± 1.028	
0-10 cm	0.218 ± 0.011	0.202 ± 0.007	0.508 ± 0.223	0.927 ± 0.159	0.058 ± 0.013	0.064 ± 0.008	0.124 ± 0.044	0.253 ± 0.058	0.02 ± 0.004	0.014 ± 0.001	16.35 ± 1.561	19.65 ± 0.963
10-20 cm	0.132 ± 0.013	0.15 ± 0.019									18.19 ± 02.23	23.20 ± 4.335
20-30 cm	0.097 ± 0.009	0.01 ± 0.012									19.10 ± 2.28	18.55 ± 2.114
Dønna												
Org.												
0-10 cm	0.231 ± 0.025	0.322 ± 0.023	2.468 ± 0.315	1.758 ± 0.198	0.035 ± 0.007	0.058 ± 0.003	0.101 ± 0.009	0.217 ± 0.017	0.016 ± 0.003	0.02 ± 0.001	19.66 ± 0.448	17.10 ± 0.491
10-20 cm	0.214 ± 0.027	0.21 ± 0.017									17.45 ± 0.544	15.56 ± 0.445
20-30 cm	0.122 ± 0.025	0.115 ± 0.009									15.56 ± 0.814	13.79 ± 0.486

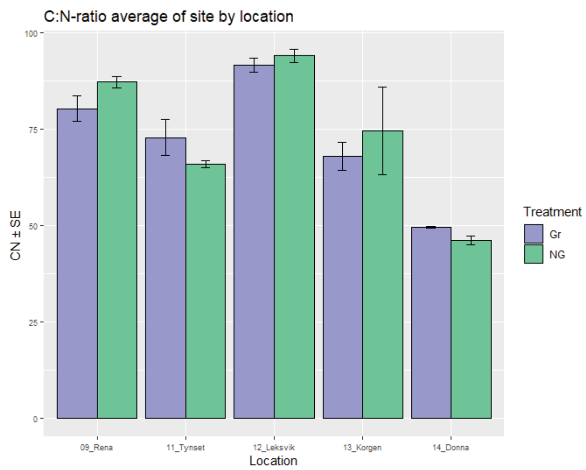
Appendix 8: SON stock distribution in profile

Appendix 8: Average SON stock distribution in profile [%] by location and treatment. The profile consists of 5 plots in each category of location and site. The profile is divided into the organic layer (red), mineral layer 0-10 cm (green), mineral layer 10-20 cm (blue) and mineral layer 20-30 cm (purple). The location is given on the x-axis and the heading frame the treatment, hence grazed and non-grazed (Gr/NG). Number of samples n in each category.



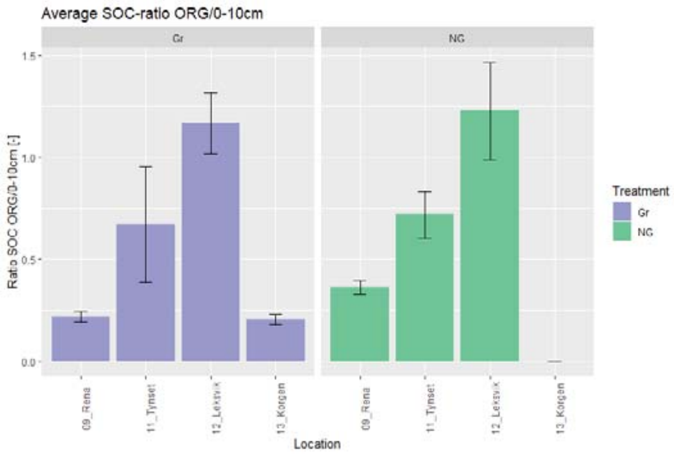
Appendix 9: Average C:N ratio ± standard error (SE) of all plots

Appendix 9: Average C:N ratio ± standard error (SE) of all plots divided by treatment and location. All locations and treatments sums to n=5 plots for each bar. For treatment grazed (Gr) blue bars and non-grazed (NG) green bars.



