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The effects of soil erosion on nutrient content in smallholding tea lands in Matara district, Sri Lanka

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A Minor Field Study

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Bachelor thesis
in Physical Geography and Ecosystem Analysis
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Cover picture: Tea land in Matara district (Photo: Carolina Emanuelsson)

Preface

The subject of soil erosion was chosen since it is a well-known problem in Sri Lanka. This study is a Minor Field Study which means that it is supported by the Swedish International Development Cooperation Agency, SIDA. The scholarship of a Minor Field Study aims to give students the opportunity to conduct a project in a developing country and carry out the studied subject in practical work. This report is a bachelor thesis of 15 ECTS in Physical Geography and Ecosystem Analysis.

The study was conducted by two persons, and due to formulaic demands, the responsibility for the text in the report had to be divided between the authors. Carolina Emanuelsson will take responsibility for the parts of 1, 3.1-3.5, 4.1-4.4, 5.1-5.2, 6.3 and 7. Elna Rasmusson will take responsibility for the parts of 2, 3.6-3.11, 4.5-4.6, 5.3 and 6.1-6.2.

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Abstract

Soil erosion is a major problem which is expanding as the natural vegetation is replaced by cultivations. This results in land degradation which decreases the quality and fertility of the soil. Sri Lanka is world leading on the market of tea, with smallholders contributing to an important amount of the production. Tea cultivation in Sri Lanka is highly influenced by the climate and varying topography, factors which also affect the process of erosion. Smallholders in Sri Lanka are very exposed to problems with erosion since much of the natural vegetation has been deforested on the behalf of tea plantations. Since the problem of erosion in Sri Lanka is more well-known in the highlands, the problem is often neglected in the areas of the lowlands even if it is still present. Therefore, this study is important in order to increase the knowledge about the problem and to be able to prevent damages caused by erosion, like the soil losing fertility.

This study enlightened the problem of erosion in the lowlands as it was done in Matara district, where the distribution of risks of erosion was analyzed and visualized with GIS. The study aimed to investigate how nutrient content in tea fields were affected by erosion. By measuring the amounts of total organic carbon and total nitrogen, potential variations in fertility in the soil could be estimated. The study raised the question if variations in fertility affected smallholders economically by altering the yield. It was assumed that slope angle in a field would correlate with the grade of erosion. Therefore, soil samples were taken from tea lands with varying steepness to investigate how nutrient content are affected by erosion. Hence, it was in the study stated that nutrient content did not correlate with slope angle.

The analyses showed that erosion were not a major threat in the area since the values of total carbon content was homogenous distributed. Still, the values were too high to be reliable. The amount of total organic carbon in the samples varied from 2.46 % to 7.00 % with the mean value of 4.79 %. The analysis of total nitrogen showed that the nitrogen content in the soils had satisfying values. The values had a small range, from 0 % to 0.18 % with a mean value of 0.033 %. The study showed that the yield of the smallholders in the area was not highly affected by variations in nutrient content and therefore probably not by erosion.

Even though the study suggests that smallholders in lowlands were not strongly affected by erosion, the problem could still be present if preventing methods are not continued to be used. Erosion is affected by different parameters that vary in importance depending on the geographical location which makes it crucial to conduct more studies of erosion in areas with different conditions to be able to control the consequences.

Keywords: Physical geography, geography, soil erosion, tea, Sri Lanka, nutrient content, smallholders, GIS

Sammanfattning

Jorderosion är ett stort problem som breder ut sig i samband med att den naturliga vegetationen avverkas. Erosion bidrar till en försämring i markkvalitet och sänker därmed markens produktionskapacitet. Sri Lanka är en världsledande exportör av te där småböndernas produktion är en viktig komponent. Teodlingen på Sri Lanka präglas av landets klimat och branta topografi, två faktorer som även spelar stor roll i erosionsutbredningen. Småbönder som odlar te på Sri Lanka är hårt utsatta för erosion då te i stor utsträckning har fått ersätta den naturliga vegetationen i landet. Erosionsproblem är mer känt i landets högländer och därför försummas ofta samma problem i lågländerna. Den här studien är därför viktig för att öka kunskapen om problemets omfattning i lågländerna och för att kunna sätta in rätt åtgärder innan marken mister sin fertilitet till följd av erosion.

Den här studien belyste problemen med erosion i de låglänta områdena då den utfördes i distriktet Matara, i vilket utbredningen av olika erosionsrisker analyserades och visualiserades med GIS. Studien syftade till att undersöka hur näringsämnen i teplantage påverkades av erosion. Genom att mäta andelarna organiskt kol och kväve i jorden kunde en potentiell variation i fertilitet uppskattas. Studien tog upp huruvida varierande fertilitet i jorden kunde påverka småbönders ekonomi och avkastning. Då fältens sluttningsvinklar antogs korrelera med graden av erosion togs jordprover från fält med varierande sluttning för att undersöka hur erosion påverkade näringsinnehållet i jorden. Studien fastslog dock att näringsinnehållet inte korrelerade med sluttningsvinkeln i fälten.

Analyserna visade att erosion inte är ett utbrett hot i distriktet då näringshalterna var höga och homogent distribuerade. Halterna organiskt kol i jordproverna varierade från 2.46 % till 7.00 % med ett medelvärde på 4.79 %. Analysen av kvävehalter i jorden visade sig ha tillfredsställande värden. Värdena låg inom ett kort intervall, mellan 0 % till 0.18 % med ett medelvärde på 0.033 %. Studien visade att småböndernas avkastning inte var påverkad av variansen i näringsinnehåll och därmed troligen inte av erosion. Trots viss osäkerhet gällande de orimligt höga halterna organiskt kol i jorden kunde den relativa variansen fortfarande tolkas med säkerhet.

Även om studien visade att småbönder i lågländerna inte påverkades nämnvärt av erosion kan problemet ändå finnas närvarande om inte åtgärder fortsätter att vidtas i förebyggande syfte. Erosion påverkas av flera parametrar som på olika geografiska platser varierar i betydelse, vilket gör det viktigt att fortsätta att utföra erosionsstudier i områden med olika förutsättningar.

Nyckelord: Naturgeografi, geografi, jorderosion, te, Sri Lanka, näringsinnehåll, småbönder, GIS

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1 Introduction

Erosion is a worldwide threat against cultivated lands since it degrades the lands and decreases the productivity, and therefore it also becomes an economical problem (Miller & Spoolman, 2010). The problem of soil erosion is increasing all over Sri Lanka since much of the natural vegetation has been replaced by cultivations. Due to the varying topography and humid climate, Sri Lanka is very sensitive to erosion. By changing the land use by deforestation and removing the natural ecosystem, the lands have received new properties to which the soil management is not always optimal. Tea is often grown in the steep slopes of the county since the plants, unlike many other crops can manage to grow at these location. Due to this the tea plantations are highly exposed to the problems of erosion. Since the most varying topography is located in the highlands, it is expected that the problems are most common here. Still, soil erosion is present also in the lowlands, even if it is not as common as in the highlands (Arasaratnam & Peiris, 2011). This is a main reason for why the study area of this study is located in Matara district, situated in the lowlands. Even if Matara district overall has a low risk of erosion it is located in the wet zone with a high annual precipitation, which may increase the water erosion (District Secriteriat-Matara, 2010). The extent of water erosion can be evaluated by studying the nutrient content in the top soil, since the nutrients would be decreased as a result of erosion. To estimate the nutrient content in the soil, organic carbon and nitrogen act as indicators of the fertility in the soil (Plaster, 2009). The soil sampling will be conducted in smallholding tea lands in Matara district. The area of a smallholding tea land is most often below one acre, which makes smallholders small scaled farmers (Daily FT, 2012).

2 Aim and approach

The aim of this study is to investigate how soil erosion affects the soil fertility in tea fields. The soil fertility will in this study be represented as total organic carbon and total nitrogen in order to be estimated quantitatively. Since tea is often grown in steep sloping fields it is relevant to determine how the nutrient amounts differ within a slope and between different fields. Furthermore, the aim includes an attempt to determine if the slope angle affects the nutrient distribution within a field. In addition to the physical and chemical studies, interviews were used to find out how the smallholders are affected by erosion; foremost economically by evaluating the yield. The interviews will examine what types of different cultivation methods that are used to minimize damages done by erosion. The study will highlight the risk of erosion in the lowlands of Sri Lanka and visualize the extent in Matara district. In order to accomplish the aim, following questions of study will be answered:

- Does soil erosion affect the nutrient content between and within tea fields?
- Is the distribution of nutrients within a tea fields affected by the slope angle?
- Are smallholders aware of and economically affected by erosion?
- How is the risk of erosion distributed in Matara district?

3 Background

3.1 Study area

Sri Lanka is located in east Asia, in the Indian Ocean. The island is located between latitudes 6° and 10° and between longitudes 79° and 82°. Sri Lanka became an independent country in 1948, after being a European colony for centuries. The capital city of the country is Colombo, located at the west coast. The population in Sri Lanka is 18.8 million (data from 2001) and the density is 312 persons per km^2, but is rather irregular distributed (Dep. of Census and Statistics b., 2001). Most of the population is found in the southwest parts of the island, around the capital city. Sri Lanka is divided into nine provinces containing 25 districts (Arasaratnam & Peiris, 2011). Matara district is located in the southern part of the country and covers 1280 km^2 and had in 2001 a population of 761,370 (Dep. of Census and Statistics c. , 2002). The study area is located close to Kamburupitiya (Fig. 1).

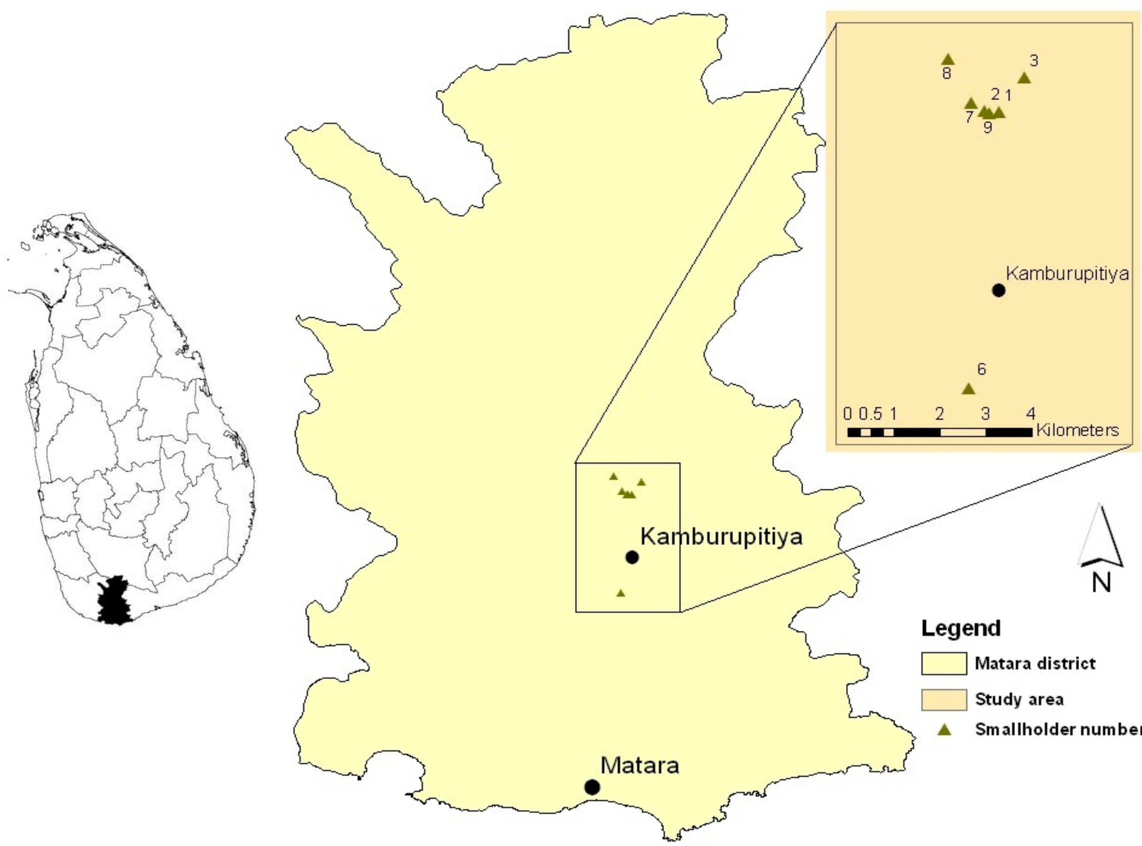


Figure 1. The location of Matara district in Sri Lanka and the location of the smallholders where soil samples were taken (International Water Management Institute, 2010).

3.2 Climate

Sri Lanka is divided into three different climatic zones (Fig. 2). The wet zone is located in the south west part of the country, including Matara district. The dry zone reaches along the eastern and the northern parts. The intermediate zone is located in the central parts including the highlands of the island, creating a border between the wet and dry zone (Ratnesiri et al., 2008). The division of these zones is influenced by different monsoons affecting the island. A northern monsoon affects the north-eastern part during December and January while the south-western parts are affected by a south monsoon during May and June. Difference in temperature in the country is strongly influenced by the topography, where the highest temperatures are found in the lowlands while the highlands experience much cooler temperatures. The average annual temperature for Sri Lanka is 28-32°C, but the average annually temperatures are only 16°C in the highlands while it reaches 32°C in the northeast coast (Climate change secretary, Year unknown). The mean annual precipitation in the wet zone is more than 2500 mm and less than 1750 mm in the dry zone, while the intermediate zone having a range in between. For all the zones, most of the precipitation falls during the monsoons (Ratnesiri et al., 2008). Matara district belongs to the wet zone and has the typical climatic conditions for the zone (District Secriteriat-Matara, 2010).

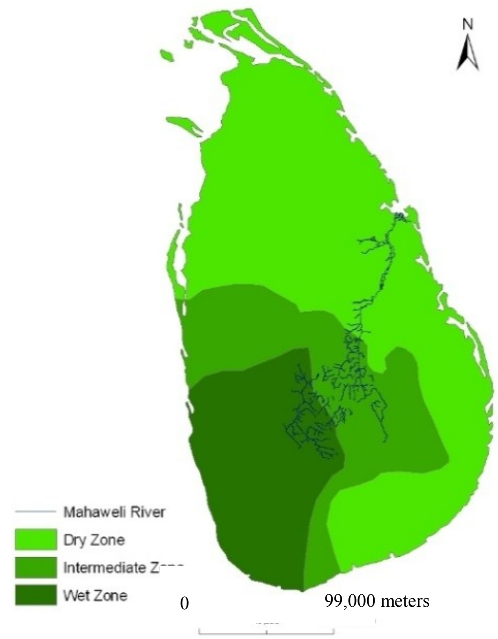


Figure 2. The location of the different climate zones in Sri Lanka (CSDS-IACC, 2010).

3.3 Geology

Sri Lanka is a part of the Indian shield. The plateau that constitute of about half of Sri Lanka is thought to origin from the Tertiary era. This plateau is located between 400-800 m a.m.sl with some flat topped hills that remains from the earlier Tertiary. Pre-Cambrian rocks in Sri Lanka differ from the ones in southern India which indicate that Sri Lanka as an island have moved and developed freely (Bridges, 1994). Sri Lanka has a varying topography with lowlands and highlands. Surrounding the highlands there are plains at different elevations, creating plateaus, ridges and valleys at different stages (Arasaratnam & Peiris, 2011). Matara district is a part of the lowlands but have an altering topography with the lowest parts at sea level by the coast and reaches up to the hilly region with a maximum elevation of 1158 m a.m.sl (District Secriteriat-Matara, 2010).

The soil types in the country are influenced by the topography and the different climates. In the wet zone, large amounts of precipitation makes leached lateritic soils, also referred to as red and yellow podzolic, the most common soil type. In the dry zone nonlateritic loamy soils such as reddish brown earth are the most common. The highlands are dominated by immature brown loams; reddish brown latosolic soils (Arasaratnam & Peiris, 2011). The soils in Matara district are mainly loamy, lateric and gravelly soils (Ranatunga et al., 2004). Soils in Matara are poor due to the intense leaking as a result of heavy precipitation. To be able to cultivate in these soils, fertilizers may have to be added (Agrolanka, Year unknown). The podzolic soils dominating the district are known as soils exposed to leaking and are also the soil type most common in the study area. The extent of leaking of aluminum and iron in the soil can be seen in the reddish color of the soil (The Free Dictionary, 2012).

3.4 Tea in Sri Lanka

Sri Lanka's agricultural history is characterized by the time as a colony. In the mid-nineteenth century, the total area of tea lands increased while the extent of natural vegetation, for example forests decreased. Tea cultivations continued to expand on behalf of coffee plantations due to a fungus that made coffee cultivation unmanageable. The increase of tea production was also important for Sri Lanka's export of crops. Today, tea is one of the most important crops in Sri Lanka's economy and the country is world leading in exporting tea (Arasaratnam & Peiris, 2011).

Out of Sri Lanka's 6.5 million ha, 222 thousand ha is used for tea cultivation (Dep. of Census and Statistics a., 2009). In Matara district the total area of smallholding tea lands are 17 thousand ha, with each smallholding tea land often being less than one acre (DailyFT, 2012). The number of smallholders growing tea in the district is approximately 46 thousand of the total 761 thousand inhabitants (Dep. of Census and Statistics c., 2002; Dep. of Census and Statistics b., 2001).

Figure 3. Shoot of Camellia sinensis (Photo: Carolina Emanuelsson).

The tea plants cultivated in Sri Lanka all belongs to the same species, *Camellia sinensis* (Fig. 3). From this species, 24 different cultivers have developed due to the species adaptation to different climate and to other natural factors (Tea Research Institute, 2012).

3.5 Soil erosion

In this study, soil erosion is defined as *"the part of the overall process of denudation that includes the physical breaking down, chemical solution and transportation of material"* (Allaby & Allaby, 2003). Erosion can be separated into wind, water, biological and anthropogenic erosion (Fairbridge, 2008). Water erosion may operate in different ways: splash, sheet, rill, gully erosion and channel flow, where sheet and rill erosion are the ones most used when measuring water erosion. Sheet and rill erosion affect the soil surface by reducing the depth of the soil. This type of erosion also affects the structure of the soil by removing the smaller and leaving the larger particles (Biot, 1987). Sheet erosion is the overland flow that is not concentrated in rills. In sheet flow, water is spread in a thin layer over the soil and is the most common form of water erosion. Soil erosion concentrated in small channels is called rills. Once a rill is formed, the erosion process speeds up due to a more concentrated erosive force (Blanco & Lal, 2008).

Water erosion includes the processes of removing particles and transporting it away. Particles that have been eroded are referred to as sediment. When the top soil is transported away as sediment, signs in form of bare plant roots or rills can be shown. Environmental conditions affect the extent of erosion mainly through climate, soil, topography and land use. Climate affects mainly by precipitation, both when it comes to the intensity and the amount of precipitation (Toy et al., 2002). The presence of monsoons may be a significantly increasing factor for erosion (Clift et al., 2010). Other climatic factors like temperature, humidity, evapotranspiration, solar radiation and wind also affect erosion but not in the same extent as precipitation (Blanco & Lal, 2008).

Topography affects erosion both in terms of concavity or convexity, but also in terms of slope length and slope angle. Runoff increases with steeper slopes and convex slopes have a higher risk of erosion than concave (Blanco & Lal, 2008).

