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Dissertation

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“Land Use and Soil Quality in an Arid Environment (Egypt)“

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I would like to dedicate this work to the memorial of my father, who unfortunately did not live to see the end of it.

Content

1.1. Introduction

Today's agriculture faces two major problems that are inherent to modern agrotechnology: High productivity necessitates intensive fertilisation and irrigation. Both of these inputs to ecosystems may cause severe imbalances. Due to the higher buffering capacity of arable land in temperate ecosystems, these effects have been neglected for a long period of time.

In contrast, subtropical and tropical regions are much quicker affected in many ways. On the one hand, degradation of organic matter is accelerated tremendously by fertilisation and thus the loss of quality of arable land occurs after a short period of application of western agronomical techniques. In temperate regions, overfertilisation mainly results in eutrophication of ground water, rivers and lakes, whereas in tropical and subtropical regions the water that has been enriched with fertiliser (mostly applied as inorganic salts) does not often reach ground water level but evaporates, leaving the respective soils in a hypersaline state, thus causing desertification (Wolff 1993).

Arable land in arid regions is especially affected by desertification, therefore arable land there is especially precious and needs protection. At the same time, the population of the world is growing at a very fast pace, which results in the loss of more arable land due to urbanisation, migration of farmers to cities, and the need for intensified production in order to feed the world.

As all these problems prevail in Egypt, and as the Egyptian government has been implementing several projects for land reclamation over the last decades, protection of existing soils as well as newly reclaimed areas have become the paramount issue.

Figure 1.1.1: Map of Egypt (Merriam-Webster's Atlas 2008)

Egypt covers an area of 980,869 km^2, of which 96% is desert and only 2.9% is arable land (CIA-The World Factbook Egypt 2007). It is located in the north eastern part of Africa between latitudes 22° and 32°N and longitudes 25° and 34° and can thus be considered an African/Asian/Mediterranean country (UNCCD 2005).

Settlement area covers an estimated 40,000 km^2 and is mostly limited to the Nile Valley and Nile Delta. In 1990, this area was one of the most densely populated areas in the world, being home to 1,900 inhabitants per km^2, whereas the per capita area of arable land is one of the lowest in the world. According to an FAO study, 4% of the population of Egypt were malnourished at the end of the 1990s, and roughly 16 million Egyptians are living in absolute poverty (i.e. living on less than 1$ per day) (Wolf 1993, World Bank 1997, FAO 2003). On the other hand, population growth in Egypt is highest in the Arab World (even though it declined from 2.8% in the year 2000 to 1.7% in 2007) and has reached an estimated total of 80,335,036 inhabitants (CIA- The World Factbook Egypt 2007).

Agriculture in Egypt contributes 13.8% to GDP and occupies 32% of the labour force. At the same time, agriculture consumes 85% of available water but only contributes to 7% of all exports. This discrepancy supports the cultivation of cash crops (CIA-The World Factbook Egypt 2007, UNDP 2005).

The Aswan High Dam, built in the 1960s, assures constant water supply to urban and rural communities, and led to 2-3 harvests per year. Due to the permanent cultivation and the disappearance of fallow periods, as well as the increased use of fertilizers, the drainage of the salts diluted in the irrigation water is no longer assured and more salt affects agricultural soils, especially in the Nile Delta, leading to a salinisation of the soils and the aquifers (Siegel 1995).

In order to meet the demands of a growing population, raising agriculture is one of the aims of the government. At the same time, resources, especially water, are limited and faced by a harsh environment. Thus, one of the declared aims of the Egyptian government is to extend the amount of arable land through ambitious desert reclamation projects, whilst protecting existing arable land from loss through growing cities as well as the consequences of false cultivation, irrigation and a harsh environment (Kotb et al 2000).

This project deals with the specific problems in Egypt, regarding land loss through soil degradation, especially caused by pollution, salinisation (including effects caused by wrong irrigation and fertilisation) and possible other causes. Thus, two experimental sites were chosen, one site in the Nile Delta which has been cultivated for centuries, and the second in Upper Egypt, which a part of a land reclamation project. The experimental sites are thoroughly described in chapter 2 of this thesis.