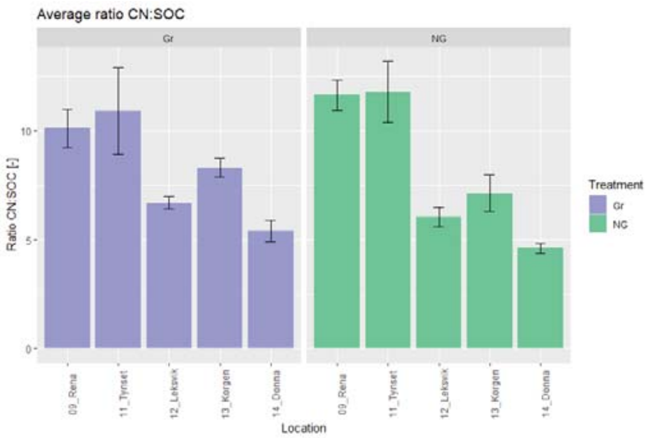
Appendix 10: Relationship of SOC between organic layer and mineral layer 0-10 cm

Appendix 10: Ratio of average SOC content ± standard error (SE) of the organic layer and mineral 1 layer (0-10 cm) divided by treatment and location. All locations and treatments sums to n=5 plots for each bar. For treatment grazed (Gr) blue bars and non-grazed.



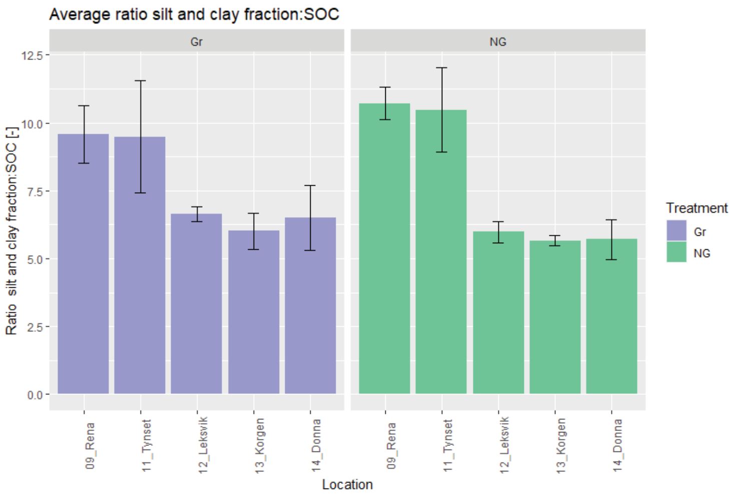
Appendix 11: Relationship between C:N ratio and SOC

Appendix 11: Ratio of average C:N and average SOC stock [kgC/m2] by treatment and location. For treatment grazed (Gr) blue bars and non-grazed (NG) green bars. The locations are given on the x-axis. Number of samples n in each category.

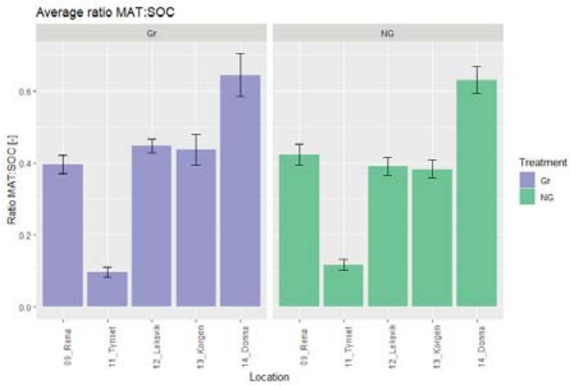


Appendix 12: Relationship between silt+clay ratio and SOC

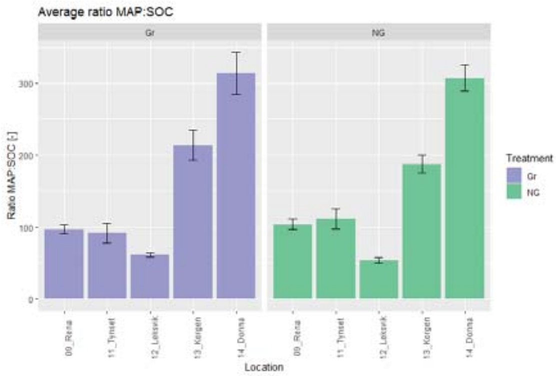
Appendix 12: Ratio of average sum of silt and clay fraction and average SOC stock [kgC/m2] by treatment and location. For treatment grazed (Gr) blue bars and non-grazed (NG) green bars. The locations are given on the x-axis.