Texture, organic matter, macro porosity and infiltration are soil properties that affect soil erosion. Depending on particle size, soils differ in the ability to be eroded. A compact soil decreases the infiltration and instead increases the runoff (Blanco & Lal, 2008).

Vegetation reduces erosion by covering the soil and by decreasing runoff. Therefore, the height and coverage of the vegetation strongly affects the amount of erosion. Root systems reduce runoff by increasing infiltration (Blanco & Lal, 2008).

Erosion of top soils may lead to loss of nutrients if they are transported away with the sediments. This cause a decrease of fertility in the eroded field which may be a problem in cultivated lands since the fields become less productive. Nutrients eroded and transported along with sediments may cause pollution or eutrophication if they reach watercourses. (Miller & Spoolman, 2010). The problems of erosion can affect all kinds of crops. Tea in Sri Lanka is often grown in slopes which increase the risk of erosion in the plantages. One problem when the top soil is removed is the roots of tea plants being exposed to sunlight. This exposure may lead to wilting of the plant (UN ESCAP, Year unknown).

3.6 Techniques in cultivating tea

There are different techniques used for soil conservation and for preventing erosion. Common techniques used in tea lands are primarily the use of ditching, intercropping, high shade trees, terraces, vetiver-grass (*Chrysopogon zizanioides*) and ground cover. The common techniques of counter seeding and stabilizing with stone walls are also well used in the area. Mentioned techniques are all commonly used in Matara district. Additional techniques in tea cultivation are the sloping agricultural land technology and the use of the grasses mana (*Cymbopogon confertiflorus*) and guathamala (*Tripsacum laxum*) which mainly are used for soil rehabilitation (Tea Research Institute, 2012).

Ditches are often used by smallholders to lead away the precipitation in constructed channels to prevent erosion of the soil. In the ditches, barriers can be built to decrease the water speed in the channel and to collect sediments. The ditches are often constructed along the plant rows in a slope, leading the water to one main ditch which is built in the slope direction (Tea Research Institute, 2012).

Intercropping means that two or more crops are grown together to increase the production of a main crop. The use of intercropping may have the advantages of gaining the maximum yield out of a limited area and preventing weed growth by contributing with competition (Gharineh &

Moosavi, 2010). The use of intercropping can also prevent erosion by increasing infiltration and protect the soil from splash erosion. The technique of intercropping is used both by smallholders and estates. Crops used in intercropping in tea lands in Matara are among others coconut (*Cocos sp.*), pepper (*Piper nigrum*), teak (*Tectona grandis*), wig banyan (*Alstonia macrophylla*) and chili (*Capsicum sp.*) (Tea Research Institute, 2012).

Shade trees are divided into two categories, high shade and medium shade. Gliricidia (*Gliricidia sepium*) is one of the medium shade trees while Silky-oak (*Grevillea robusta*) and Albizzia (*Albizzia sp.*) are high shade trees (Fig. 4). They are mainly used to protect tea plants from too intense sunlight since the tea plant uses C-3 photosynthesis and therefore have a higher productivity when the sunlight is not too intense (Prabhakaran Nair, 2010). The crown of shade trees also gives a shield against splash erosion when precipitation is high in energy. High shade trees can also be used as timber and are very common in all scales of tea lands (Tea Research Institute, 2012). When the shade trees are cut, the litter can be used as mulch which in itself can protect from erosion and increase the amount of organic matter in the soil. The mulch is left undisturbed on the soil to act as a cover and to decompose (Altieri, 1995).

Figure 4. Silky-oak acting as shade trees in a tea land (Photo: Carolina Emanuelsson).

The use of terraces is a method which means changing a slope into many steps, like in a stair, to decrease the erosion from overland flow. Terraces slow down the flow by separating the slope into flat sections. The technique also enables tea plants to grow in soils in flat sections instead of in a sloping field. Maintaining terraces usually demands much labor work and are also costly to construct and are therefore not common in smallholding tea lands (Tea Research Institute, 2012).

The grass vetiver is grown as soil conservation to protect the soil from eroding (Fig. 5). The grass is easily cultivated in different types of soil and does not need frequent maintenance. Due to its solid root system it stabilizes the soil and prevents erosion caused by water runoff. The vetiver grass is also very persistent against disturbances like flooding, draught and diseases. The technique of using vetiver grass is not as commonly used in the lowlands as in the highland tea fields (Tea Research Institute, 2012).

Figure 5. Vetiver growing along a ditch (Photo: Carolina Emanuelsson).

The use of ground cover is a method for preventing erosion by protecting the soil from splash erosion and increasing the infiltration from over land flow. The crops used as ground cover are not grown for harvest. Different cover crop species are butterfly peas (*Centrosema pubescens)*, wild ground nut (*Calopogonium mucunoides)* and silverleaf (*Desmodium uncinatum).* These crops grow underneath the tea plants in a compact sheet covering the soil (Tea Research Institute, 2012). Depending on the type of cover crop used, benefits like increased soil fertility by decomposition and nutrient-fixing, control of insect pests and adjusting the microclimate may be received (Altieri, 1995).

Mana and guathamala grass are used for soil rehabilitation in all scales of tea lands because of its nitrogen fixing qualities. It is normally grown alone for about two years in the field before planting the tea plants. The grasses could be used to prevent erosion, in the same way as the use of vetiver but are mainly used for recovering the soil. Due to the very high nutrient content, the harvested grass is for better use to the soil than as fodder for cattle and are therefore left in the field for decomposing (Tea Research Institute, 2012).

The sloping agricultural land technology, SALT, is a technique for reducing erosion and recycling fertility by leaving cut leaves from hedgerows. The technique has in Sri Lanka proven to be useful in both large-scaled and smallholding agriculture. SALT means a double hedgerow planted in counter to the slope. By using nitrogen fixing bushes and trees in combination with vetiver, erosion can be prevented. The rows are separated with 6-7 meters with around 6 rows of tea bushes in between. When the hedges are cut, the waste products are spread over the soil as green manure. The hedgerows can protect tea plants from pest attacks by providing home for predators. Other benefits from the shrubs are the use as fodder or medicinal herbs (Tea Research Institute, 2012).

3.7 Soil development

The thickness and the structure of a horizon in the soil are determined by the surrounding environment. The climate influences the soil by the amount of precipitation and the temperature. The parent material affects the drainage and the eluviation of the soil. The activity of forming organic matter is affected by the vegetation type present. Topography like slope and aspect control the forming of a catena. Catena is the different types of soil formed at different positions in a slope. Depending on which condition the soil is developed under, they can consist of different horizons. If organic matter is present, it is accumulated in the dark O-horizon in the upper layer (Fig. 6). When the organic matter is decomposed, it develops into an A-horizon with mixed organic material and minerals. This horizon may be eluviated by leaching of elements like iron and aluminum and is then called E-horizon, like in the red and yellow podzolics. The accumulation of the leached elements takes place in the B-horizon. Below these horizons the more or less solid parent material is located (Olaitan & Lobin, 1986).

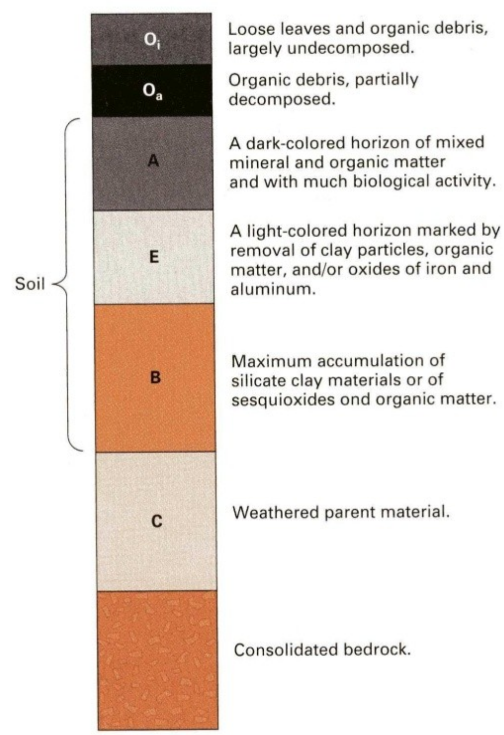


Figure 6. Classification of soil horizons (Åkerman, 2012).

The O-horizon consists of organic material that is decomposed by microorganisms into rest products, also referred to as humus. When humus is mixed with mineral particles and living or dead organisms, an organic soil is formed. The soil has a darker color when the percentage of humus is high, which also make the soil more productive. The development of humus may be limited by the pH in the soil since the growth of microorganisms is prohibited by acid conditions (Plaster, 2009). Non decomposed matter deposited on the surface is referred to as litter. Organic matter includes both litter and humus (Olaitan & Lobin, 1986). The organic matter content in the soil can be reduced if the remains in form of litter and humus are eroded (Biot, 1987). Once erosion has started in a soil, the aggregates of organic matter that binds the soil start to dissolve. When the organic matter decreases the infiltration also decreases, which makes the erosion increase even more, and will then speed up the process of erosion (Altieri, 1995).

3.8 Soil conditions

It is not only the amount of nutrients in the soil that determine the soil fertility but it is also depending on what different elements there are present and available to the plants. For the roots to be able to absorb the nutrients in the soil, the nutrients have to be in accessible forms to the roots. Also the structure and size of the root system determine the capacity for nutrient uptake (Wild, 1989). Different factors like soil temperature and the supply of water and oxygen affect nutrient uptake. In cooler soil temperatures, plants take up fewer nutrients since the processes of root interception and respiration are slowed down. A reduction of oxygen also decreases the plant respiration which leads to decreased nutrient uptake. Water in the soil act as a medium in which nutrients are transported by flow or diffusion to the roots, which means that absence of water in a soil reduces the ability for roots to absorb nutrients. There are 17 different elements needed for plant growth which are referred to as the plants nutrients. Among these, the most essential are carbon and the primary macronutrients; nitrogen, phosphorus and potassium (Plaster, 2009).

In young soils the pH are strongly influenced by the parent material, while in more developed soils pH is a result from interaction of soil minerals, solved ions and cation exchange. Different types of vegetation grow best in certain ranges in pH, for example the tea plant grows best in soils with a pH around 4.5 - 5.5. The effects of pH in the soil are mainly altering the possibility for nutrient uptake by plants, since pH in the soil control reactions between elements and change the form of elements into non available forms for plant uptake (Plaster, 2009). The precipitation affects the leaching of the soil which in turn decreases the soil-pH. Intense and rich precipitation increases the leaching of the soil and worsens the soil conditions for plant growth. The tea plants grow most optimal in areas with annual precipitations of 2500-3000 mm fairly distributed over the year, even though seasonal rains can give unique flavors to the tea product (Prabhakaran Nair, 2010).

3.9 Carbon in the soil

Photosynthesis makes the plants take up carbon dioxide (CO_2) from the atmosphere. Carbon dioxide in combination with soil water produces carbohydrates available for plants. Carbohydrates are organic molecules containing carbon as well as hydrogen and oxygen. Carbon that is taken up by plants recycles, either by respiration or by organic matter and enable the soil to act as a carbon reserve. The process of forming humus results in a deeper O-horizon, rich in carbon, where plants and animals are present (Rowell, 1994).

3.10 Nitrogen in the soil

Nitrogen is often bound in the soil in different amino groups that descends from proteins in plants, animals and microorganisms (Rowell, 1994). The total nitrogen in the soil consists of nitrate (NO_3^-), nitrogen dioxide (NO_2^-), ammonium (NH_4^+) and organic nitrogen (Wanniarachchi & Samarawickrama, Year unknown). Nitrogen is essential for plant growth and with no supply of this nutrient, plants will soon wilt. To access nitrogen, plants are depending on bacteria that transform nitrogen from the atmosphere into nitrate, which is an available form for plant uptake (Olaitan & Lobin, 1986). Ammonium is also accessible for plants, even if it often is converted into nitrate (Plaster, 2009). The amount of available nitrogen in the top soil is strongly related to the organic matter content since more than 90 % of the nitrogen is found in organic matter (Wild, 1989).

3.11 USLE

The Universal Soil Loss Equation, USLE, was empirical derived by Wischmeier and Smith in the 1930s, as a method to calculate the amount of soil lost by erosion. The equation is based on practices in soil erosion in the United States, but is said to be universal. When USLE is applied to other parts of the world it is necessary to calibrate the parameters to the geographical properties. The equation gives the quantitative measurements of erosion in ton per ha and year (Blanco & Lal, 2008). USLE is built on six factors that affect erosion:

$$A = S \cdot L \cdot R \cdot K \cdot C \cdot P,$$

where A is the loss of soil in ton per ha and year. S is the factor of slope angle, L is the factor of slope length, R is the factor for rain erosivity, K is the factor for soil erodibility, C is the factor for land cover and P is the factor for crop management (Blanco & Lal, 2008). These factors have different impact on the equation depending on the geographical conditions where the equation is applied. Therefore, a quantitative number of importance is often set to the different factors to adjust to their different impacts (Helldén, 1987).

Slope properties such as the angle and length affect erosion in a field. Steeper and longer slopes increase erosion due to higher speed of overland flow. The angle is measured in percent or degrees and then converted into a USLE factor. The length is converted from meters to a factor in the equation. A digital elevation model may be used to determine the slope angle, but the slope length is not possible to estimate with a model (Mårtensson, 2009).

There are many different ways to measure the rain intensity but it is most often the highest intensity that is wanted. The intensity of rainfall can be measured as the kinetic energy of the raindrops. The original measuring technique measured the maximum rain intensity during a 30 minutes period in combination with the loss of soil, to be able to see correlation (Mårtensson, 2009).

The erodibility of a soil is a measure of how easily the particles in the soil are removed (Blanco & Lal, 2008). The erodibility is determined by the physiological, chemical and organic properties of the soil. The erodibility can be obtained by using either a nomograph or an equation. In either way the percentage of different sized particles, structure, organic matter content and permeability must be determined (Mårtensson, 2009).

The factor for land covers is referred to as what type of vegetation is present. Vegetation is important to erosion since it provides a cover of the soil and since root systems have the capacity to decrease erosion risk. A suitable way of determining the land cover is by using satellite images (Mårtensson, 2009).

The factor for crop management is determined by the cultivation method and by what actions are taken to control erosion (Blanco & Lal, 2008). The factor can be derived from the land cover data if assuming a certain technique is used for a specific crop. But the practices can also differ from the same crops and the management factor is therefore problematic to determine (Mårtensson, 2009).

4 Method

4.1 Visualization of the risk of erosion

To examine the distribution of different risk areas and the extent of erosion in Matara district, a map was created in ArcGIS as a pre-study, version 9.3. The flowchart of the work conducted in ArcMap can be seen in Appendix I. The USLE equation was used to calculate the risk of erosion. The different percentages of areas exposed to varying risks of erosion in Matara were thereafter calculated from the map. There are different modified versions of USLE, but in this study the original equation has been used. The equation had to be modified since the parameter for slope length could not be determined due to lack of details in the input data and was therefore excluded from the equation. Since USLE was applied on digital data, the data was collected from different appropriate sources: International Water Management Institute (IWMI) (International Water Management Institute, 2010), Aster (Aster GDEM, 2011) and National Renewable Energy Laboratory (NREL) (Cowlin, 2011). Only the data from IWMI and NREL was made specifically for Sri Lanka. Additional map material such as roads, rivers and administrative boundaries was collected from IWMI.

Land use data in vector format was collected from NREL. This layer was used to create two new layers, one showing the USLE values of land cover and one showing values of land management factor. Vector data containing mean annual precipitation was collected from IWMI. In the input data, precipitation was represented in minimum values for each polygon (for example: >900 mm), but this value was changed into a fixed value. This fixed value was set to be the minimum value for each polygon. The minimum value was chosen in order to cover the entire range of precipitation in each polygon. A soil map in vector format was collected from IWMI. A digital elevation model in raster format with a resolution of 30 meters was collected from Aster.

The data layers of precipitation, soils and land use was converted into raster layers with the same resolution as the DEM. All the data layers were converted into the geographic coordinate system World Geodetic System, WGS, 1984. Direct values and equations for deriving values for the different parameters in USLE were mainly taken from a report by Wijesekera and Samarakoon (2001) over a study on USLE in Sri Lanka: *Extraction of parameters and modelling soil erosion using GIS in a grid environment.* The values were applied since these have been used previously in the same geographical area and were used to create new raster layers for each parameter.

Values for erodibility of the different soil types in the map were taken from the reference; Joshua (1977), used by Wijesekera and Samarakoon (2001), but values for bogs and alluvial soils were missing in this reference. The value for alluvial soils was instead estimated by literature. Since alluvial soils are rather undeveloped soils with no horizons it is similar to the regosols which are young soils and therefore the alluvials were given the same value of erodibility (Olaitan & Lobin, 1986). The bog soils were given an estimated value which implied lower erodibility since it contains a high percentage of organic matter which decreases the erodibility by binding particles together (Toy & Foster, 1998).

The USLE values for land cover were taken from the study by Wijesekera and Samarakoon (2001). The values from this study were given as interval, which were calculated into the median to function in the equation. Some minor categories of land cover were not presented by

Wijesekera and Samarakoon (2001) but instead placed in another suitable category. Values for the management factor, P, were taken directly from the report. Equations for calculating the slope steepness, S and the rain intensity factor, R presented by Wijesekera and Samarakoon (2001) were used. S was calculated from the slope gradient in percentage and R was calculated from the mean annual precipitation in mm (Wijesekera & Samarakoon 2001). The slope length factor could not be determined by the digital data and was therefore not included in the equation.

Five of the raster layers were multiplied according to the USLE equation to get a value of the total loss of soil, A, for each cell. The resulting values were categorized into three groups: low, medium and high risk of erosion, using the function of natural breaks in ArcMap. The program identified these breaks by classifying the values that match each other the best, by making the differences between the classes as big as possible (ArcGIS Desktop Help, 2008). This classification was done since USLE show the relative differences better than the exact amounts of eroded soil.

4.2 Structure of field work

Four field visits were made between 23/3-5/4 2012. In total, 99 soil samples were collected from five flat fields and from six sloping fields, with nine samples from each field. Different fields were selected before soil samples were taken by observing suitable sites. Intercropped fields with another main crop than tea were excluded. When selecting the fields for soil sampling, fields with young plants were preferred. Two fields out of the total 11 had plants older than the preferred maximum age of six years. An estate was also visited to make a comparable interview and observations. Measurements and observations were made at each sampling point. Interviews were done at every soil sampling site and at three additional locations.

4.2.1 Interviews

By doing interviews, additional information to support the study could be received, for example the yield. By making interviews with the smallholders, their opinion about erosion and their experience of erosion could be taken in to consideration.

In the interviews with the smallholders, a form of semi-structured interview technique was used. Semi-structured interview is a technique that is more structured and controlled than an unstructured interview, but has not only strict questions as a structured interview. Instead the semi-structured technique is built on a predetermined schedule with topics that are discussed during the interview. This makes it possible for the interviewed to develop his or her answers. Semi-structured interviews have benefits when time is a limiting factor and can be used for both specific questions and open discussion topics (Willis, 2006). The interview technique used in this study was mainly a semi-structured technique that had been modified to be more structured with some ready-made questions as a starting base. This technique was ideal for getting to know the smallholder's understanding of erosion problems. It also enabled details to be shown by opening up for a more free discussion.

Since the interviews were short with only 15 questions (Appendix II), there was no recording but instead notes were taken during the conversation. This was applicable since there were two interviewers which decreased the risk of missing any information. After completing an interview notes were taken regarding the impressions gained during the conversation, such as the attitude of the person interviewed. The notes from the interviews were evaluated and analyzed the same day as the interviews were conducted so that no details would be forgotten.

The interviews did mainly take place in the tea fields to make the smallholders more comfortable and to make it possible for the smallholder to show his or her answers practically. Otherwise the interviews were held at the smallholder’s house. The interview started with a presentation of the project, either by the interviewers or by the supervisor in field in advance. To avoid getting answers that the smallholders believe was wanted, the presentation did not include any expected results or predictions. An interpreter assisted to translate the local language. This person was familiar to the questions and the purpose of the interviews before the field visits to prevent misunderstandings.

4.2.2 Soil sampling

Several soil samples were taken in sloping fields to investigate if there were any successive variation at different locations in a tea field. A field was divided into three blocks, the first block at the upper part of the slope, the second in the middle and the third block at the lower part (Fig. 7). The size of these blocks varied with the different sizes of the fields. When small fields were measured, the blocks covered the whole field, while this was not possible in bigger fields. The maximum length used in large fields was set to 30 meters. The width of one block was determined so that each block was quadrat shaped. Three samples were taken from each block to use the mean value of these as the representing value for the entire block, to make it more representative. These samples were taken from a horizontal line with equal space in between in each block. Totally nine samples were taken from each slope. The method was applied both when taking samples in soils in sloping fields and on soils in flat fields.

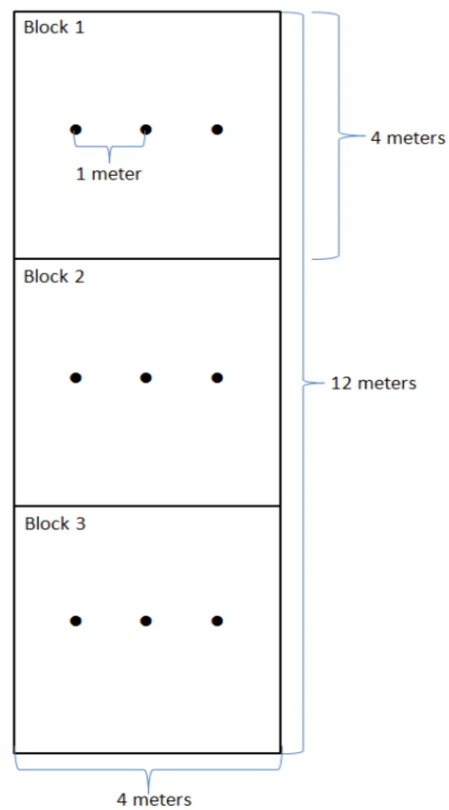


Figure 7. Example of how blocks were divided within a field with three sample points in each block.

When taking a sample the most upper part of the soil was removed to avoid soil that has been exposed to disturbances along with vegetation, litter and stones. Samples were collected from a depth of approximately 10 centimeters and contained 200 – 250 grams of soil.

Only soil from the O-horizon was relevant in the study. The soil were collected with a spade and placed in a polythene bag, where the air was squeezed out before the bag was sealed. Each bag was marked with a specific combination of numbers for each sample. The first number in the combination represents the smallholder site, the second the field within the site and the third the block number. The letters a-c represented the sample point within the block, where a being the point to the right seen from block 1. The numbers was used in a protocol, presented in Appendix III where all attributes was noted, and also to be able to identify the samples when doing the analysis. Since the fields were homogenous there was only one protocol for each field, only the slope angle and length were filled in separately for each sampling point. Slope angle was determined by measuring *h* as in Fig. 8. The slope angle was determined by using an inclinometer, measuring tape and trigonometry. The angle was calculated by using the equation: $v = \sin^{-1}(h/2)$, where v is the slope angle, h is the measured height and the length is two meters.

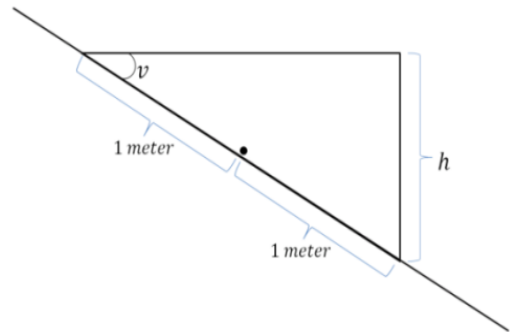


Figure 8. Schematic figure how to determine slope angle within a field.

Angles measured to less than 10° with the inclinometer were assumed to be negligible. This was done since slope angles less than 10° were too small to measure with the available equipment. In flat fields, the slope angles were consequently <10°. Slope length was measured with measuring tape from the upper part of block number one down to a sample point (Fig. 7). High or low productivity was calculated from the information regarding yield gained during the interviews. Elevation and coordinates for every field were collected with a GPS and a compass was used to determine the aspect of the field. pH was measured with a pen-type pH-meter by mixing soil from each sample with distilled water.

4.3 Laboratory work

The upper layer in the soil is where all the carbon is stored and due to this, loss of total organic carbon is a good indicator of the amount of top soil erosion and was therefore used in this study. Nutrients like nitrogen, phosphorous and potassium are the main indicators that show the fertility of the soil but might be misleading since these elements often are added in fertilizers. Nitrogen is the most required element for all plants and is an important component in protein and chlorophyll (Plaster, 2009) and is therefore the only nutrient that was analyzed in this study.

4.3.1 Carbon

To determine the amount of Total Organic Carbon, TOC in the soil the method used was loss on ignition. This is a semi-quantitative method based on eliminating all organic matter by heating the soil and then estimating the weight loss of the samples. The amount of organic matter in the samples can be determined using this method. To get the TOC content in the soil, a conversion factor is used to recalculate the organic matter content into TOC. The recalculation from organic matter to TOC is not exact, but it is an approved method. By assuming that organic matter contains 58% organic carbon, the conversion factor was determined to 1.724. This conversion factor varies from 1.724 to 2.5, due to soils and horizons, meaning it is not universal. The amount of organic matter was recalculated to TOC by dividing the amount of organic matter with the conversion factor (Schumacher, 2002).

After collecting the soil samples they were put in a freezer to prevent the organic matter from decompose as freezing stops the activity of microorganisms in the soil (Bartholomew, 1957). 14-15 grams of soil from each soil sample was weighted and put in cups. During this procedure, roots and small stones was removed from the soil. The weighted soil was dried in an oven for about eight hours to remove the moisture from the soil to receive the initial weight. Drying of the samples made the color of the soil turn from brown to greyish due to the removal of moisture.

After the water was removed the samples were ignited in a muffle furnace at 400° C for about seven hours. Temperatures over 440° C could cause the inorganic carbon to be destroyed and affect the result by the risk of overestimating the amount of organic carbon in the soil. Temperatures below 350° C could result in all organic carbon not being removed from the sample (Schumacher, 2002). The ignited samples received a distinctive reddish color since there was no organic matter left, only the minerals.

After the ignition the samples were once again weighted to receive the amount of organic matter that had been reduced during the ignition. From the organic matter, TOC in each soil sample was calculated into percent. The mean TOC of the three samples within a block was calculated to represent the soil condition in the entire block.

4.3.2 Nitrogen

To determine the total nitrogen content in the soil samples the Kjeldahl method was used. Since the method was developed in 1883, in purpose to be a fast method to state the amount of protein in seeds by determining the nitrogen content, it has been improved and remodeled into different types. The method consists of three major steps; digestion, distillation and titration (Persson, 2008). In digestion the organic nitrogen in the soil is decomposed by adding an acid solution and then boiled with sulfuric acid. The product from digestion is ammonium sulfate solution. In the distillation, a base is added in order to transform ammonium (NH_4) into ammonia (NH_3). When boiling, ammonia vaporizes and the gas is lead to a receiving solution where it is suspended.

Figure 9. The machines used in the macro-Kjeldahl method. Digesting unit to the left and distilling unit to the right. (Photo: Carolina Emanuelsson and Elna Rasmusson)

Titration is made to quantify the amount of ammonia in the solution and is conducted in different ways depending on the method and instrument used (ExpotechUSA, Year unknown).

The macro-Kjeldahl method, used in this study is a variant of Kjeldahl and differs from the original method in the types of chemicals used for digestion and distillation and in the type of machines used (Fig. 9). The classical macro-Kjeldahl needs larger volumes of soil samples and therefore heavier equipment. After air-drying during more than one day, the samples were dried in an oven at about 100° C for three hours. The soil was grinded into finer particles to increase the area of the particles in order to make the nitrogen in the soil more accessible for reactions. The nitrogen content was determined for each block. About 3-4 grams of soil from each sample in a block was mixed to a total weight of around 10 grams and put in a Kjeldahl flask. In the flask, 10 grams of potassium sulfate (K_2SO_4), two grams of copper sulfate ($CuSO_4$) and 30 ml of concentrated sulfuric acid (H_2SO_4 (98 %)) was added to the soil and mixed together. The flasks were then digested through heating for around six hours. When the mixture had cooled, 300 ml of distilled water were added in the flask and also some pieces of porcelain were added to prevent accumulation of the sample in the bottom. The distilled water reacts with ammonia in the flask and form ammonium hydroxide (NH_4OH). The ammonium hydroxide reacts with the sulfuric acid and form ammonium sulfate ($(NH_4)_2SO_4$) and water. Two catalysts were added, 90 ml of sodium hydroxide (NaOH (40 %)) to make the solution alkaline and one gram of Devada's alloy powder containing 50 % copper, 45 % aluminum, and 5 % zinc. Devada's alloy powder allows the compounds of nitrate (NO_3^-) and nitrogen dioxide (NO_2^-) to transform into ammonia. In an Erlenmeyer flask, 25 ml of sulfuric acid (H_2SO_4 (40 %)) and an indicator fluid containing bromocrysol and metyl were added to be the receiving fluid in the distillation process. The distillation process lasted for about three hours, until 150-200 ml of fluid were dissolved in the Erlenmeyer flask. During the titration, sodium hydroxide was slowly added into the Erlenmeyer flask to determine the excess acid in the mixture. When the color of the mixture changed from red to green, the amount of added sodium hydroxide was equal to the amount of excess sulfuric acid in the flask, given that they were of the same concentration. When the amount of excess acid was determined, the remaining part of the added acid was bound with nitrogen. Since nitrogen bind to a certain amount of sulfuric acid (1.4 g nitrogen per 1000 ml sulfuric acid), the amount of total nitrogen could be determined with a conversion factor of 0.0014 g:

0.0014 · [remaining amount of acid (ml)] = [total amount of nitrogen (g)] (Wanniarachchi et al., 2003).

4.4 Statistical analysis

To analyse the data statistically, SPSS was used. All data was first tested in both a Kolmogorov-Smirnov and a Shapiro-Wilk test to check if the data was normally distributed. In the tests, the mean values from the blocks were used to avoid pseudo-replication (Quinn & Keough, 2002). The normality-test showed that the data over TOC was normally distributed with significances ($P > 0.05$) of 0.200 and 0.304 (Fig. 10). On the other hand, data of nitrogen showed significances of 0.005 and 0.002 and was therefore not normally distributed. The data of nitrogen could not be transformed and due to this, non-parametric tests had to be used instead, even if non-parametric tests often are weaker than parametric (Bärring et al., 2010).

The mean value of the three sample points in a block or the mean value from the entire field was used in the tests. To investigate if nutrient content was affected by erosion within a field, an ANOVA-test was performed to find out if there were significant differences in TOC between the blocks in the sloping fields. To test the difference in total nitrogen content between the blocks in the sloping fields a Kruskal-Wallis-test was used. Only values from the sloping fields were used in these tests since it was expected that any difference between the blocks would be found only in sloping fields. In the ANOVA-test, the variance within and between the three groups (the blocks) was used to determine the significance with the null hypothesis stating that there are no significant difference between the groups. The Kruskal-Wallis-test is a non-parametric alternative to the ANOVA-test that is used if the data to be analyzed is not normally distributed (Bärring et al., 2010).

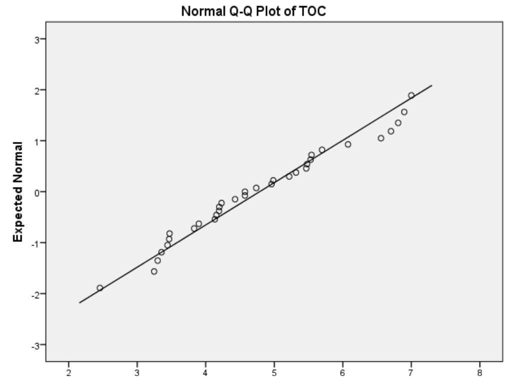


Figure 10. The normality plot of measured values for TOC content in the soil.

To find out if there was any difference in the extent of erosion between sloping and flat fields, an independent two sample t-test was performed to see if there were any significant differences in TOC between the sloping and the flat fields. Independent two sample t-tests compare the mean values of the two groups (the field types) to find out if they differ significantly or not, as the null hypothesis suggest. To test the same for nitrogen, a Mann Whitney U-test was used. Mann Whitney U-tests are the non-parametric alternative to two sample t-tests (Bärring et al., 2010).

Tests of simple regression were used to test if TOC depends on the slope angle or if yield depend on TOC. The tests were used for analyzing if one variable is significantly depending on another. The non-parametric alternative used to test if total nitrogen depends on slope angle or if yield depend on total nitrogen, was the Spearman rank correlation (Bärring et al., 2010). The variables tested for correlation were also analyzed graphical to visualize possible trends in the result.

5 Result

5.1 Visualization of the risk of erosion

A map that visualizes the distribution of risks of erosion in Matara district is shown in Fig. 12. As the map shows, there were not many areas in the district that were exposed to a high risk of erosion. The risk of erosion was generally higher further north in the district and lower along the coast. The areas of high risk were often clustered together in certain areas. High risk areas covered 6.9 % of the district, the areas of medium risk covered 33.5 % of the area and the low risk areas covered 59.6 % of the total district area. This numbers showed that most of Matara district were not highly exposed to risk of erosion. Out of the seven different sites from where soil samples were collected, five sites were located in areas with low risk and two sites in areas with medium risk of erosion. The different amounts of soil loss with the number of cells in the resulting map are shown in Fig. 11. The mean value of the quantitative soil loss was 0.98 tons per ha and year. The distribution pattern of the risk of erosion in the resulting map compared with the input data over land use indicates that dense vegetation such as forests prevent the risk of erosion, since forest and low risk of erosion cover the same areas. In the land use map, the areas of where tea is grown cannot be connected to any specific level of risk of erosion. A map showing the land use in Matara is presented in Fig. 13.

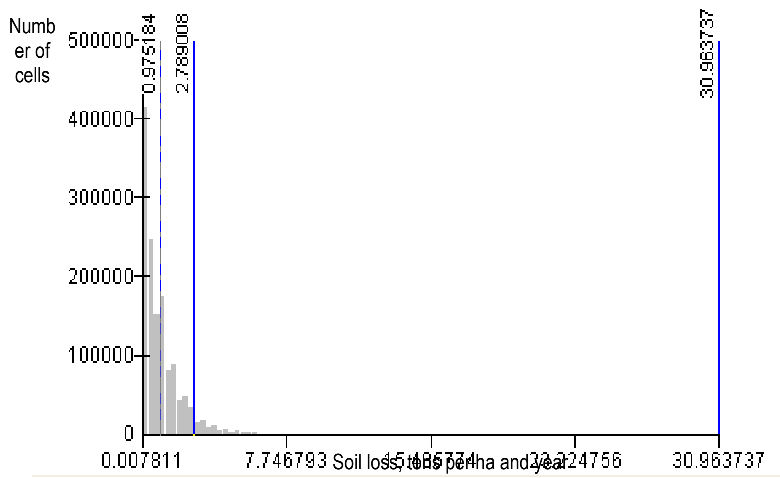


Figure 11. Diagram imported from ArcMap, showing the number of cells with different amounts of soil loss. The blue lines with attached number show the break values for the classification. The dotted line represents the mean value of the soil loss.

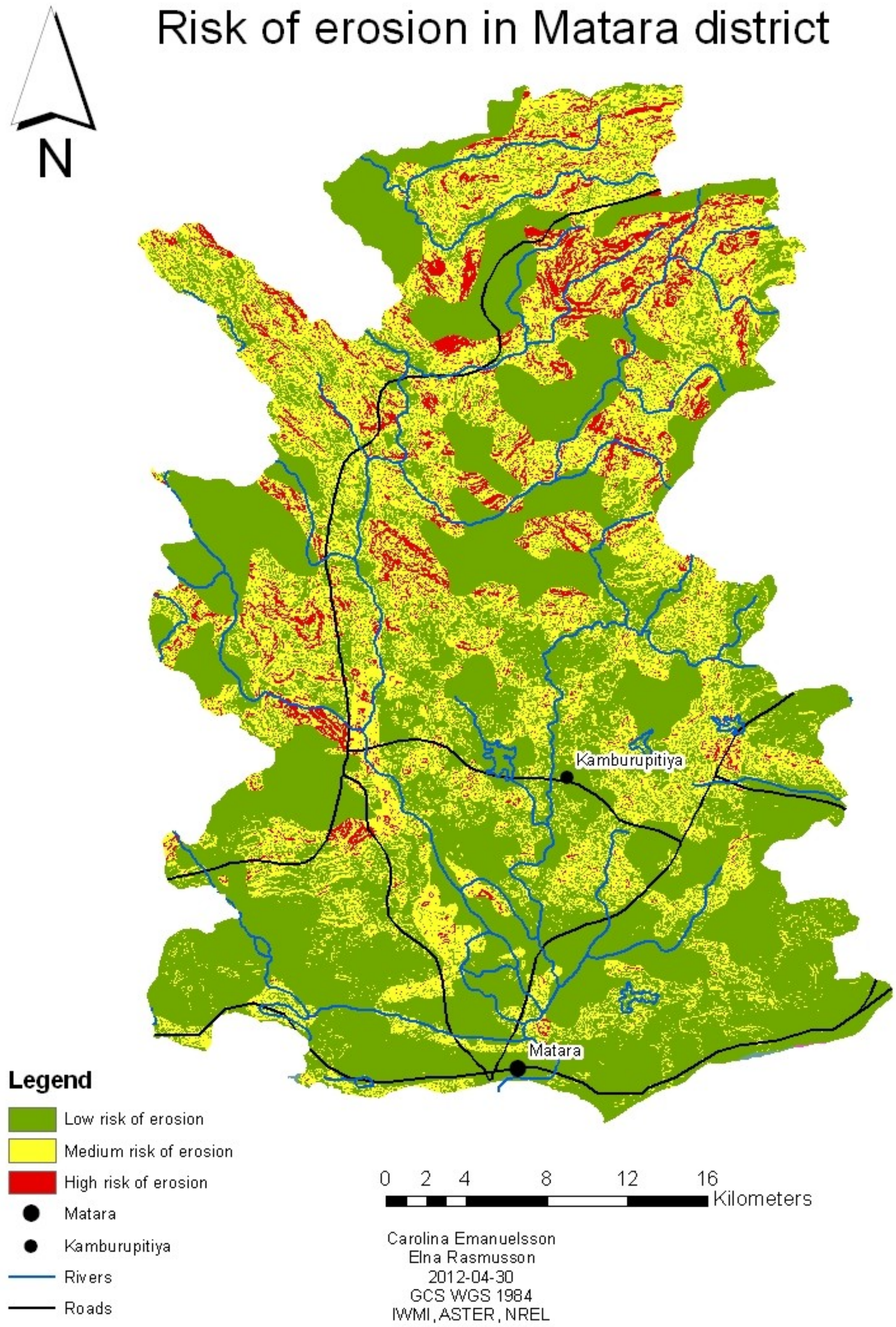


Figure 12. The resulting map showing the distribution of risk of erosion in Matara district.