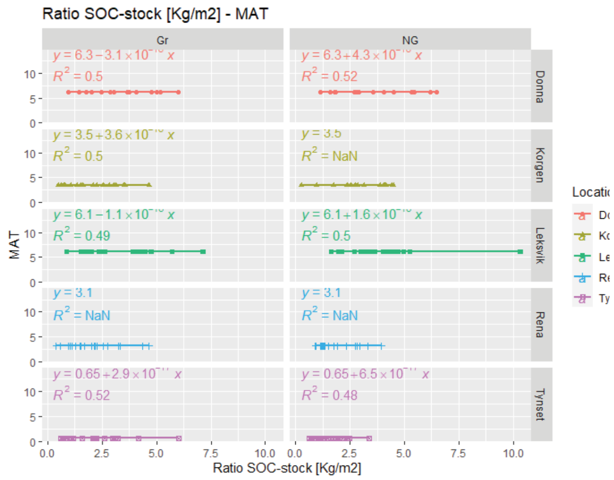
Appendix 13: Relationship between climatic factors and SOC

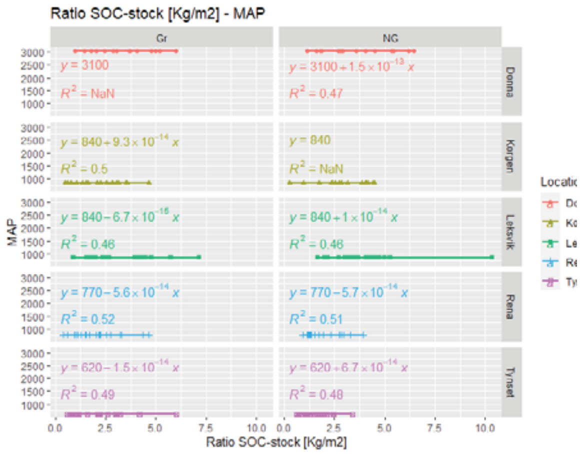


Appendix 13.1: Ratio of mean annual temperature (MAT) and average SOC stock [kgC/m2] by treatment and location. For treatment grazed (Gr) blue bars and non-grazed (NG) green bars. The locations are given on the x-axis.



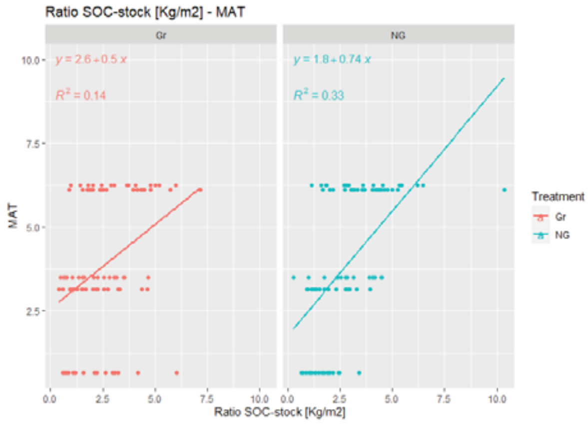
Appendix 13.2: Ratio of mean annual precipitation (MAP) and average SOC stock [kgC/m2] by treatment and location. For treatment grazed (Gr) blue bars and non-grazed (NG) green bars. The locations are given on the x-axis.

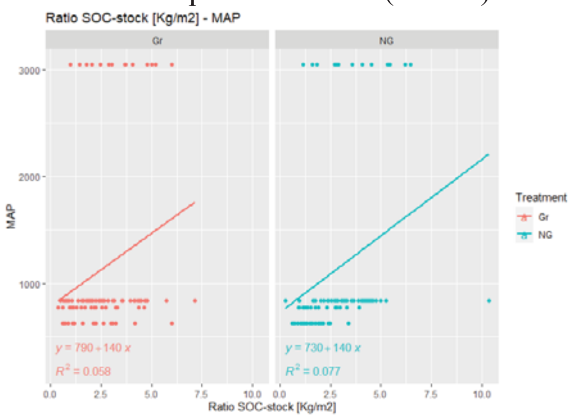




Appendix 13.3: linear regression between the MAT and average SOC stock [kgC/m2] divided by treatment and location. The frame on the right side filters the locations, the frame on the top the treatment (Gr/NG).