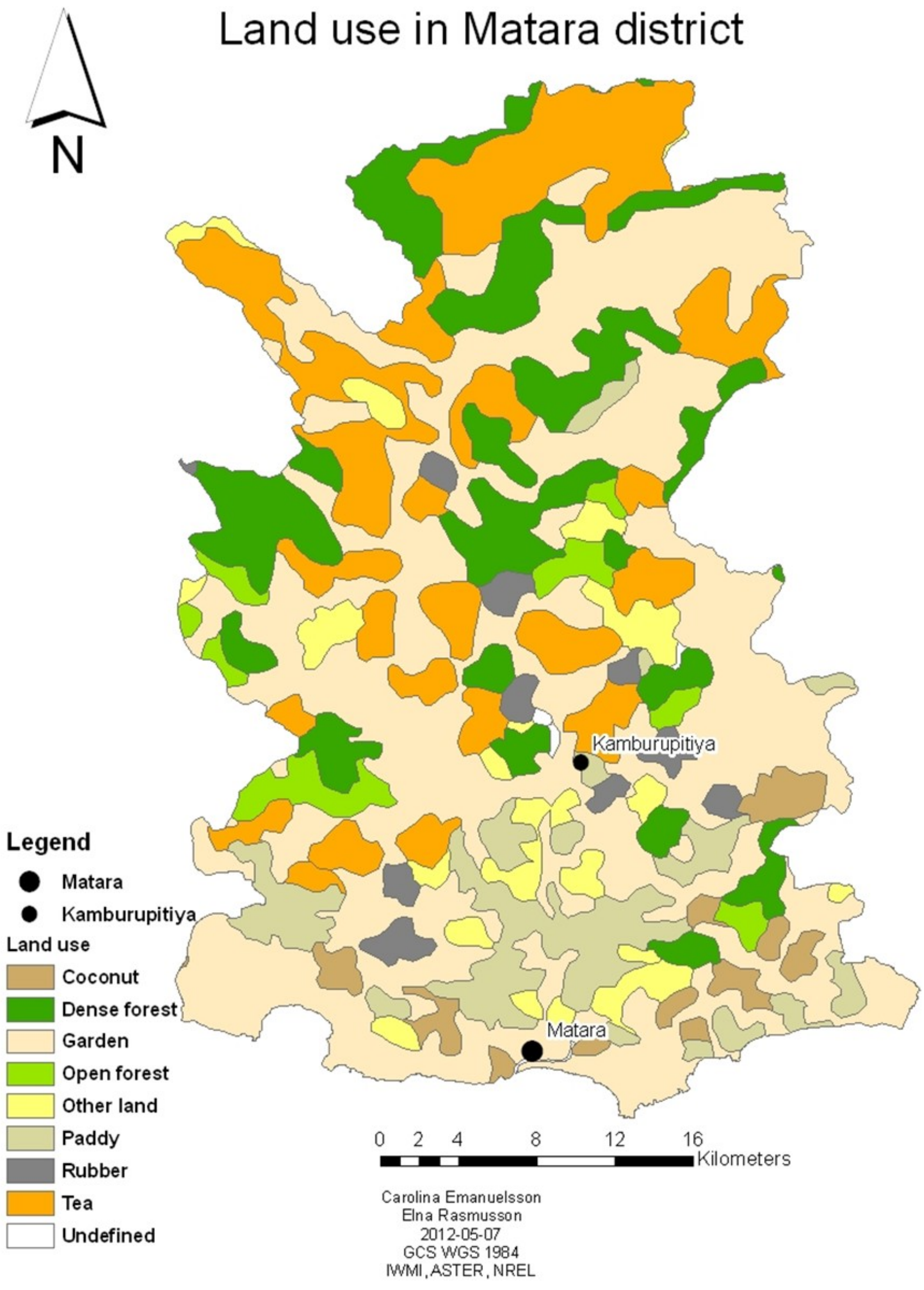


Figure 13. Map showing the land use in Matara district.

5.2 Interviews and soil sampling

In total, 12 interviews were conducted with smallholders concerning their tea lands (Appendix IV). The result of the varying yields, field types and observed erosion signs in each field are shown in Table 1.

Table 1. Selected results from the interviews and soil sampling. The results are only from fields where soil samples were taken.

	Field number										
	1:1	1:2	2:1	3:1	3:2	6:1	7:1	7:2	8:1	8:2	9:1
Field type	Sloping	Flat	Sloping	Sloping	Flat	Flat	Sloping	Flat	Flat	Sloping	Sloping
Yield, kg per m^2	0.033	0.033	0.099	0.11	0.026	0.035	0.099	0.13	0.12	0.12	0.037
Erosion signs	Rills	Exposed roots	Exposed roots	Rills	Rills	Exposed roots	Big rills	Tiny rills	Collapsed drains	Collapsed drains	Earthflow

The interviews also revealed that most of the smallholders had another main occupation, for example housewives or retirees. The tea lands visited had an area from 0.1 to 0.6 ha and the domestic workers used in the lands varied from none to five. In every tea land except for one, there was no irrigation even though the tea plants in some of the lands were occasionally suffering from drought. For most of the smallholders, irrigation was a too expensive method. Every interviewed smallholder applied fertilizers in their tea lands three to four times per year using the same method. Manure were not used in any of the tea lands, instead mulch from the shade trees were placed on the ground in some of the lands. Almost every smallholder that used mulching applied the mulch during rain season. The most used protection method against erosion was drains, which were present in every field. The accumulating sediment had to be removed from the drains with different frequency. According to the smallholders, the technique of intercropping was used in eight of the fields, though some of them referred shade trees as intercropping (Appendix IV). Every smallholder had the knowledge that erosion was present in their tea land, but not many could tell where in the field the erosion occurred. Only one could see the difference in productivity in his field due to the erosion. Every smallholder thought that the erosion increased during the rain season and therefore believed that the factor causing erosion was rainfall. The answers were very similar regarding the cultivation technique. It was learned that many of the smallholders had been trained by a governmental institute, Tea Small Holdings Development Authority. These trainings are arranged as programs by the main organization, Tea Research Institute and cover all aspects of tea cultivation (Cyril, 2012).

Measurement and observations were filled out in protocols in situ from the fields where soil samples were taken (Appendix V). The field numbers from where samples were collected can be seen in Table 1. The soil type, red yellow podzolic was the same in all of the sampling sites, though the characteristics varied from reddish to brownish color and also in grain size. Erosion assumed being present in every studied field since signs of erosion were observed in all of the fields. The mean slope angle for a block varied from <10° to 64.3 °. The values of pH in the blocks ranged from 5.08 to 7.02 with a mean value of 6.17 (Appendix VI).

5.3 Statistical analysis

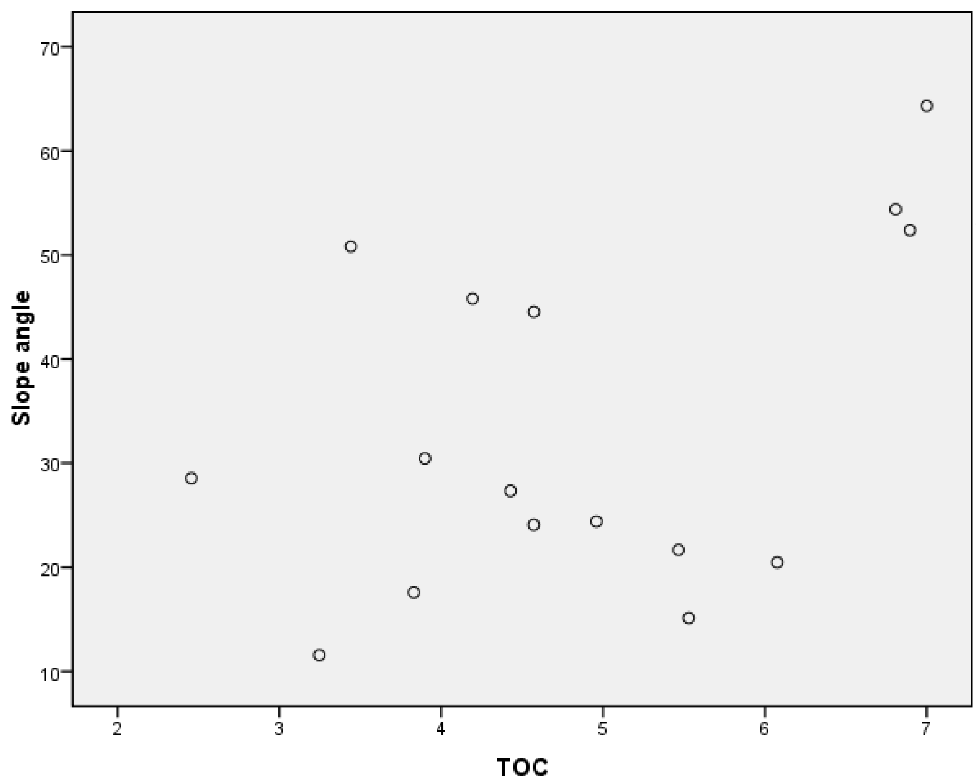
5.3.1 Carbon

The results from the carbon analysis are presented in Appendix VII. The values show that the TOC in the blocks varied from 2.46 % to 7.00 %, where most of the values were rather high within this range. The mean value in all of the fields was 4.79 % with a standard deviation of 0.310. The values had overall a high carbon content which indicated fertile soils. The variation of TOC between the blocks had an indistinct pattern which indicated that there was no extensive erosion since there was no gradual increase of carbon along the slopes. In the resulting values there were no signs of differences in TOC within the fields.

The result of the ANOVA-test showed that there was no significant difference ($P > 0.05$) in TOC content between the blocks in the sloping fields. The F-value of the test was 0.120, which lay within the confidence interval with a significance of 0.888. Due to the high value of no significance, there was no motive to proceed with testing if there were any significance between each of the blocks separately.

An independent two sample t-test showed that there was no significant difference ($P > 0.05$) in carbon content between flat and sloping fields. The mean value for the TOC in sloping fields was 4.762 % with standard deviation of 1.160. The mean value of TOC in flat fields was 4.813 % with the standard deviation of 0.6221. The resulting t-value from the test was -0.098 which fell within the confidence interval. The value of significance was 0.924, which states that no kind of significance is present.

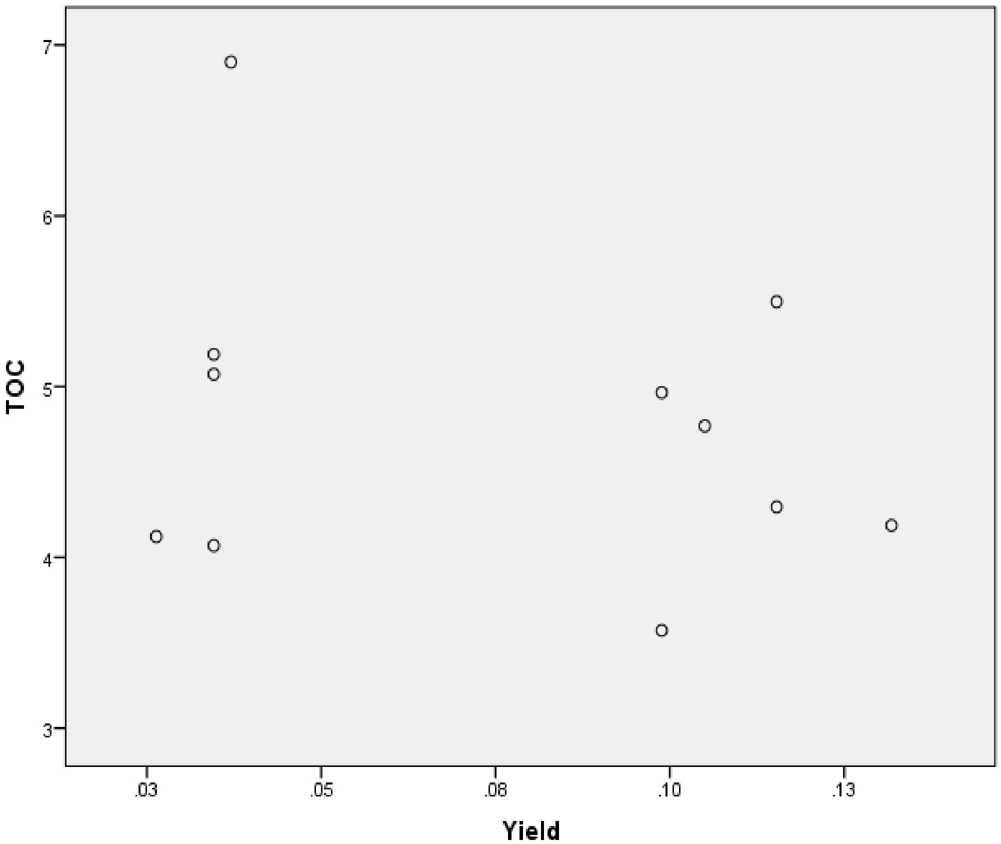
A test of simple regression showed that the carbon did not significantly depend ($P > 0.05$) on the slope angle. The regression test (in which the null hypothesis was $\rho \neq 0$) showed the significance of 0.091. The r^2-value of the test was 0.190, which is rather low compared to the optimal value for total correlation; 1. The plot of TOC and slope angle is presented in Fig. 14. The regression model, also shown in Fig. 14 show how the depending variable, TOC is determined by the independent variable, slope angle.



R[redacted]ression model:
y[redacted]3.610+0.037x

Figure 14. Scatterplot showing the relation between TOC (%) in the soil and the slope angle (°) with the regression model in which y = TOC and x = slope angle.

A scatterplot showing the relation between TOC and yield is presented in Fig. 15 along with the regression model. The result from a regression test conducted to see if yield was depending on TOC content, showed the r^2-value of 0.062 and no significance ($P > 0.05$) with the value of 0.389. The scatterplot show how the smallholder's production was affected by the TOC in the soil. Yet, there were no significance in the regression test, and the plot showed no correlation, which means that in this range of TOC, the yield was not affected by the amount of TOC in the soil.



Regression model:

y = 0.051+0.005x

Figure 15. Scatterplot showing how yield in kg per m^2 and TOC (%) in the soil correlates and the regression model. In the regression model, y = yield and x = TOC.

5.3.2 Nitrogen

The results from the total nitrogen analysis are presented in Appendix VIII. The mean values in the blocks ranged from 0 % to 0.18 %, while the mean value of total nitrogen in all of the fields was 0.033 % with the standard deviation of 0.0462. In the values of total nitrogen, no distinct trends could be seen between the blocks. Neither could any differences within the different fields be distinguished.

The result of the Kruskal-Wallis-test showed that there was no significant ($P > 0.05$) difference in total nitrogen between the blocks. The value of significance of the test was 0.909 which means that nitrogen was not accumulated in any particular part of the fields.

A Mann Whitney U-test showed that there was no significant ($P > 0.05$) difference in total nitrogen between sloping and flat fields. The mean value of total nitrogen in sloping fields was 0.08136 % with standard deviation of 0.04425. Corresponding mean value for the flat fields was 0.1154 % with standard deviation of 0.04571. The value of significance from the test was 0.144. Consequently, the result showed that the amount of nitrogen in the soil did not depend on the field type.

The result from the Spearman rank-test showed that the value of significance was 0.485. This means that the amount of total nitrogen was not significantly ($P > 0.05$) depending on slope angle. Instead, the amounts of nutrients were evenly distributed in all the sloping fields. A scatterplot showing the relation between slope angle and total nitrogen are presented in Fig. 16.

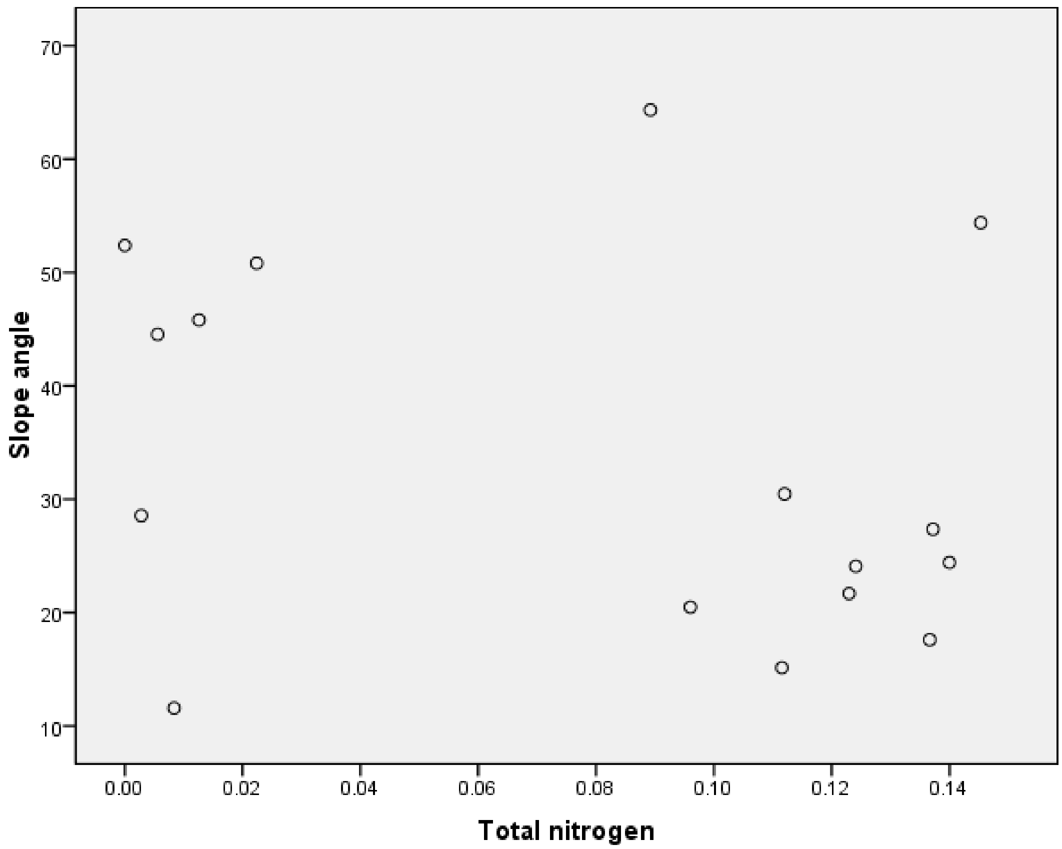


Figure 16. Scatterplot showing the relation between slope angle (°) and total nitrogen (%).

The scatterplot of yield and total nitrogen content show that there was a correlation between the variables (Fig. 17). This means that high nitrogen content in the soil correlates with increased yield. The value of significance from a Spearman rank-test was 0.039 ($P < 0.05$), which confirmed the correlation.

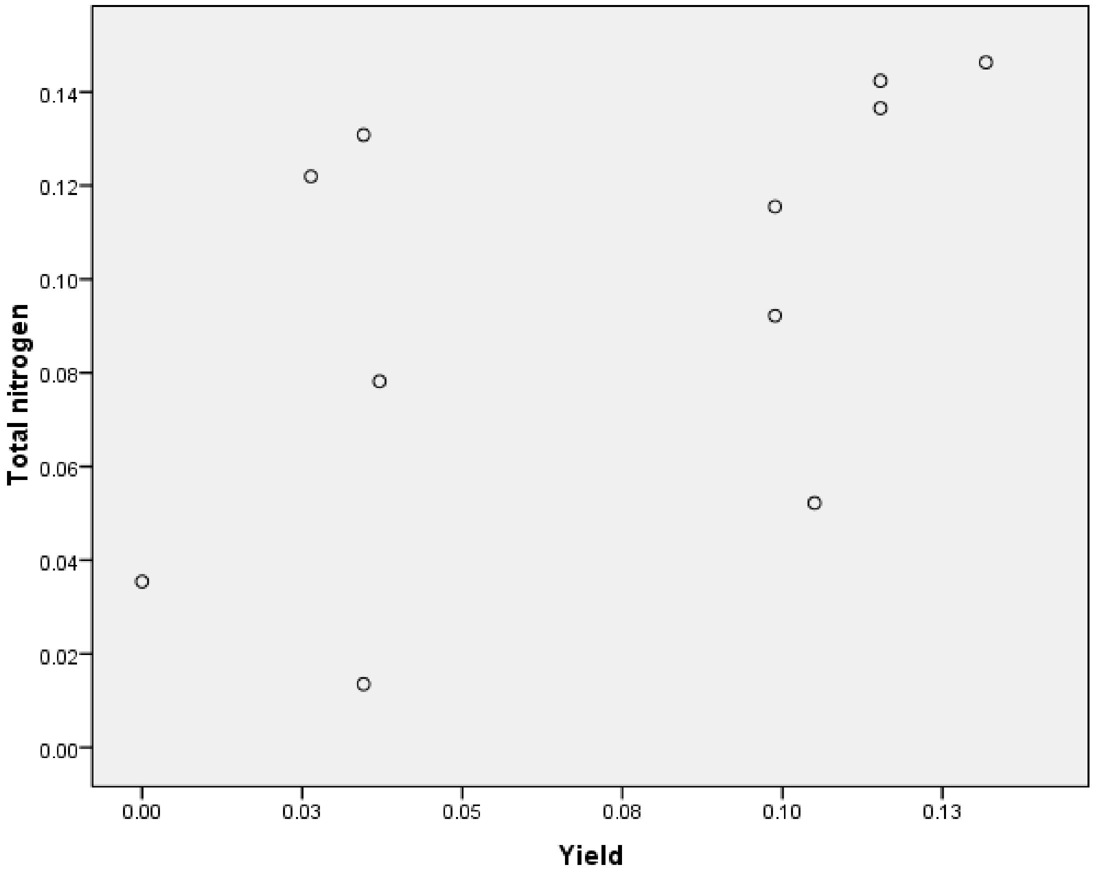


Figure 17. Scatterplot showing the relation between yield in kg per m^2 and total nitrogen in the soil (%).

6 Discussion

6.1 Visualization of the risk of erosion

The USLE equation function most correctly when field measurements are done since the parameters of the equation is depending on current time and place. The purpose of using USLE in this study was not to determine the amount of soil loss in the district, but the extent and the distribution of the risks. Field measurement was not possible in this part of the study since it would be too time consuming. Since the input data used in the equation were estimated from other sources, there was no possibility to evaluate the accuracy of the data. The year of production was for the land use data unknown which could mean that it might have been out of date and therefore be less correct. Some parameters are more affected by frequent updating than others. Data over precipitation and land use may vary significantly over time while parameters like soil type and slope angle are much more stable and are therefore not affected by the year of the produced data in the same extent. Even the fact that the parameters are natural factors that depend and are affected by each other was neglected since the data were derived from different years and their internal dependence could not be taken in consideration.

It is very difficult to set the values within each factor in the USLE-equation. The decided values must be defendable and have the correct impact in the equation. Besides the fact that expertise is necessary, it is time consuming to retrieve these values. Due to this, previously used values for the factors where used instead.

The factor of slope length, L was excluded from the equation since it could not be calculated from the DEM. Calculating the slope length from a DEM is a complex process in ArcGIS and is therefore often set to be a constant when calculating USLE from GIS data (Hickey, 2000).When USLE are applied in larger scales it can be difficult to define the actual length of a slope since details like the crest and the end of the slope might not be shown in the DEM (Mårtensson, 2009).

The same values for the factor of erodibility, K as used in Joshua's report were used in this study. As Joshua states in his report there was, and is still today little information about erosivity in tropical soils and especially for Sri Lankan soils. Joshua studied the erodibility of soils in Sri Lanka but did not treat alluvials or bogs (Joshua, 1977). As stated before, the lack of information about Sri Lankan soils lead to the only alternative to estimate the erosivity from other sources. This may have resulted in an incorrect difference between the values of erodibility of the different soil types.

Rasterisation of the vector layers of soil, land use and precipitation was the most optimal solution for calculating USLE in ArcMap since the equation are based on multiplication. In the process of rasterisation, the layers loses some details since the created cells in the raster only can contain one value each which makes a generalization necessary. The one original raster file of the digital elevation model retained its accurateness since it was not modified in any way. In the data over precipitation there were some coastal parts of Matara district missing. When multiplied in the equation, these areas without values for R gave the result of zero, and therefore these areas are not shown in the resulting map.

The mean value of annual soil loss in Matara district was calculated to 0.99 tons per ha, which is compared to other studies a reasonable value. A previous study of soil erosion in the highlands presented a mean value of 4.3 tons per ha and year (Udayakumara et al., 2010). It is expected that the amount of erosion should be greater in the highlands due to the topography.

The reason that the resulting map show very few areas that are exposed to a high risk of erosion may have different causes. Matara district belongs to the lowlands with a not very steep topography, which may explain why the district is not very exposed to erosion. Since the result from the USLE-calculation showed the quantitative amount of soil loss per ha and year, it had to be classified into suitable categories. This was done since the quantitative values have a higher uncertainty than using the result as relative values. The classification of the risk, low, medium or high, was made by using the natural breaks in ArcMap. This was assumed to be the best method since there were some values of the raster cells which were much higher than the main part. The values could not be equally divided since this would have resulted in almost no values in the class of high risk of erosion, which might have been misleading. Since the values of high soil loss were few and spread in a wide range, the interval of this class had to be much wider than the two other classes, reaching from 2.8 to 31 tons per ha and year. The areas classified into high risk of erosion in the map can therefore have very different actual risk of erosion. Another reason for the low amount of high risk areas may be the inaccuracy of the input data that were low in details. The areas of high risk of erosion might be clustered further north in the district due to the more steep topography located here than along the coast. These areas might also be clustered together as a result of the generalized input data.

The resulting map can be used as an indication of which factors in the USLE-equation that affects the risk of erosion in Matara the most. By comparing the distribution pattern of the different classes with the pattern in the input maps over the factors, similarities can be seen with some of the factors. The most distinct similarities are with the layer of land use, both due to land cover and land management (Fig. 12, Fig. 13). In areas with forest as vegetation, there is low risk of erosion according to the produced map. These similarities are very distinct which makes the land use type probably the factor with highest influence on erosion in the district. The soil map and the precipitation data are more homogenous in the district and do therefore not influence in the same range as land use. The effects of the digital elevation model can be seen in the result as the higher elevation is located further north in the district along with the higher risks of erosion.

6.2 Interviews and soil sampling

Only 12 interviews were conducted due to time limitations. This amount is not satisfying for making any statements from the results, yet trends can be discussed foremost since the answers turned out to be very similar.

Since the interviews were conducted with an interpreter that read the questions from a paper, there was less possibility for the interviewers to structure the interviews. With less control over the questions asked, there was no guarantee that the questions asked were not directing in any way.

A supervisor who guided in field had chosen smallholders to visit with whom he had previous relations to. This made the meetings more relaxed but it could also have affected the answers if the smallholders had received previous information about the study and the aims, something that could not be prevented. When the interview was held with an additional person from the household, the interviewed may in some occasions have been affected and silenced by the other person. The interviewers may have missed out on detailed information later during the day due to a high number of interviews conducted throughout one day.

The result from the interviews show that most of the smallholders interviewed had another main occupation which suggest that tea lands visited are too small to act as an only income. The price for one kilogram tea in Sri Lanka fluctuates on a monthly basis and has generally decreased during the recent years which might have made tea holding less favorable. Today, the price of tea lies around 55-60 rupees per kilogram (The Sunday Leader, 2012). If the tea lands are not the main income, it is possible that the smallholders may not put all their effort into maintaining them. The erosion in the tea lands may for this reason not be a great issue for the smallholders. The prevention method most used was drains and shade trees, most likely since building and maintaining drains as well as planting shade trees is rather simple. The few terraces observed were old and left without maintenance, probably since many preventing methods, such as terraces, are very expensive to maintain. Another reason might be that the smallholders do not prioritize these since they do not think of erosion as a major threat. Besides this, it is not always possible for smallholders to act sustainable in long term since they need to strive for as high yield as possible in their everyday lives.

Some of the smallholders do not even know their own tea lands as they do not harvest themselves but have domestic workers. This may affect the answers in the interviews as these smallholders did not know the real answer, for example about erosion signs in their land. For most of the smallholders, irrigation was too expensive. The importance of irrigation could due to this not be investigated but some of the smallholders stated that the plants sometimes suffered from drought which indicates that irrigation in some cases actually might be needed.

In questions regarding how the small holders grew their tea, almost all of the smallholders answered in the same way. The smallholders confirmed the fact that they got training in tea cultivating from a governmental institute, which can explain the similar answers that the interviews resulted in. There were also a risk of them rather answer what they have been trained than how they actually grow the tea. If all the smallholders actually are growing tea as taught, their impact on the tea plants and the soil should be the same.

The majority of the resulting pH values in the studied fields were high, with a mean value of 6.17 compared to the optimal range of pH for tea plants; 4.5 – 5.5. High pH indicates that no intense leaching had occurred in the fields which might be explained by less erosion in the area. Since pH impacts the forming of humus, a relation can be seen between the high values of pH and the high values of TOC. The high pH values may also be explained by samples being taken just before the rain season, which would mean even less leaching of the soils. It might also be that the high pH values measured was a result of the soil not being mixed enough with the distilled water before measuring, rather than the soil having high pH.

6.3 Statistical analysis

The signs of erosion observed in every visited field acted as confirmation that erosion was present in the area. Though this definition of erosion might not be entirely correct since the signs observed could have been formed in previous years. Still, this was the best definition of erosion applicable in the area.

The soil samples were collected just before the rain season, when the climate was very dry. Since erosion increase with the more intense precipitation during rain season, this may be the reason why the erosion was not visible in the result. Soil samples taken during or after the rain season might have shown a more distinct soil loss and a more varied nutrient distribution.

If the amount of soil samples analyzed were larger, the statistical analysis would have given a more correct result. When larger amount of samples are analyzed, a bigger part of the reality can be explained by the result. This study may have received a different result if more soil samples were collected and analyzed, but due to time and budget limitations this was not possible. This is also visible in the plots; samples from 11 fields might not be enough to state the conditions in the studied tea lands.

Different types of tests were used when analyzing the TOC and total nitrogen results. This had to be done since the data over total nitrogen content was not normally distributed in contrast to the data on TOC. The fact that the resulting data from the nitrogen measuring were not normally distributed might be explained by greater variance in the values for total nitrogen than among the values for TOC. In the data of total nitrogen there were many samples with low amounts of total nitrogen which might be the reason for the data not being normally distributed. Greater variance might be based on greater uncertainty in the resulting values, which can be caused by human impact through fertilizing unlike in the case for carbon. Soil treated differently with fertilizers may result in outliers which would prohibit a normal distribution.

6.3.1 Carbon

The balance used when measuring the weight of the soil samples had an error range on 0.01 grams. This might have a small effect on the resulting weights measured such as the moisture content and organic matter content. Since the error range was low, it should not have a significant impact on the results.

Since soil from the same samples was used in both the carbon and nitrogen analyses, and since some samples had to be measured over again, the samples were frozen and thawed several times. At one occasion the freezer stopped working and all the samples were thaw for a longer time. This could have resulted in loss in quality since samples were exposed to oxygen during repeated measuring and due to the possibility for the samples to be contaminated by outer factors during this time.

The values of TOC in the samples may have been affected by unwanted fragments in the samples, for example stones that would have decreased the amount of TOC or plant fragments that would have increased the amount of TOC in the sample. This fragment was as much as possible avoided, but since very small amounts of soil were used, also very small fragments would be able affect the result.

The very high resulting values of TOC in the soil are most probably explained by remaining moisture in the samples even after drying. This would cause greater loss of weight in the muffle furnace due to loss of both organic matter and moisture. This could have been avoided by drying the samples in the oven for a longer time period, yet this was not a possibility in this study since electricity was not accessible for longer time durations. Another main reason to the high TOC values was probably to high temperatures used in the muffle furnace. Temperatures over 440° C could also remove the inorganic carbon which would then be falsely included in the calculation of TOC. The temperatures in the muffle furnace were fluctuating over the set temperature of 400° C which made it impossible to control the actual temperature.

Since all the samples could not fit in the muffle furnace at the same time, the time duration of the ignition varied among the samples. This may have affected the result since some were in there for longer time than others. Samples that were in the muffle furnace for a longer time ran greater risk of losing the inorganic carbon in addition to the organic. A specific time duration of the ignition was determined and was held as much as possible. The effects of the varying duration should therefore be minimal.

The ANOVA-test of carbon distribution between the blocks showed that there was no significant accumulation of carbon in any of the block. The theory was that carbon would be accumulated gradually along the slope, with highest amounts in the lowest block. One reason why the theory was proven wrong could be that the blocks not always covered the whole field which lead to the last block being located within the slope instead of in the footslope. The lowest block may even in these locations have steeper slope angles than the upper blocks and therefore accumulation would not occur here but instead occur where the field is flattened out. Covering a whole field with the blocks was in some cases not practically possible. In cases where the entire field was covered within the blocks the absence of accumulated carbon may be explained by factors like soil type or infiltration capacity having more influence over the TOC in the soils. In all of the sampling points, the soil type was the same with only small variances and should due to this have somewhat the same infiltration capacity. The tea plants may also affect both the rate of infiltration and splash erosion depending on the plants density and their arrangement in the field.

It was expected that the TOC content would be lower in the sloping fields as a result of heavier top soil erosion. The result showed clearly that the amount of TOC was very similar in flat and sloping field, as could also be seen as the standard deviations of the values from flat and sloping fields also overlapped each other. This similar values indicates that there is not more top soil erosion in the sloping fields. It also shows that slope angle is not a strongly influencing factor of the erosion process in the area. This could have the same reasons as why the value of TOC did not differ between the blocks. The reason for TOC in the soils being the same in flat and sloping fields might also be due to an overall low risk of erosion in the study area. It might be that the amount of erosion is too low to be shown in TOC content even in sloping fields. Since the study area is located in the lowlands, the problem of erosion is not as established as in the highlands due to the more uniform topography. It is reasonable that the problem of erosion in tea fields is greater in the highlands which might explain the results.

A regression-test showed that TOC did not depend significantly on slope angles, which is an additional indicator that other factors than slope angle affect the carbon distribution and therefore also the top soil erosion. In regression tests, a distinct correlation is needed to receive a significant regression when low numbers of samples are analyzed. The low number of samples analyzed in this study may therefore be the reason why no correlation was detected in the regression-test. Figure 14 show clearly that the amount of samples were too small in order to do any statements based on the plot in the figure. The plot of TOC and slope angle also visualizes that a correlation between the factors does not exist. Yet, if some values in the plot are assumed to be outliers and therefore eliminated, a trend of decreasing TOC with increasing slope angle might be distinguishable. The method of measuring slope angle may contain errors due to practical problems in the field. The slopes are often irregular and not as straight as in the presumed model, which means that the slope in the model was simplified. During measuring, the higher density of bushes made it difficult to determine the angles with accuracy. Due to these circumstances, the measured angles may contain some smaller errors from the measuring.

Plotting the yield and TOC, it can be shown that the values for TOC are rather constant even if the yield differs. The different yields of the smallholders were derived from the interviewed based on the smallholder's idea about the size of their fields and about the amount of produced tea per month in their field. The calculated yield might therefore contain a certain amount of error since the sizes of the fields were not measured precisely and since the amount of production could not be measured. In the range measured in this study, the TOC has no or little influence on the productivity of the tea plants. Even if the carbon affects the yield, other factors that are natural and human influenced, may affect with greater importance. Biot (1987) states in *Forecasting Productivity Losses Caused by Sheet and Rill Erosion* that soil depth and available water capacity are factors with great importance for the productivity. This statement may be applicable even in this study, which would explain the non-existing correlation between yield and TOC. Therefore the carbon in the soil is not directly affecting the smallholders in terms of productivity. As mentioned in previous section, the amount of analyzed samples is too few to state any correlation between the factors.

The result shows that all the blocks except for one had a value of TOC over the critical value of 2.5 %. 24 blocks out of the total 33 had a value of TOC over 4 % which is considered as good soils. This show that the soils analyzed in this study is mostly good and fertile soils. The very high TOC measured was probably too high to consider reliable, yet they had to be accepted since there was no time to redo the measurements. Despite the uncertainty in the result, the relative difference between the samples should still be correct and applicable in the analysis. Other studies where carbon content in tea lands in Sri Lanka have been measured show substantially lower contents, for example values from the Uva highlands presented by Illukpitiya et al. (2004) (Table 2). It might be that the carbon content is much lower in the highlands due to more intense tea cultivation and more dramatic topographic variations. Despite this, a previous study regarding soil quality in tea lands in Galle district, which is located in the lowlands next to Matara district, presented values of organic carbon content being significantly lower than both the values from the highlands and the values presented in this study (Wanniarachchi et al. 2003) (Table 2)

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Table 2. The values for mean organic carbon content in the soil from different studies conducted in Sri Lanka.

	Emanuelsson & Rasmusson, 2012	Illukpitiya et al., 2004	Wanniarachchi et al., 2003
Mean organic carbon content	4.79 %	2.60 %	1.26 %

Since Galle and Matara district have similar geographical conditions, soils in tea lands in the district should not differ this much in organic carbon contents. From this, it is not possible to state whether the result in Galle is unusually low or if the result from this study is remarkably high, yet most likely is that the values in this study are too high. A contributing factor for the different results in the studies is probably the fact that two different methods for determination of organic carbon content were used. In the previous Galle-study, a more complex method was used, but this method was too time demanding and too expensive to use in this study (Wanniarachchi et al., 2003). Still, since all the values in this study have been compiled with the same method, they can still show relative differences between the fields in the study.

6.3.2 Nitrogen

By using the macro-Kjeldahl method certain sources of errors are likely to occur. The long process and the frequent handling of the samples enabled more mistakes to be made. Likely, the most affecting factor of error in the method was the varying time and temperature during digestion and distilling. The process when organic nitrogen is transformed into ammonium might not have been completed in each digestion process since there was no indication of when time was enough. Due to this, all of the nitrogen might not have been decomposed in every sample which would lead to all nitrogen not being included in the analyze. Despite this, the directed time of digestion was always held to minimize the risk of the organic nitrogen not being transformed. Since the samples could not be analyzed at the same time due to limitations in the equipment, they had to be analyzed in different sequences. In the different steps in the method the following issues could occur: wrong sample size relative to the amount of acid, leaching of nitrogen by steam, inaccuracy of equipment, caking of samples in the Kjeldahl flask or titration errors (ExpotechUSA, Year unknown). In the titration part, the volume of the receiving sulfuric acid needed to be very accurate to be able to define the exact amount of nitrogen in the acid. In some titrations the amount of nitrogen turned out to be unreasonable low, probably due to any of the error sources. Due to this, these samples were analyzed once again. Some of the re-done samples received a completely different nitrogen content which shows that the method is very sensitive for variations in performance. Despite the sources of errors associated with the macro-Kjeldahl method, this was the only available method for nitrogen determination. Even if the error sources were present, the quantification of the impact was not possible to estimate. The awareness of the error sources made it possible to minimize uncertainties.