Appendix 13.4: linear regression between the MAP and average SOC stock [kgC/m2] divided by treatment and location. The frame on the right side filters the locations, the frame on the top the treatment (Gr/NG).



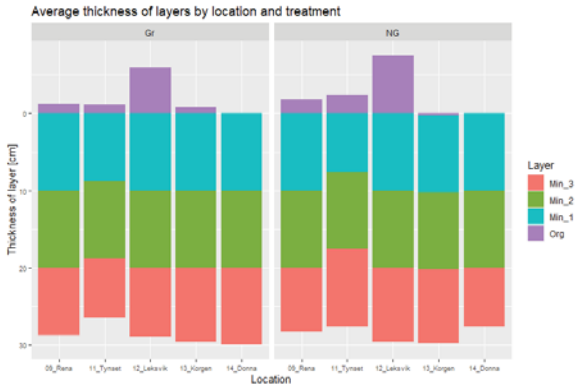


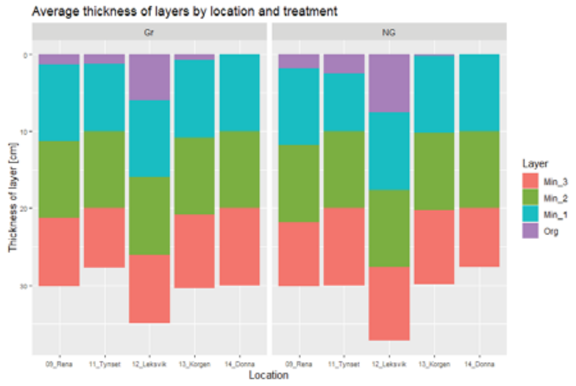
Appendix 13.5: linear regression between the MAT and average SOC stock [kgC/m2] for all locations divided by treatment. The frame on the top side filters the locations, the frame on the top the treatment (Gr/NG).

Appendix 13.6: linear regression between the MAP and average SOC stock [kgC/m2] for all locations divided by treatment. The frame on the top side filters the locations, the frame on the top the treatment (Gr/NG).

Appendix 14: Sampling depths

Appendix 14.1, 14.2: Average thickness of all layers, organic layer in purple (Org), mineral layer 0-10 cm (Min_1) in blue, mineral layer 10-20 cm in green (Min_2) and mineral layer 20-30 cm in red (Min_3). The average of each category (n=5), hence no sample collected counted as a result. The bar plot represents an average plot of location and site. The figure 14.1 displays the organic layer above ground, figure 14.2 displays the organic layer beneath ground.





Appendix 15: Table of count of samples for SOC-, LSOC- and SON-stocks and CN-ratio

Appendix 15: Table of number of samples for SOC-, LSOC- and SON-stocks and CN-ratio per location, treatment, and layer.

Row Labels	*Count of SOC_stock_Kg_m2*	*Count of Labile_SOC_Kg_m2*	*Count of CN*	*Count of SON_stock_Kg_m2*
Donna	**29**	**29**	**30**	**29**
Gr	**15**	**15**	**15**	**15**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
NG	**14**	**14**	**15**	**14**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	4	4	4	4
NO sample			1	
Korgen	**35**	**35**	**35**	**35**
Gr	**19**	**19**	**19**	**19**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	4	4	4	4
NG	**16**	**16**	**16**	**16**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	1	1	1	1
Leksvik	**40**	**40**	**40**	**40**
Gr	**20**	**20**	**20**	**20**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	5	5	5	5
NG	**20**	**20**	**20**	**20**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	5	5	5	5
Rena	**40**	**40**	**40**	**40**
Gr	**20**	**20**	**20**	**20**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	5	5	5	5
NG	**20**	**20**	**20**	**20**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	5	5	5	5
Tynset	**38**	**38**	**40**	**38**

Gr	**18**	**18**	**20**	**18**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5	5	5
Org	3	3	5	3
NG	**20**	**20**	**20**	**20**
Min_1	5	5	5	5
Min_2	5	5	5	5
Min_3	5	5		
Org	5	5		