Due to time limitations, the samples from each block had to be merged to minimize the amount of analysis. Even if the same amount of each sample point were represented in the analyzed soil, the amount of nitrogen could vary drastically within a block. If nitrogen was accumulated at any location in a block, the merged result might have been misleading since possible outliers could not be detected, as the total nitrogen content could not be evaluated in each sample point. One of the merged samples was destroyed due to the use of wrong acid in combination with time limitations, and had to be excluded from the study.

The resulting values of total nitrogen lay within a reasonable range for tea lands in the area. In a previous report by Wanniarachchi & Shyamalee (2005), the mean total nitrogen was measured to lie within the range of nitrogen content measured in this study (Table 3). Furthermore, a study conducted in districts located at higher elevations, from 500 – 1500 m a.m.sl (whereas this study was conducted at elevations around 100 m a.m.sl) show that the nitrogen content in Sri Lanka lies around the same value (Wickremansinghe et al., Year Unknown) (Table 3).

Table 3. Values for mean total nitrogen content measured in different studies conducted in Sri Lanka.

	Emanuelsson & Rasmusson, 2012	Wickremansinghe et al., Year unknown	Wanniarachchi & Shyamalee, 2005
Mean total nitrogen content	0.033 %	0.145 %	0.10 %

The different studies, including this study, indicate that the amounts of total nitrogen in the soils of Sri Lanka are rather evenly distributed. Hence, from the few amount of reports it is not enough to claim any statements about total nitrogen in Sri Lankan soils. Tropical soils, especially in the wet zone are generally low in nitrogen and are unable to keep crops without fertilizing. Since the values are overall low, there are no limiting values for when a soil is poor or good when it comes to total nitrogen in these soils. Instead higher amounts of total nitrogen are always wanted (Wanniarachchi, 2012). Even if the resulting values of total nitrogen content in this study were similar to those in previous studies, the mean value was somewhat lower. The difference between the resulting values in this study and previous studies could be explained by the use of fertilizers. From the interviews of this study, it was learned that fertilizers are spread during rain season. Since the soil samples analyzed in this study was collected just before the rain season, it might have been a long time ago since the soil was fertilized. The lower nitrogen content in this study area could also be the cause of less intense fertilizing in the lowlands. Since erosion is a more extensive problem in the highlands, the use of fertilizers might be needed with higher frequency.

The total nitrogen content in the blocks proved to be randomly distributed. This indicates that the nitrogen distribution in the studied fields was not affected by erosion. The differences in nitrogen content between the sample points could be due to the fertilizers being unevenly spread. Though, the effects of the spreading technique should not have a great impact if they are not recently spread. It is difficult to estimate the extent of fertilizing in the study area since the resulting values showed no distinguishable extreme values, such as outliers within any certain fields. The differences in the amount of total nitrogen between the samples were small which made it more difficult to establish the cause of variance.

Comparing the total nitrogen content between sloping and flat fields showed that there was no difference. Most likely the same result would be shown with an independent t-test, even if Mann Whitney U-tests are not as strong in its result as a t-test. The mean values were similar even if the mean content in sloping fields were somewhat lower than in flat fields. The slightly higher total nitrogen content in flat fields could be an indicator of a more stable soil since the nutrients are not leached as much as in sloping fields. Though, this was not likely since the standard deviation of the means overlapped each other. The reason for similar total nitrogen content in different field types could be that the grade of erosion is equal in sloping and flat fields. This would mean that slope angle does not affect the erosion nor the nutrient content in the soil as much as other factors, which was also proved with the Spearman rank-test. The test of Spearman rank showed that total nitrogen in the soil did not depend on the slope angle. Just like discussed in previous section, factors like precipitation and infiltration capacity could have a greater impact on erosion and therefore also on the nutrient distribution in the soil than the slope angle.

A Spearman rank-test showed that the yield significantly depended on total nitrogen content. The scatterplot showed that the values were rather spread, but still there was a visible trend of increasing yield with increasing total nitrogen in the soil. Nitrogen was added as fertilizers in every studied field which might have impact on the correlation. The result might not be due to erosion, but can simply be explained by how the smallholders fertilize their fields. This result shows that fertilizing within the same range as studied increases the production and is a well-known technique in the area. The field sizes used when calculating the yield has the same sources of errors as mentioned in previous section for carbon.

It cannot be stated that the amount of nutrient content was explained only by fertilizers. Nutrients like nitrogen are a natural part of the soil and could therefore also have been affected by the general soil conditions that are controlled by natural factors like precipitation, vegetation cover or leaching.

7 Conclusion

The map of erosion showed that soil erosion was present in small amounts, evenly distributed in Matara district. This study verified that there was no difference in total organic carbon (TOC) or total nitrogen content between and within the fields in the study area. The result of the study suggested that erosion did not affect the content or distribution of TOC or total nitrogen that represented the nutrient content in the soil. Neither could slope angle explain the distribution of TOC or total nitrogen within a field.

Smallholders in the study area were aware of the problem of erosion; still they were not affected economically by erosion when it comes to total organic carbon content in the soil. There is however a correlation between yield and total nitrogen in the soil. The different correlations between yield and total organic carbon and between yield and total nitrogen suggest that the amount and distribution of total nitrogen is more affected by fertilizing than by erosion. Since erosion was present in every field but no correlation between yield and total organic carbon was shown, the assumption can be made that erosion does not affect the yield in a great extent. Instead the correlation between yield and total nitrogen indicates that fertilizing, in the studied extent is favorable for the yield.

Even if erosion is not affecting the smallholders in the area economically, their knowledge about the problem is not sufficient today and may therefore be improved since the problem may increase in the future. Erosion is an ongoing problem that will continue and change character with changing land use. Therefore it is crucial to highlight the problem in different geographical areas.

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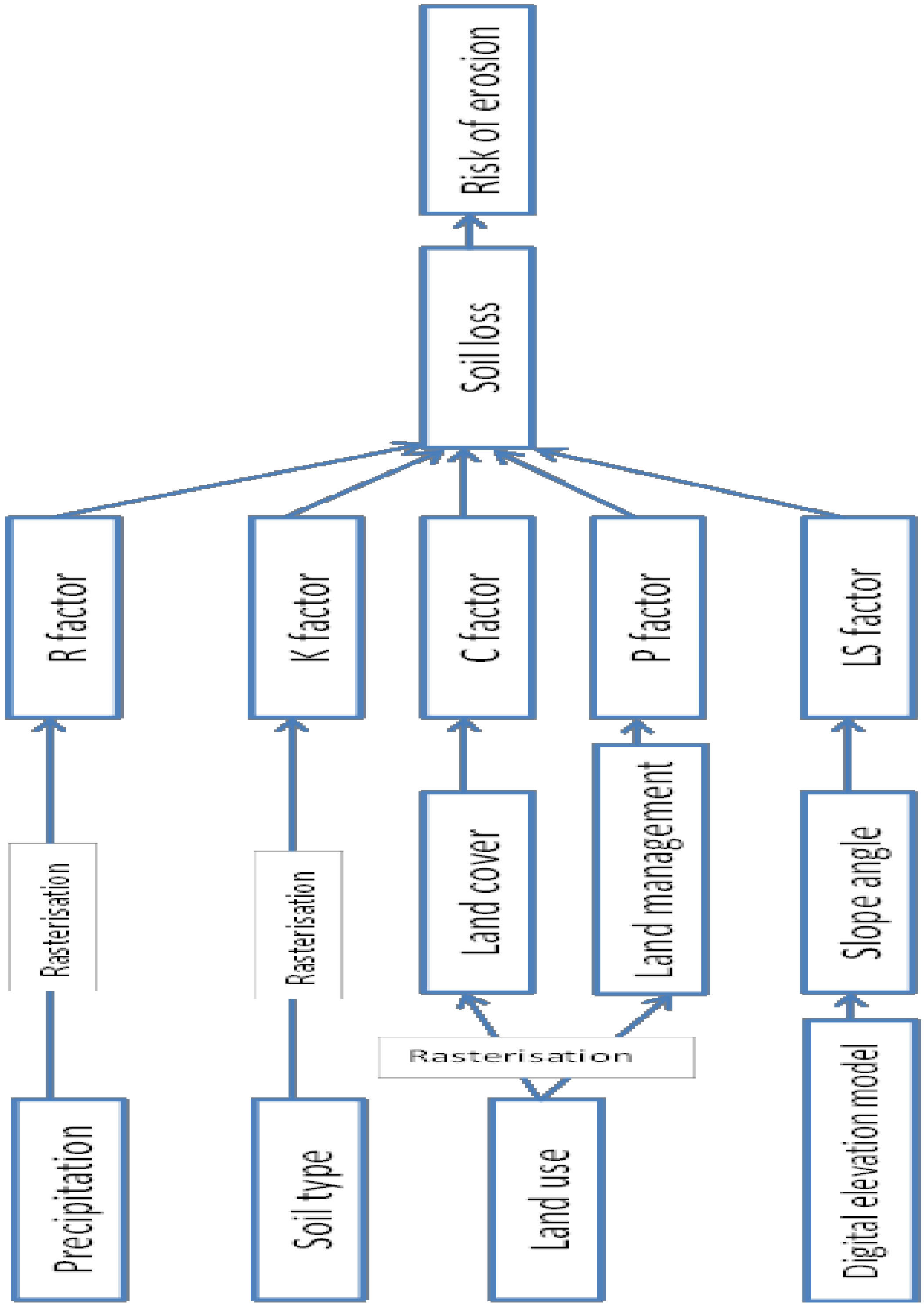
9 Appendix I

Flowchart used for creating map of erosion in ArcGIS



10 Appendix II

Questions for interviews

Age, gender, profession, position (owner/family/worker?) and yield?
Do you have domestic workers?
How often do you harvest?
How old are the plants in your tea land?
How many acres is your tea land?
Do you use irrigation in your tea plantations?

- During what time of the year do you use irrigation?
- How do you use irrigation?

Is it anytime plants are suffering from drought?

- Do the plants recover from drought?

How often do you use fertilizers in your tea land?

- How do you spread the fertilizers?
- During what time of the year do you use fertilizers?

Do you use manure in the tea plantations?
Do you use pesticides in tea plantations?

- Which type of pesticides do you use?

Is there any difference in productivity within the field?

- Where is the difference?

Do you have terraces?

- How often do you have to repair or maintain them?

Do you use drains?

- How often do you empty them?
- Where do they fill most quickly?

Do you use intercropping?

- What type of crop?

Do you have any exposed roots of the tea bushes?
How often is the tea bushes pruned?
Do you mulch during rain season?
Do you have erosion in you tea land?

- Where do you have erosion?
- Have the erosion increased or decreased during the years?
- Is the erosion the same during the year?
- What causes erosion in your tea land?

How do you prevent erosion?

11 Appendix III

Protocol for soil sampling

Smallholder number	
Date	
Soil characteristic	
Low or high productivity	
Plants in intercropping	
Grade of shading	
Erosion signs	
Slope lenght to sampling point	
Slope angle	
Form vertical to slope	
Form horizontal to slope	
Elevation from GPS	
Coordinates from GPS	
Aspect	
pH	
Comments	

12 Appendix IV

Result of interviews

Questions	Smallholder 1	Smallholder 2	Smallholder 3:1	Smallholder 3:2
Date	20120323	20120323	20120323	20120323
Age	38	40	56	56
Gender	Female	Female	Male	Male
Profession	Housewife	Housewife	Retired	Retired
Position	Owner	Owner	Owner	Owner
Yield, (kg/month)	140	100	425	80
Yield (kg/ m^2)	0.03459	0.09884	0.1050	0.02636
Calculated income (rs/month)	8120	5800	24650	4640
How many domestic workers do you have?	1	1	5	1
How often do you harvest?	1/week	1/week	2/week	1/week
How old is the tea plants in the tea land? (years)	3	5	3	15
How many acres is your tea land?	1	0.25	1	0.75
Area (m^2)	4047	1012	4047	3035
Do you use irrigation in the tea land?	No	No	Yes	No
- During what time of the year do you use irrigation?	-	-	During drought	-
- How do you use irrigation?	-	-	Waterpump well	-
Is it anytime plants are suffering from drought?	Yes	Yes	No	No
- Does the plants recover from drought?	Some die, some recover	Yes	Yes	-
How often do you use fertilizers in the tea plantations?	Every 2.5 month	Every 3 month	Every 4 month	Every 4 month
- How do you spread the fertilizers?	By hand 3 inches from the stem	By hand 3 inches from the stem	Around stems	Around stems
- During what time of the year do you use fertilizers?	In the rain season	In the rain season	In the rain season	In the rain season
Do you use manure in the tea plantations?	No	No	No	No
Do you use pesticides in tea plantations?	No	No	No	Yes
- Wich type of pesticides do you use?	-	-	-	Weedicides, once
Is there any difference in productivity within the field?	Yes	No	No	No
- Where is the difference?	Less productivity in the slope	-	-	-
Do you have terraces?	No	No	No	No
- How often do you maintain them?	-	-	-	-
Do you use drains?	Yes	Yes	Yes	Yes
- How often do you empty them?	Every 6 months	Every year	Every 2 year	Every 2 year
- Where do they fill most quickly?	In the slope	No difference	In the lower part of the slope	Unknown
Do you use intercropping?	Yes	Yes	Yes	Yes, very much
- Which types of crop in intercropping?	Gliricida, coconut	Gliricida	Gliricida	Mainly coconut and peppar
Is there any exposed roots of tea bushes?	No	No	No	No
How often is the tea bushes pruned?	Every 3 year	Every 2 year	Every 3 year	Every 2 year
Do you mulch during rain season?	No	Yes, with Gliricidia	Yes, with shade trees	Yes
Do you have erosion in your tea land?	Yes	Yes	Yes	Yes, little
- Where do you have erosion?	In slopes	Everywhere, more in steep slopes	Unknown	Unknown
- Have erosion increased or decreased during the years?	Increased	Increased	Increased	Unknown
- Is the erosion the same during the year?	More during rain season	More during rain season	More since cinnamon was cultivated and during rain season	More during rain season
- What causes erosion in your tea land?	Rainfall	Rainfall	Rainfall	Rainfall
How do you prevent erosion?	Drains and intercropping	Drains and intercropping	Drains and intercropping	Drains and intercropping
Interviewers comments	Nearby river that some times flood,	Stop harvesting during drought	Will start with manure from	Focus on field is to produce
	provide water to tea bushes	Manual weeding	poletrees (hard to get hold off)	coconut and peppar instead of tea
	Spread the same amount of fertilizers in the entire tea land	Steeper slopes give more	Manual weeding	Less erosion due to high
	Manual weeding	sediments in drains	Irrigation to costfull	shade and not very steep
	5 drains	4 drains		Less harvesting during drought
	Depending by rain when harvesting			4 drains
	Possible gathering of nutrients in the waterstream			Manual weeding
	Irrigate the plants when they are young			
	Two persons interviewed, he			
	answered in housewifes place sometimes			

Questions	Estate	Smallholder 4:1	Smallholder 4:2	Smallholder 5
Date	20120323	20120323	20120323	20120323
Age	Unknown	Unknown	Unknown	Unknown
Gender	Male	Male	Male	Male
Profession	Estate owner	Farmer	Farmer	Retired
Position	Owner	Owner	Owner	Owner
Yield, (kg/month)	Unknown	60	40	200
Yield (kg/ m^2)	Unknown	0.01977	0.03954	0.06589
Calculated income (rs/month)	Unknown	3480	2320	11600
How many domestic workers do you have?	20	0	0	2
How often do you harvest?	Unknown	Unknown	1/week	1/week
How old is the tea plants in the tea land? (years)	14	20	5	5
How many acres is your tea land?	35	0.75	0.25	0.75
Area (m^2)	141645	3035	1012	3035
Do you use irrigation in the tea land?	No	No	No	No
- During what time of the year do you use irrigation?	-	-	-	-
- How do you use irrigation?	-	-	-	-
Is it anytime plants are suffering from drought?	Unknown	Unknown	Unknown	Unknown
- Does the plants recover from drought?	-	-	-	-
How often do you use fertilizers in the tea plantations?	Every 3 month	Never	Every 3 month	Every 3 month
- How do you spread the fertilizers?	Where its needed	-	Around stems	Around stems
- During what time of the year do you use fertilizers?	Unknown	-	Unknown	Unknown
Do you use manure in the tea plantations?	No	No	No	No, gliricidia instead
Do you use pesticides in tea plantations?	Yes	No	No	Yes
- Wich type of pesticides do you use?	Pesticide and weedicide	-	-	Weedicide, once/year
Is there any difference in productivity within the field?	Yes	No	No	No
- Where is the difference?	More further down	-	-	-
Do you have terraces?	Yes at ground level	No	No	Yes, old ones
- How often do you maintain them?	Unknown	-	-	Never
Do you use drains?	Yes	Yes	Yes	Yes
- How often do you empty them?	Every 3 year	Every 6 month	Unknown	Every 6 month
- Where do they fill most quickly?	Unknown	Unknown	Unknown	Unknown
Do you use intercropping?	Yes	Yes, very much	Yes	Yes
- Which types of crop in intercropping?	Gliricida, albizzia and other shade trees (teak, wig banyan, coconut)	Peppar, shade trees	Gliricidia	Gliricidia
Is there any exposed roots of tea bushes?	Yes	Unknown	No	Unknown
How often is the tea bushes pruned?	Every 3 year	Every 3 year	Every 3 year	Every 3 year
Do you mulch during rain season?	Unknown	Yes, with mana	Yes, with mana	Yes, compost
Do you have erosion in your tea land?	Yes	Little, due to high shade tress	Yes	Yes
- Where do you have erosion?	In the slopes	Unknown	Everywhere	Unknown
- Have erosion increased or decreased during the years?	Unknown	Unknown	Decreased, due to drains	Unknown
- Is the erosion the same during the year?	Unknown	Unknown	More during rain season	More during rain season
- What causes erosion in your tea land?	Unknown	Rainfall	Rainfall	Rainfall
How do you prevent erosion?	Drains, terraces, grass (guatamala), intercropping	Drains, Intercropping	Drains, intercropping, mulching	Terraces, Drains, Intercropping
Interviewers comments	Nitrogen-testing before fertilizing	5-6 subdrains and one maindrain	Soil rehabilitation with mana grass (1,5 year)	About 5 terraces
	Flat lands have higher productivity	Trees will soon be replanted	No manure, because mana is enough	4 parallel drains
	Exposted roots, plant do not die, but less harvest	to higher productivity	3 drains	Good knowledge about erosion
	Too expensive with terraces in the slope	No economics is spend on		
	More knowledge about erosion than small holders	the field today		

Questions	Smallholder 6	Smallholder 7:1	Smallholder 7:2	Smallholder 8	Smallholder 9
Date	20120403	20120405	20120405	20120405	20120405
Age	56	60	60	34	46
Gender	Female	Male	Male	Male	Male
Profession	Housewife	Owner of tempel	Owner of tempel	Bussiness man	English teacher
Position	Owner	Owner	Owner	Owner	Owner
Yield, (kg/month)	140	300	400	700	60
Yield (kg/ m^2)	0.03459	0.09884	0.1318	0.1153	0.03706
Calculated income (rs/month)	8120	17400	23200	40600	3480
How many domestic workers do you have?	2	Some	Some	3	1
How often do you harvest?	1/week	1/week	1/week	1/week	1/week
How old is the tea plants in the tea land? (years)	4	18	5	10	3
How many acres is your tea land?	1	0.75	0.75	1.5	0.4
Area (m^2)	4047	3035	3035	6071	1619
Do you use irrigation in the tea land?	No	No	No	No	No
- During what time of the year do you use irrigation?	-	-	-	-	-
- How do you use irrigation?	-	-	-	-	-
Is it anytime plants are suffering from drought?	No	Yes	Yes	Yes	No
- Does the plants recover from drought?	-	No	No	No	
How often do you use fertilizers in the tea plantations?	Every 3 month	Every 4 month	Every 4 month	Every 3 month	Every 3 month
- How do you spread the fertilizers?	Around stems	Unknown	Unknown	Circle aroud stem	Unknown
- During what time of the year do you use fertilizers?	In rain season	In rain season	In rain season	When soils are wet	Unknown
Do you use manure in the tea plantations?	No	No	No	No, gliricidia	No
Do you use pesticides in tea plantations?	No	Yes	Yes	No	No
- Wich type of pesticides do you use?	-	Unknown	Unknown	-	-
Is there any difference in productivity within the field?	No	No	No	No	No
- Where is the difference?	-	-	-	-	-
Do you have terraces?	No	No	No	Yes	No
- How often do you maintain them?	-	-	-	Once every 4 month	-
Do you use drains?	Yes	Yes	Yes	Yes	Yes, one
- How often do you empty them?	Every 2 year	Unknown	Unknown	Every 2.5 years	Unknown
- Where do they fill most quickly?	No difference	Unknown	Unknown	Unknown	Unknown
Do you use intercropping?	Yes	No	No	No	No
- Which types of crop in intercropping?	Pepper, clove, silky-oak, nedung	Gliricidia, avocado, rubber	Gliricidia	-	Shade trees
Is there any exposed roots of tea bushes?	No	Yes	No	No	Yes
How often is the tea bushes pruned?	Every 2 year	Every 3 year	Every 3 year	Every 3 year	Every year
Do you mulch during rain season?	Yes, with glorocedia	Yes, with gliricidia	Yes, with gliricidia	No	Unknown
Do you have erosion in your tea land?	Yes	Yes	No	Yes	Yes
- Where do you have erosion?	No particular spot	Unknown	-	Unknown	Unknown
- Have erosion increased or decreased during the years?	Little increase	Increased this year	-	Not increased due to control	Same
- Is the erosion the same during the year?	Unknown	More during rain season	-	More during rain season	Yes
- What causes erosion in your tea land?	Rainfall	Rainfall	-	Rainfall	Rainfall
How do you prevent erosion?	Drains, cover ground	Drains	Drains	Terraces and drains	Drain
Interviewers comments	Intercropping in field margins	Exposed roots due to old plants	Well-grown plants	Two fields where measured	Exposed roots due to very steep slope
	Trees surrounding the field	One terrace observed in the field	Flat land	One sloping and one flat	Soon time for pruning
	Flat slope	No intercropping but shade trees			Cut shade trees to increase productivity
	Only 2-3 drains, no sharp boundaries	Plants are in need of replanting			Just above a water stream
	Manual weeding	Shallow roots			No interpreter needed

13 Appendix V

Result of the protocols

Smallholder number	1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3	2.1.1	2.1.2	2.1.3
Date	20120328	20120328	20120328	20120328	20120328	20120328	20120328	20120328	20120328
Soil characteristic	Reddish	Reddish	Reddish	Brownish	Brownish	Brownish	Somewhat reddish	Somewhat reddish	Somewhat reddish
Productivity	Low	Low	Low	Low	Low	Low	High	High	High
Plants in intercropping	Coconut, gliricidia,	Coconut, gliricidia,	Coconut, gliricidia,	Gliricidia,	Gliricidia,	Gliricidia,	Gliricidia	Gliricidia	Gliricidia
	wig banyan, chili,	wig banyan, chili,	wig banyan, chili,	coconut	coconut	coconut			
	pepper	pepper	pepper						
Grade of shading	Shaded	Shaded	Shaded	Open	Open	Open	Open	Open	Open
Erosion signs	Rills	Rills	Rills	Exposed roots	Exposed roots	Exposed roots	Exposed roots	Exposed roots	Exposed roots
				of trees	of trees	of trees	of trees	of trees	of trees
Slope lenght (m)	12	12	12	21	21	21	30	30	30
Point a	2	6	10	3.5	10.5	17.5	5	15	25
Point b	2	6	10	3.5	10.5	17.5	5	15	25
Point c	2	6	10	3.5	10.5	17.5	5	15	25
Slope angle									
Point a, measured h (m)	0.87	0.95	0.79	<10	<10	<10	<10	0.41	0.63
Point a, calculated from h (°)	0.45	0.49	0.41	<10	<10	<10	<10	0.21	0.32
Point a, measured with inclinometer (°)	40	30	25	<10	<10	<10	<10	15	20
Point b, measured h (m)	0.93	1.05	0.9	<10	<10	<10	0.47	0.38	0.58
Point b, calculated from h (°)	0.48	0.55	0.47	<10	<10	<10	0.24	0.19	0.29
Point b, measured with inclinometer (°)	50	30	30	<10	<10	<10	25	20	25
Point c, measured h (m)	0.86	0.93	0.9	<10	<10	<10	0.43	0.5	0.59
Point c, calculated from h (°)	0.44	0.48	0.47	<10	<10	<10	0.22	0.25	0.30
Point c, measured with inclinometer (°)	50	25	35	<10	<10	<10	15	25	20
Mean slope angle in block, calculated (°)	46	51	45	<10	<10	<10	15	22	30
Mean slope angle in block, inclinometer (°)	47	28	30	<10	<10	<10	13	20	22
Form vertical to slope	Straight	Straight	Straight	Straight	Straight	Straight	Convex	Convex	Convex
Forn horizontal to slope	Straight	Straight	Straight	Concave	Concave	Concave	Convex	Convex	Convex
Elevation from GPS (m a.s.l.)	89	89	89	89	89	89	86	86	86
Coordinates from GPS (° N)	6.12	6.12	6.12	6.12	6.12	6.12	6.12	6.12	6.12
Coordinates from GPS (° E)	80.57	80.57	80.57	80.57	80.57	80.57	80.57	80.57	80.57
Aspect	East	East	East	East	East	East	Northwest	Northwest	Northwest
Comments from field	Random plants have died			Larger than field 1:1:1-3			Young intercropping trees		
				Random plants have died					
				Prioritized field					
				Many and more distinct drains					
				7 meter to water stream from block 3					
				Steep slope to water stream					

Smallholder number	3.1.1	3.1.2	3.1.3	3.2.1	3.2.2	3.2.3	6.1.1	6.1.2	6.1.3
Date	20120328	20120328	20120328	20120328	20120328	20120328	20120403	20120403	20120403
Soil characteristic	Brownish, coarse-grained	Brownish, coarse-grained	Brownish, coarse-grained	Brownish	Brownish	Brownish	Brownish	Brownish	Brownish
Productivity	High	High	High	High	High	High	Low	Low	Low
Plants in intercropping	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia, pepper,	Gliricidia, pepper,	Gliricidia, pepper,
							clove, silky-oak,	clove, silky-oak,	clove, silky-oak,
							nedung	nedung	nedung
Grade of shading	Totally open	Totally open	Totally open	Totally open	Totally open	Totally open	Little shaded	Little shaded	Little shaded
Erosion signs	Rills	Rills	Rills	Rills	Rills	Rills	Exposed roots of	Exposed roots of	Exposed roots of
							nearby trees	nearby trees	nearby trees
Slope lenght (m)	15	15	15	18	18	18	12	12	12
Point a	2.5	7.5	12.5	3	9	15	2	6	10
Point b	2.5	7.5	12.5	3	9	15	2	6	10
Point c	2.5	7.5	12.5	3	9	15	2	6	10
Slope angle									
Point a, measured h (m)	0.29	0.25	0.38	<10	<10	<10	<10	<10	<10
Point a, calculated from h (°)	0.15	0.13	0.19	<10	<10	<10	<10	<10	<10
Point a, measured with inclinometer (°)	25	15	12	<10	<10	<10	<10	<10	<10
Point b, measured h (m)	<10	0.29	0.41	<10	<10	<10	<10	<10	<10
Point b, calculated from h (°)	<10	0.15	0.21	<10	<10	<10	<10	<10	<10
Point b, measured with inclinometer (°)	<10	15	14	<10	<10	<10	<10	<10	<10
Point c, measured h (m)	0.2*	<10	0.43	<10	<10	<10	<10	<10	<10
Point c, calculated from h (°)	0.2	<10	0.22	<10	<10	<10	<10	<10	<10
Point c, measured with inclinometer (°)	20	<10	13	<10	<10	<10	<10	<10	<10
Mean slope angle in block, calculated (°)	12	9	20	<10	<10	<10	<10	<10	<10
Mean slope angle in block, inclinometer (°)	15	10	13	<10	<10	<10	<10	<10	<10
Form vertical to slope	Convex	Convex	Convex	Straight, terraces	Straight, terraces	Straight, terraces	Straight	Straight	Straight
Forn horizontal to slope	Convex	Convex	Convex	Concave	Concave	Concave	Concave	Concave	Concave
Elevation from GPS (m a.s.l.)	106	106	106	106	106	106	38	38	38
Coordinates from GPS (° N)	6.13	6.13	6.13	6.13	6.13	6.13	6.06	6.06	6.06
Coordinates from GPS (° E)	80.57	80.57	80.57	80.57	80.57	80.57	80.56	80.56	80.56
Aspect	Undefined	Undefined	Undefined	Undefined	Undefined	Undefined	Northeast-east	Northeast-east	Northeast-east
Comments from field	Branches from pruned trees layed on soil			Branches from pruned trees on soils			No drains observed		
	Owner: "No erosion in plants younger than 8 years"			Owner: "No erosion in plants younger than 8 years"					
	Fresh-pruned plants			Fresh-pruned plants					
	Easy to dig in soil			Well done terracess with stone blocks					
	Well done drains with stone blocks			Added composited materials twice a year					
	Added composited materials twice a year			3 big terracess					
				Located below a slope					

Smallholder number	7.1.1	7.1.2	7.1.3	7.2.1	7.2.2	7.2.3	8.1.1	8.1.2	8.1.3
Date	20120405	20120405	20120405	20120405	20120405	20120405	20120405	20120405	20120405
Soil characteristic	Clay	Clay	Clay	Brown, clay	Brown, clay	Brown, clay	Brownish	Brownish	Brownish
Productivity	High	High	High	High	High	High	High	High	High
Plants in intercropping	Gliricidia,	Gliricidia,	Gliricidia,	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia
	avocado, rubber,	avocado, rubber,	avocado, rubber,						
	jack tree	jack tree	jack tree						
Grade of shading	Little shaded	Little shaded	Little shaded	Shaded	Shaded	Shaded	Shaded	Shaded	Shaded
Erosion signs	Big rills	Big rills	Big rills	Tiny rills	Tiny rills	Tiny rills	Collapsed drains	Collapsed drains	Collapsed drains
Slope lenght (m)	21	21	21	21	21	21	15	15	15
Point a	3.5	10.5	17.5	3.5	10.5	17.5	2.5	7.5	12.5
Point b	3.5	10.5	17.5	3.5	10.5	17.5	2.5	7.5	12.5
Point c	3.5	10.5	17.5	3.5	10.5	17.5	2.5	7.5	12.5
Slope angle									
Point a, measured h (m)	0.58	<10	0.56	<10	<10	<10	<10	<10	<10
Point a, calculated from h (°)	0.29	<10	0.28	<10	<10	<10	<10	<10	<10
Point a, measured with inclinometer (°)	25	<10	15	<10	<10	<10	<10	<10	<10
Point b, measured h (m)	0.52	0.34	0.61	<10	<10	<10	<10	<10	<10
Point b, calculated from h (°)	0.26	0.17	0.31	<10	<10	<10	<10	<10	<10
Point b, measured with inclinometer (°)	20	15	25	<10	<10	<10	<10	<10	<10
Point c, measured h (m)	0.59	0.36	0.45	<10	<10	<10	<10	<10	<10
Point c, calculated from h (°)	0.3	0.18	0.23	<10	<10	<10	<10	<10	<10
Point c, measured with inclinometer (°)	15	20	15	<10	<10	<10	<10	<10	<10
Mean slope angle in block, calculated (°)	29	18	27	<10	<10	<10	<10	<10	<10
Mean slope angle in block, inclinometer (°)	20	17.5	18	<10	<10	<10	<10	<10	<10
Form vertical to slope	Concave	Concave	Concave	Concave	Concave	Concave	Convex	Convex	Convex
Forn horizontal to slope	Concave	Concave	Concave	Concave	Concave	Concave	Convex	Convex	Convex
Elevation from GPS (m a.s.l.)	57	57	57	0	0	0	60	60	60
Coordinates from GPS (° N)	6.12	6.12	6.12	6.12	6.12	6.12	6.13	6.13	6.13
Coordinates from GPS (° E)	80.56	80.56	80.56	81.08	81.08	81.08	80.57	80.57	80.57
Aspect	East	East	East	North	North	North	West	West	West
Comments from field	Newly pruned			Healthy looking bushes			Newly pruned, many brances on the ground		
	Terraces			Prioritized field			Well maintained field with many drains and terraces		
	Much space between bushes			Gliricida were well structured			Barriers in the ditch		
				Ground cover			Structured gliricidia		
				Easy to dig in soil					
				Drains					

Smallholder number	8.2.1	8.2.2	8.2.3	9.1.1	9.1.2	9.1.3
Date	20120405	20120405	20120405	20120405	20120405	20120405
Soil characteristic						
Productivity	High	High	High	Low	Low	Low
Plants in intercropping	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia	Gliricidia
Grade of shading	Shaded	Shaded	Shaded	Little shaded	Little shaded	Little shaded
Erosion signs	Collapsed drains	Collapsed drains	Collapsed drains	Earth slide	Earth slide	Earth slide
Slope lenght (m)	21	21	21	12	12	12
Point a	3.5	10.5	17.5	2	6	10
Point b	3.5	10.5	17.5	2	6	10
Point c	3.5	10.5	17.5	2	6	10
Slope angle						
Point a, measured h (m)	0.44	0.45	<10	1.04	1.12	1.07
Point a, calculated from h (°)	0.22	0.23	<10	0.54	0.59	0.56
Point a, measured with inclinometer (°)	10	20	<10	30	20	25
Point b, measured h (m)	0.48	0.39	<10	1	1.17	0.85
Point b, calculated from h (°)	0.24	0.2	<10	0.52	0.62	0.44
Point b, measured with inclinometer (°)	10	25	<10	25	25	15
Point c, measured h (m)	0.53	0.59	<10	1.08	1.34	1.09
Point c, calculated from h (°)	0.27	0.3	<10	0.57	0.72	0.57
Point c, measured with inclinometer (°)	10	15	<10	25	30	30
Mean slope angle in block, calculated (°)	24	24	<10	54	64	52
Mean slope angle in block, inclinometer (°)	10	20	<10	27	25	23
Form vertical to slope	Straight, terraces	Straight, terraces	Straight, terraces	Straight	Straight	Straight
Forn horizontal to slope	Straight	Straight	Straight	Straight	Straight	Straight
Elevation from GPS (m a.s.l.)	64	64	64	54	54	54
Coordinates from GPS (° N)	6.13	6.13	6.13	6.19	6.19	6.19
Coordinates from GPS (° E)	80.57	80.57	80.57	80.56	80.56	80.56
Aspect	West	West	West	South	South	South
Comments from field	Block 3 were just above a terrace			Very steep		
	Angle could not be measured in block 3			Very close to water stream		
	Newly pruned, many brances on the ground			Some small shade trees		
	Well maintained field with many drains and terraces					
	Barriers in the ditch					
	Structured gliricidia					

14 Appendix VI

The resulting values of the pH measuring

	pH	mean in block	mean in field			pH	mean in block	mean in field
1:1:1a	6.8				7:1:1a	5.63		
1:1:1b	6.48				7:1:1b	5.6		
1:1:1c	6.13	6.47			7:1:1c	5.52	5.58	
1:1:2a	6.9				7:1:2a	5.06		
1:1:2b	6.05				7:1:2b	5.09		
1:1:2c	5.95	6.3			7:1:2c	5.09	5.08	
1:1:3a	6.76				7:1:3a	5.38		
1:1:3b	6.14				7:1:3b	5.53		
1:1:3c	6.01	6.30	6.36		7:1:3c	5.65	5.52	5.39
1:2:1a	6.73				7:2:1a	5.57		
1:2:1b	6.51				7:2:1b	5.68		
1:2:1c	5.86	6.37			7:2:1c	5.65	5.63	
1:2:2a	6.19				7:2:2a	5.94		
1:2:2b	6.06				7:2:2b	5.61		
1:2:2c	6.54	6.26			7:2:2c	5.51	5.69	
1:2:3a	5.91				7:2:3a	6.73		
1:2:3b	5.97				7:2:3b	5.68		
1:2:3c	6	5.96	6.20		7:2:3c	6.15	6.19	5.84
2:1:1a	5.66				8:1:1a	7.91		
2:1:1b	5.62				8:1:1b	7.2		
2:1:1c	6.09	5.79			8:1:1c	6.1	7.07	
2:1:2a	6				8:1:2a	6.39		
2:1:2b	6				8:1:2b	6.42		
2:1:2c	5.86	5.95			8:1:2c	5.74	6.18	
2:1:3a	5.99				8:1:3a	6.67		
2:1:3b	5.95				8:1:3b	6.36		
2:1:3c	5.98	5.97	5.91		8:1:3c	6.47	6.5	6.58
3:1:1a	6.73				8:2:1a	7.28		
3:1:1b	6.89				8:2:1b	7.16		
3:1:1c	5.82	6.48			8:2:1c	7.42	7.29	
3:1:2a	7.12				8:2:2a	7.37		
3:1:2b	6.39				8:2:2b	6.76		
3:1:2c	6.65	6.72			8:2:2c	7.45	7.19	
3:1:3a	6.23				8:2:3a	6.09		
3:1:3b	5.9				8:2:3b	6.64		
3:1:3c	7.78	6.64	6.61		8:2:3c	7.02	6.58	7.02
3:2:1a	6.68				9:1:1a	6.07		
3:2:1b	6.18				9:1:1b	5.94		
3:2:1c	7.15	6.67			9:1:1c	5.8	5.94	
3:2:2a	5.98				9:1:2a	5.99		
3:2:2b	6.13				9:1:2b	6.19		
3:2:2c	6.56	6.22			9:1:2c	5.94	6.04	
3:2:3a	5.84				9:1:3a	6.58		
3:2:3b	5.89				9:1:3b	6.16		
3:2:3c	5.82	5.85	6.25		9:1:3c	6.22	6.32	6.10
6:1:1a	5.84							
6:1:1b	6.06							
6:1:1c	5.59	5.83						
6:1:2a	5.66							
6:1:2b	5.27							
6:1:2c	5.62	5.52						
6:1:3a	5.48							
6:1:3b	5.47							
6:1:3c	5.7	5.55	5.63					