Appendix 16: Table of MAT and MAP

Appendix 16.1 Table of data collected from (Norway, 2022) for Rena

Navn	*Stasjon*	*Tid(norsk normaltid)*	*MAT (år)*	*MAP*
Rena - Haugedalen	SN7010	1991	2,9	650
Rena - Haugedalen	SN7010	1992	3,6	769,2
Rena - Haugedalen	SN7010	1993	2,5	776,9
Rena - Haugedalen	SN7010	1994	2,2	722,3
Rena - Haugedalen	SN7010	1995	2,4	591,8
Rena - Haugedalen	SN7010	1996	1,5	706,8
Rena - Haugedalen	SN7010	1997	3,5	718,2
Rena - Haugedalen	SN7010	1998	3,1	713
Rena - Haugedalen	SN7010	1999	3,5	846,2
Rena - Haugedalen	SN7010	2002	3,1	741,4
Rena - Haugedalen	SN7010	2006	4,3	918,5
Rena - Haugedalen	SN7010	2008	4,2	954,5
Rena - Haugedalen	SN7010	2010	0,7	717
Rena - Haugedalen	SN7010	2012	3	1037,1
Rena Flyplass	SN7950	2013	2,6	764,2
Rena Flyplass	SN7950	2014	4,7	896,5
Rena Flyplass	SN7950	2015	3,9	794,6
Rena Flyplass	SN7950	2016	3,2	651,2
Rena Flyplass	SN7950	2017	2,7	748,9
Rena Flyplass	SN7950	2018	3,6	618,6
Rena Flyplass	SN7950	2019	3,2	928,3
Rena Flyplass	SN7950	2020	5,2	773,4
Rena Flyplass	SN7950	2021	2,8	713,9
SUM			72,4	17752,5
Average			3,147826	771,8478

Appendix 16.2 Table of data collected from (Norway, 2022) for Tynset

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Middeltemperatur (år)*
Venabu	SN13420	1991	0,6
Venabu	SN13420	1992	0,8
Venabu	SN13420	1993	-0,4
Venabu	SN13420	1994	-0,2

Venabu	SN13420	1995	0,2
Venabu	SN13420	1996	-0,6
Venabu	SN13420	1997	1
Venabu	SN13420	1998	0,1
Venabu	SN13420	1999	0,8
Venabu	SN13420	2000	1,4
Venabu	SN13420	2001	0
Venabu	SN13420	2002	1,1
Venabu	SN13420	2003	1,2
Venabu	SN13420	2004	1
Venabu	SN13420	2005	1,2
Venabu	SN13420	2006	1,8
Venabu	SN13420	2008	0,9
Venabu	SN13420	2009	0,4
Venabu	SN13420	2010	-1,5
Venabu	SN13420	2011	1,2
Venabu	SN13420	2012	-0,2
Venabu	SN13420	2013	0,2
Venabu	SN13420	2014	1,6
Venabu	SN13420	2015	1,1
Venabu	SN13420	2016	0,9
Venabu	SN13420	2017	0,4
Venabu	SN13420	2018	1,2
Venabu	SN13420	2019	0,9
Venabu	SN13420	2020	1,9
Venabu	SN13420	2021	0,5
SUM			19,5
Average			0,65

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Årsnedbør*
Ellefsplass	SN770	1991	504,3
Ellefsplass	SN770	1992	591,4
Ellefsplass	SN770	1993	644,1
Ellefsplass	SN770	1994	521,5
Ellefsplass	SN770	1995	466,8
Ellefsplass	SN770	1996	495,6
Ellefsplass	SN770	1997	629,9
Ellefsplass	SN770	1998	622,7
Ellefsplass	SN770	1999	680,1
Ellefsplass	SN770	2000	740,5
Ellefsplass	SN770	2001	730
Ellefsplass	SN770	2002	540,4
Ellefsplass	SN770	2003	612,3
Ellefsplass	SN770	2004	569,7
Ellefsplass	SN770	2005	611