16 Appendix VII

Result of carbon analysis

	Cup, g	Soil, g	Cup + soil when dried, g	Difference dried /not dried, g	Dried soil, g	Cup + soil when furnanced, g	Furnanced soil, g	Organic matter in soil, g	Organic matter in soil, %	TOC in soil, g	TOC in soil, %	Mean TOC in block, %	Mean TOC in field, %
1:1:1a	15.89	14.29	27.31	2.87	11.42	26.31	10.42	1	8.757	0.5800	5.079		
1:1:1b	16.96	14.27	29.05	2.18	12.09	27.87	10.91	1.18	9.760	0.6845	5.661		
1:1:1c	16.67	14.53	28.96	2.24	12.29	28.57	11.9	0.39	3.173	0.2262	1.841	4.194	
1:1:2a	15.77	14.77	28.37	2.17	12.6	28.06	12.29	0.31	2.460	0.1798	1.427		
1:1:2b	16.99	14.69	29.17	2.51	12.18	28.45	11.46	0.72	5.911	0.4176	3.429		
1:1:2c	18.69	14.83	31.1	2.42	12.41	29.93	11.24	1.17	9.428	0.6787	5.469	3.442	
1:1:3a	15.61	14.83	28	2.44	12.39	27.07	11.46	0.93	7.506	0.5394	4.354		
1:1:3b	16.03	14.51	28.04	2.5	12.01	26.84	10.81	1.2	9.992	0.6961	5.796		
1:1:3c	16.24	14.57	28.27	2.54	12.03	27.53	11.29	0.74	6.151	0.4292	3.568	4.573	4.069
1:2:1a	15.77	14.3	27.9	2.17	12.13	26.7	10.93	1.2	9.893	0.6961	5.738		
1:2:1b	16.17	14.16	28.1	2.23	11.93	26.89	10.72	1.21	10.14	0.7019	5.883		
1:2:1c	22.57	14.1	34.5	2.17	11.93	33.47	10.9	1.03	8.634	0.5974	5.008	5.543	
1:2:2a	16.79	14.26	28.76	2.29	11.97	27.66	10.87	1.1	9.190	0.6381	5.330		
1:2:2b	16.4	14.86	28.6	2.66	12.2	27.13	10.73	1.47	12.05	0.8527	6.989		
1:2:2c	16.21	14.83	28.44	2.6	12.23	26.89	10.68	1.55	12.67	0.8991	7.351	6.557	
1:2:3a	18.73	14.13	31.29	1.57	12.56	30.45	11.72	0.84	6.688	0.4872	3.879		
1:2:3b	16.65	14.7	29.65	1.7	13	28.87	12.22	0.78	6.000	0.4524	3.480		
1:2:3c	16.12	14.25	28.72	1.65	12.6	28.06	11.94	0.66	5.238	0.3828	3.038	3.466	5.189
2:1:1a	16.58	14.76	29.46	1.88	12.88	28.16	11.58	1.3	10.09	0.7541	5.855		
2:1:1b	15.67	14.22	28.27	1.62	12.6	27.13	11.46	1.14	9.048	0.6613	5.248		
2:1:1c	16.14	14.4	28.72	1.82	12.58	27.53	11.39	1.19	9.459	0.6903	5.487	5.530	
2:1:2a	16.59	14.6	29.18	2.01	12.59	27.94	11.35	1.24	9.849	0.7193	5.713		
2:1:2b	16.79	14.93	29.76	1.96	12.97	28.6	11.81	1.16	8.944	0.6729	5.188		
2:1:2c	15.49	14.81	28.15	2.15	12.66	26.95	11.46	1.2	9.479	0.6961	5.498	5.466	
2:1:3a	15.91	14.43	28.54	1.8	12.63	27.51	11.6	1.03	8.155	0.5974	4.730		
2:1:3b	18.71	14.35	31.32	1.74	12.61	30.54	11.83	0.78	6.186	0.4524	3.588		
2:1:3c	15.31	14.36	27.84	1.83	12.53	27.11	11.8	0.73	5.826	0.4234	3.379	3.899	4.965
3:1:1a	15.76	14.3	28.76	1.3	13	28.05	12.29	0.71	5.462	0.4118	3.168		
3:1:1b	16.12	14.77	29.23	1.66	13.11	28.49	12.37	0.74	5.645	0.4292	3.274		
3:1:1c	17.76	14.97	30.6	2.13	12.84	29.87	12.11	0.73	5.685	0.4234	3.298	3.247	
3:1:2a	16.29	14.53	29.34	1.48	13.05	28.4	12.11	0.94	7.203	0.5452	4.178		
3:1:2b	16.14	14.71	28.67	2.18	12.53	27.76	11.62	0.91	7.263	0.5278	4.213		
3:1:2c	15.89	14.6	28.35	2.14	12.46	26.94	11.05	1.41	11.32	0.8179	6.564	4.985	
3:1:3a	16.12	14.81	29.06	1.87	12.94	27.67	11.55	1.39	10.74	0.8063	6.231		
3:1:3b	15.64	14.7	28.71	1.63	13.07	27.37	11.73	1.34	10.25	0.7773	5.947		
3:1:3c	14.94	14.83	28.17	1.6	13.23	26.79	11.85	1.38	10.43	0.8005	6.050	6.076	4.769
3:2:1a	15.9	14.64	29.17	1.37	13.27	28.07	12.17	1.1	8.289	0.6381	4.808		
3:2:1b	15.65	14.59	28.61	1.63	12.96	27.59	11.94	1.02	7.870	0.5916	4.565		
3:2:1c	15.66	14.84	28.97	1.53	13.31	27.86	12.2	1.11	8.340	0.6439	4.837	4.737	
3:2:2a	22.26	14.51	35.01	1.76	12.75	34.1	11.84	0.91	7.137	0.5278	4.140		
3:2:2b	22.16	14.93	35.69	1.4	13.53	34.81	12.65	0.88	6.504	0.5104	3.773		
3:2:2c	18.83	14.93	32.21	1.55	13.38	31.16	12.33	1.05	7.848	0.6090	4.552	4.155	
3:2:3a	20.47	14.91	33.87	1.51	13.4	33.03	12.56	0.84	6.269	0.4872	3.636		
3:2:3b	22.19	14.88	35.39	1.68	13.2	34.61	12.42	0.78	5.909	0.4524	3.428		
3:2:3c	20.3	14.57	33.28	1.59	12.98	32.53	12.23	0.75	5.778	0.4350	3.352	3.472	4.121
6:1:1a	15.96	14.45	28.4	2.01	12.44	27.7	11.74	0.7	5.627	0.4060	3.264		
6:1:1b	16.45	14.48	28.94	1.99	12.49	28.22	11.77	0.72	5.765	0.4176	3.344		
6:1:1c	15.75	14.94	28.45	2.24	12.7	27.73	11.98	0.72	5.669	0.4176	3.288	3.299	
6:1:2a	16.61	14.57	28.86	2.32	12.25	27.69	11.08	1.17	9.551	0.6787	5.540		
6:1:2b	16.64	14.54	28.91	2.27	12.27	27.84	11.2	1.07	8.720	0.6206	5.058		
6:1:2c	15.06	14.22	26.88	2.4	11.82	25.85	10.79	1.03	8.714	0.5974	5.055	5.218	

	Cup, g	Soil, g	Cup + soil when dried, g	Difference dried /not dried, g	Dried soil, g	Cup + soil when furnanced, g	Furnanced soil, g	Organic matter in soil, g	Organic matter in soil, %	TOC in soil, g	TOC in soil, %	Mean TOC in block, %	Mean TOC in field, %
6:1:3a	15.3	14.81	27.2	2.91	11.9	25.87	10.57	1.33	11.18	0.7715	6.483		
6:1:3b	15.79	14.03	27.07	2.75	11.28	25.77	9.98	1.3	11.52	0.7541	6.685		
6:1:3c	16.77	14.92	28.89	2.8	12.12	27.44	10.67	1.45	11.96	0.8411	6.939	6.702	5.073
7:1:1a	16.37	14.89	28.45	2.81	12.08	27.94	11.57	0.51	4.222	0.2958	2.449		
7:1:1b	16.79	14.39	28.67	2.51	11.88	28.17	11.38	0.5	4.209	0.2900	2.441		
7:1:1c	15.64	14.29	27.34	2.59	11.7	26.84	11.2	0.5	4.274	0.2900	2.479	2.456	
7:1:2a	16.57	14.91	29.02	2.46	12.45	28.35	11.78	0.67	5.382	0.3886	3.122		
7:1:2b	16.95	14.85	29.04	2.76	12.09	28.1	11.15	0.94	7.775	0.5452	4.510		
7:1:2c	16.25	14.82	28.27	2.8	12.02	27.47	11.22	0.8	6.656	0.4640	3.861	3.831	
7:1:3a	15.48	14.64	27.7	2.42	12.22	26.9	11.42	0.8	6.547	0.4640	3.797		
7:1:3b	16.02	14.57	28.56	2.03	12.54	27.68	11.66	0.88	7.018	0.5104	4.071		
7:1:3c	18.69	14.86	30.47	3.08	11.78	29.37	10.68	1.1	9.338	0.6381	5.416	4.428	3.572
7:2:1a	15.61	14.35	27.51	2.45	11.9	26.66	11.05	0.85	7.143	0.4930	4.143		
7:2:1b	15.67	14.48	27.53	2.62	11.86	26.68	11.01	0.85	7.167	0.4930	4.157		
7:2:1c	16.12	14.05	27.88	2.29	11.76	27.01	10.89	0.87	7.398	0.5046	4.291	4.197	
7:2:2a	16.21	14.34	28.36	2.19	12.15	27.54	11.33	0.82	6.749	0.4756	3.915		
7:2:2b	15.77	14.62	28.14	2.25	12.37	27.19	11.42	0.95	7.680	0.5510	4.455		
7:2:2c	18.73	14.67	30.81	2.59	12.08	29.91	11.18	0.9	7.450	0.5220	4.322	4.230	
7:2:3a	15.9	14.35	27.74	2.51	11.84	26.87	10.97	0.87	7.348	0.5046	4.262		
7:2:3b	16.17	14.88	28.59	2.46	12.42	27.67	11.5	0.92	7.407	0.5336	4.297		
7:2:3c	16.14	14.84	28.53	2.45	12.39	27.71	11.57	0.82	6.618	0.4756	3.839	4.133	4.187
8:1:1a	15.98	14.88	28.31	2.55	12.33	27.14	11.16	1.17	9.489	0.6787	5.504		
8:1:1b	16.47	14.31	28.2	2.58	11.73	27.06	10.59	1.14	9.719	0.6613	5.637		
8:1:1c	15.76	14.69	28.36	2.09	12.6	27.21	11.45	1.15	9.127	0.6671	5.294	5.478	
8:1:2a	16.64	14.69	28.97	2.36	12.33	27.79	11.15	1.18	9.570	0.6845	5.551		
8:1:2b	16.64	14.56	28.85	2.35	12.21	27.63	10.99	1.22	9.992	0.7077	5.796		
8:1:2c	15.07	14.66	27.39	2.34	12.32	26.17	11.1	1.22	9.903	0.7077	5.744	5.697	
8:1:3a	15.31	14.66	27.86	2.11	12.55	26.78	11.47	1.08	8.606	0.6265	4.992		
8:1:1b	15.81	14.4	28.06	2.15	12.25	26.93	11.12	1.13	9.224	0.6555	5.351		
8:1:3c	16.79	14.77	29.1	2.46	12.31	27.91	11.12	1.19	9.667	0.6903	5.607	5.317	5.497
8:2:1a	19.89	14.89	32.55	2.23	12.66	31.45	11.56	1.1	8.689	0.6381	5.040		
8:2:1b	22.59	14.27	34.85	2.01	12.26	33.81	11.22	1.04	8.483	0.6032	4.920		
8:2:1c	15.23	14.33	27.73	1.83	12.5	26.67	11.44	1.06	8.480	0.6148	4.919	4.960	
8:2:2a	22.54	14.67	35.14	2.07	12.6	34.07	11.53	1.07	8.492	0.6206	4.926		
8:2:2b	24.44	14.6	36.71	2.33	12.27	35.62	11.18	1.09	8.883	0.6323	5.153		
8:2:2c	15.9	14.89	28.5	2.29	12.6	27.71	11.81	0.79	6.270	0.4582	3.637	4.572	
8:2:3a	16.03	14.27	28.77	1.53	12.74	28.1	12.07	0.67	5.259	0.3886	3.050		
8:2:3b	15.66	14.87	28.7	1.83	13.04	27.99	12.33	0.71	5.445	0.4118	3.158		
8:2:3c	20.31	14.79	33.55	1.55	13.24	32.67	12.36	0.88	6.647	0.5104	3.855	3.355	4.295
9:1:1a	19.9	14.71	31.84	2.77	11.94	30.41	10.51	1.43	11.98	0.8295	6.947		
9:1:1b	22.61	14.44	34.49	2.56	11.88	33.06	10.45	1.43	12.04	0.8295	6.982		
9:1:1c	15.24	14.6	27.21	2.63	11.97	25.87	10.63	1.34	11.19	0.7773	6.493	6.807	
9:1:2a	22.55	14.46	34.3	2.71	11.75	32.9	10.35	1.4	11.91	0.8121	6.911		
9:1:2b	24.46	15	36.61	2.85	12.15	35.13	10.67	1.48	12.18	0.8585	7.066		
9:1:2c	15.91	14.76	27.97	2.7	12.06	26.51	10.6	1.46	12.11	0.8469	7.022	7.000	
9:1:3a	16.04	14.31	27.53	2.82	11.49	26.17	10.13	1.36	11.84	0.7889	6.866		
9:1:3b	15.67	14.8	27.5	2.97	11.83	26.07	10.4	1.43	12.09	0.8295	7.012		
9:1:3c	20.33	14.87	32.25	2.95	11.92	30.85	10.52	1.4	11.74	0.8121	6.813	6.897	6.901

17 Appendix VIII

Result of nitrogen analysis

	Cup, g	Soil, g	Grained soil, g	Titrated NaOH, ml	N in soil, g	N in soil, %	Mean in field
1:1:1a	21.9	14.71					
1:1:1b	20.48	13.57					
1:1:1c	20.57	14.26	10	24.1	0.00126	0.0126	
1:1:2a	22.39	13.43					
1:1:2b	14.92	13.88					
1:1:2c	22.38	12.25	10.01	23.4	0.00224	0.02238	
1:1:3a	15.61	12.61					
1:1:3b	15.62	12.84					
1:1:3c	20.99	13.06	10.03	24.6	0.00056	0.005583	0.01352
1:2:1a	15.67	14.02					
1:2:1b	16.2	13.89					
1:2:1c	23.47	14.78	10.01	21.5	0.0049	0.04895	
1:2:2a	16.39	14.73					
1:2:2b	21.6	12.03					
1:2:2c	25.84	13.64	10.01	22.1	0.00406	0.04056	
1:2:3a	25.45	13.5					
1:2:3b	26.59	13.95					
1:2:3c	24.03	14.86	10	23.8	0.00168	0.0168	0.03544
2:1:1a	17.53	12.65					
2:1:1b	16.03	13.67					
2:1:1c	16.17	13.21	10.04	17	0.0112	0.1116	
2:1:2a	16.12	13.57					
2:1:2b	15.77	12.37					
2:1:2c	22.19	13.7	10.02	16.2	0.01232	0.1230	
2:1:3a	18.73	13.08					
2:1:3b	20.64	13.76					
2:1:3c	16.59	13.07	10	17	0.0112	0.112	0.1155
3:1:1a	16.11	13.77					
3:1:1b	21.31	12.6					
3:1:1c	18.71	14.73	10.03	24.4	0.00084	0.008375	
3:1:2a	16.95	14.26					
3:1:2b	18.68	13.59					
3:1:2c	16.13	13.51	10.04	Sample destroyed			
3:1:3a	16.78	13.86					
3:1:3b	15.9	13.09					
3:1:3c	16.03	14.5	10.06	18.1	0.00966	0.09602	0.05220
3:2:1a	20.29	12.61					
3:2:1b	22.23	13.24					
3:2:1c	19.92	12.99	10.05	14.1	0.01526	0.1518	
3:2:2a	18.67	13.41					
3:2:2b	16.11	14.97					
3:2:2c	17.75	12.25	10.01	18.2	0.00952	0.09510	
3:2:3a	22	14.83					
3:2:3b	15.62	12.77					
3:2:3c	15.48	12.96	10.01	16.5	0.0119	0.1189	0.1219
6:1:1a	29.85	14.02					
6:1:1b	22.5	13.87					
6:1:1c	22.69	14.54	10.04	17.6	0.01036	0.1032	

	Cup, g	Soil, g	Grained soil, g	Titrated NaOH, ml	N in soil, g	N in soil, %	Mean in field
6:1:2a	23.6	11.84					
6:1:2b	22.15	11.03					
6:1:2c	20.61	11.89	10	16.6	0.01176	0.1176	
6:1:3a	22.27	11.59					
6:1:3b	23.06	10.85					
6:1:3c	19.2	10.83	10.03	12.7	0.01722	0.1717	0.1308
7:1:1a	16.25	14.06					
7:1:1b	16.59	14.6					
7:1:1c	21.92	14.53	10.03	24.8	0.00028	0.002792	
7:1:2a	16.97	13.41					
7:1:2b	16.21	13.6					
7:1:2c	16.39	13.95	10.04	15.2	0.01372	0.1367	
7:1:3a	15.66	13.28					
7:1:3b	16.17	13.43					
7:1:3c	15.77	13.17	10	15.2	0.01372	0.1372	0.09222
7:2:1a	20.44	14.56					
7:2:1b	22.24	12.84					
7:2:1c	15.65	14.25	10.02	12	0.0182	0.1816	
7:2:2a	22.17	14.07					
7:2:2b	18.81	14.4					
7:2:2c	22.14	14.54	10	14.6	0.01456	0.1456	
7:2:3a	15.87	13.7					
7:2:3b	16.27	13.26					
7:2:3c	16.11	14.92	10.03	17	0.0112	0.1117	0.1463
8:1:1a	20.33	13.57					
8:1:1b	15.68	13.69					
8:1:1c	15.26	12.93	10.01	14.9	0.01414	0.1413	
8:1:2a	22.61	14.3					
8:1:2b	16.05	14.37					
8:1:2c	19.91	13.36	10.03	13.8	0.01568	0.1563	
8:1:3a	15.81	13.64					
8:1:3b	16.67	13.08					
8:1:3c	15.09	14.19	10.05	15.7	0.01302	0.1296	0.1424
8:2:1a	16.8	12.95					
8:2:1b	15.32	13.36					
8:2:1c	22.57	14.81	10	15	0.014	0.14	
8:2:2a	15.93	14.2					
8:2:2b	16.65	14.05					
8:2:2c	15.99	13.11	10.04	16.1	0.01246	0.1241	
8:2:3a	24.47	13.37					
8:2:3b	16.49	13.31					
8:2:3c	15.79	13.2	10.01	14.6	0.01456	0.1455	0.1365
9:1:1a	22.55	14.33					
9:1:1b	23.09	14.75					
9:1:1c	22.3	14.31	10.02	14.6	0.01456	0.1453	
9:1:2a	21.76	11.09					
9:1:2b	23.47	11.71					
9:1:2c	24.04	11.36	10.04	18.6	0.00896	0.08924	
9:1:3a	27.91	24.96					
9:1:3b	23.12	18.76					
9:1:3c	22.31	21.53	10	25	0	0	0.07818

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