Ellefsplass	SN770	2006	655,7
Ellefsplass	SN770	2007	619,8
Ellefsplass	SN770	2008	678,4
Ellefsplass	SN770	2009	685
Ellefsplass	SN770	2010	603
Ellefsplass	SN770	2011	822
Ellefsplass	SN770	2013	565,4
Ellefsplass	SN770	2014	701,6
Ellefsplass	SN770	2015	684,5
Ellefsplass	SN770	2016	582,3
Ellefsplass	SN770	2017	626,4
Ellefsplass	SN770	2018	608,1
Ellefsplass	SN770	2019	651,1
Ellefsplass	SN770	2020	622,2
Ellefsplass	SN770	2021	607,5
SUM			18673,3
Average			622,4433

Appendix 16.3 Table of data collected from (Norway, 2022) for Leksvik

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Middeltemperatur (år)*	*Årsnedbør*
Værnes	SN69100	1991	6,2	813,3
Værnes	SN69100	1992	6,5	889,9
Værnes	SN69100	1993	5,5	844,1
Værnes	SN69100	1994	5,5	885,2
Værnes	SN69100	1995	5,3	867,4
Værnes	SN69100	1996	4,8	554,5
Værnes	SN69100	1997	6,2	938,4
Værnes	SN69100	1998	5,7	872,4
Værnes	SN69100	1999	6,2	853,5
Værnes	SN69100	2000	6,8	668,7
Værnes	SN69100	2001	5,1	982
Værnes	SN69100	2002	6,4	688,7
Værnes	SN69100	2003	6,3	897,3
Værnes	SN69100	2004	6,4	1006,2
Værnes	SN69100	2005	6,4	910,3
Værnes	SN69100	2006	7	842
Værnes	SN69100	2007	6,1	1020,3
Værnes	SN69100	2008	6,6	744,5
Værnes	SN69100	2009	6,1	969,7
Værnes	SN69100	2010	3,4	742,8
Værnes	SN69100	2011	7	1079,5
Værnes	SN69100	2012	5,4	887,4
Værnes	SN69100	2013	6	837,7
Værnes	SN69100	2014	7,8	555,9

Værnes	SN69100	2015	7,2	-
Værnes	SN69100	2016	6,3	-
Værnes	SN69100	2017	6,3	885,1
Værnes	SN69100	2018	6,3	651,1
Værnes	SN69100	2020	7,7	700,6
Værnes	SN69100	2021	5,9	974,5
			184,4	23563
			6,146667	**841,5357**

Appendix 16.4 Table of data collected from (Norway, 2022) for Korgen

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Middeltemperatur (år)*
Mo I Rana Lufthavn	SN79600	2004	3,2
Mo I Rana Lufthavn	SN79600	2005	2,8
Mo I Rana Lufthavn	SN79600	2006	4,2
Mo I Rana Lufthavn	SN79600	2007	3,7
Mo I Rana Lufthavn	SN79600	2008	4,2
Mo I Rana Lufthavn	SN79600	2009	3,6
Mo I Rana Lufthavn	SN79600	2010	0,9
Mo I Rana Lufthavn	SN79600	2011	4,5
Mo I Rana Lufthavn	SN79600	2012	2,5
Mo I Rana Lufthavn	SN79600	2013	3,4
Mo I Rana Lufthavn	SN79600	2014	4,4
Mo I Rana Lufthavn	SN79600	2015	3,9
Mo I Rana Lufthavn	SN79600	2016	3,6
Mo I Rana Lufthavn	SN79600	2017	3,5
Mo I Rana Lufthavn	SN79600	2018	3,1
Mo I Rana Lufthavn	SN79600	2019	3,3
Mo I Rana Lufthavn	SN79600	2020	4,7
Mo I Rana Lufthavn	SN79600	2021	3,1
SUM			62,6
Average			3,477778

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Middeltemperatur (år)*	*Årsnedbør*
Bardal	SN78350	1991	-	2028,7
Bardal	SN78350	1992	-	1943,7
Bardal	SN78350	1993	-	1463,1
Bardal	SN78350	1994	-	1527,3
Bardal	SN78350	1995	-	2377,8
Bardal	SN78350	1996	-	1588,6
Bardal	SN78350	1997	-	1806,9
Bardal	SN78350	1998	-	1536,7
Bardal	SN78350	1999	-	1669

Bardal	SN78350	2000	-	1456,8
Bardal	SN78350	2001	-	1603,1
Bardal	SN78350	2002	-	1681,9
Bardal	SN78350	2003	-	1731,4
Bardal	SN78350	2006	-	1687,4
Bardal	SN78350	2007	-	1943,5
Bardal	SN78350	2008	-	1414,6
Bardal	SN78350	2009	-	1565,2
Bardal	SN78350	2010	-	1213,1
Bardal	SN78350	2011	-	2211,9
Bardal	SN78350	2015	-	2087,1
Bardal	SN78350	2016	-	1491,2
Bardal	SN78350	2017	-	1736,4
Bardal	SN78350	2018	-	1551,8
Bardal	SN78350	2019	-	1544,9
Bardal	SN78350	2020	-	2022,6
Bardal	SN78350	2021	-	1739,7
SUM				44624,4
Average				1716,323

Appendix 16.5 Table of data collected from (Norway, 2022) for Dønna

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Årsnedbør*
Lurøy	SN80200	1992	3370,9
Lurøy	SN80200	1993	2359,1
Lurøy	SN80200	1994	2669,1
Lurøy	SN80200	1995	4131,8
Lurøy	SN80200	1996	2962,8
Lurøy	SN80200	1997	3020,3
Lurøy	SN80200	1998	2614,4
Lurøy	SN80200	1999	3236,7
Lurøy	SN80200	2000	2853,9
Lurøy	SN80200	2001	2758,7
Lurøy	SN80200	2002	2696,1
Lurøy	SN80200	2003	3024,8
Lurøy	SN80200	2004	2896,3
Lurøy	SN80200	2005	3929,4
Lurøy	SN80200	2006	3063,4
Lurøy	SN80200	2007	3347,8
Lurøy	SN80200	2008	2644,3
Lurøy	SN80200	2009	2701,4
Lurøy	SN80200	2010	2334,9
Lurøy	SN80200	2011	3978,7
Lurøy	SN80200	2012	2699,5
Lurøy	SN80200	2013	3585,1

Lurøy	SN80200	2014	2375,6
Lurøy	SN80200	2015	3765,5
Lurøy	SN80200	2016	2774
Lurøy	SN80200	2017	3404,9
Lurøy	SN80200	2018	2953,4
Lurøy	SN80200	2019	2703,3
Lurøy	SN80200	2020	3809,2
Lurøy	SN80200	2021	2946,3
SUM			91611,6
Average			3053,72

Navn	*Stasjon*	*Tid(norsk normaltid)*	*Middeltemperatur (år)*
Vega - Vallsjø	SN76450	1992	6,2
Vega - Vallsjø	SN76450	1993	5,8
Vega - Vallsjø	SN76450	1994	5,3
Vega - Vallsjø	SN76450	1995	5,5
Vega - Vallsjø	SN76450	1996	5,6
Vega - Vallsjø	SN76450	1997	6,1
Vega - Vallsjø	SN76450	1998	6,1
Vega - Vallsjø	SN76450	1999	6,1
Vega - Vallsjø	SN76450	2000	6,3
Vega - Vallsjø	SN76450	2001	5,5
Vega - Vallsjø	SN76450	2002	6,8
Vega - Vallsjø	SN76450	2003	6,8
Vega - Vallsjø	SN76450	2004	6,6
Vega - Vallsjø	SN76450	2006	7,1
Vega - Vallsjø	SN76450	2007	6,6
Vega - Vallsjø	SN76450	2008	6,7
Vega - Vallsjø	SN76450	2009	6,5
Vega - Vallsjø	SN76450	2010	4,7
Vega - Vallsjø	SN76450	2011	7,2
Vega - Vallsjø	SN76450	2012	5,3
Vega - Vallsjø	SN76450	2013	6,4
Vega - Vallsjø	SN76450	2014	7
Vega - Vallsjø	SN76450	2015	7
Vega - Vallsjø	SN76450	2016	6,4
Vega - Vallsjø	SN76450	2017	6,5
Vega - Vallsjø	SN76450	2018	6,1
Vega - Vallsjø	SN76450	2019	6,1
Vega - Vallsjø	SN76450	2020	7,2
Vega - Vallsjø	SN76450	2021	6
SUM			181,5
Average			6,258621

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