The following is an introduction to the problems regarding land loss and land reclamation in Egypt, as well as the specific problems regarding water pollution and water scarcity, a general introduction to soil quality assessment and an overview of the research hypothesis and objectives. As environmental problems in Egypt and arid environments in general are very diverse, this study is by no means complete, and only focuses on providing background information for the research concept of this thesis, as outlined on page 40.

1.1.1. Climate

The climate in Egypt ranges from arid in the North (Alexandria) to hyper-arid in the South (Aswan) (Kotb et al 2000). Aridity prevails if evaporation (measured over a year) exceeds precipitation; it is therefore classed as a dry area. According to the aridity index, (P/ETP: where P=precipitation, ETP= potential evapo-transpiration, calculated according to Penman's formula), the arid regions are classified as hyper-arid if P/ETP<0.03 and arid if P/ETP= 0.03-0.20. These classes can, in turn, be subdivided according to the mean temperature of the coldest month and that of the hottest month of the year. Consideration is also given to the time of rainy periods relative to the temperature (Middleton &Thomas 1997, UNCCD 2005, Le Houérou 1996).

Approximately 96% of Egypt's area can be classified as hyper-arid and the remaining 4% as arid (Le Houérou 1996). Hyper-arid provinces include the Eastern Desert and the north eastern part of the Western Desert (mild winter, hot summer) and the highlands of southern Sinai (hyper-arid with cool winters, the mean temperature of the coldest month ranges between 0-10°C). Arid provinces include the northern Mediterranean coastal belt province, with winter rainfall, and the more inland province with a longer dry period. Both provinces are characterized by a mild winter and a hot summer (UNCCD 2005).

In general, summers in Egypt are hot (with a mean temperature of 20-30°C during the hottest month) or very hot (mean temperature of the hottest month exceeding 30°C). Winter is either warm (mean of the coldest month 20-30°C) or mild (mean minimum of the coldest month is 10-20°C). Rainfall can be divided into three belts, the Mediterranean coastal belt, middle Egypt (30° N latitude as its southern boundary) and Upper Egypt. Both the coastal belt and middle Egypt have a winter rainfall, with the rainy season extending from November to April, though it is mainly concentrated in December and January. Upper Egypt is almost rainless; precipitation is not an annually recurring incident- 10mm may occur only once every ten years (UNCCD 2005).

Table 1.1.1: Mean monthly climatological data in Egypt (Aboukhaled et al. 1975)

City	Temperature				Rainfall (mm year^{-1})	Relative humidity (%)	Relative Duration of bright sunshine (%)	Evaporation (mm day^{-1})
	January		August					
	Max. (°C)	Min. (°C)	Max. (°C)	Min. (°C)				
Alexandria	18.5	9.3	30.6	22.8	191.8	65-72	63-89	1.6-7.5
Giza	19.5	6.4	34.4	20.4	20.2	53-73	68-86	1.5-7.7
Aswan	24.2	9.5	42	26.4	1.4	18-41		2.8-8.5

For climate data of the experimental sites, please refer to chapter 2, Material and Methods.

1.1.2. Land Use

The total land area of Egypt is approximately 100 million ha (Mha), however, it is considered a heavily populated country, with 80 million people living on less than 4% of the land, mostly in the Nile Valley and the Nile Delta, as well as the cities along the northern coastal periphery. This means that the per capita share of agricultural land is less than 0.05 ha. In Europe this figure is 1.26-1.68 ha.

The agriculturally used area can be divided into 3 parts:

1. Ancient, irrigated land, approximately 2.5 Mha (or 6 million feddans where 2.4 feddan equal 1 ha) in the Nile Valley and the Nile Delta. These are the most fertile soils in Egypt; alluvial, deep, dark brown, heavily to medium textured soils. These soils are mostly Vertisols, with some Entisols and Aridosols, which means deep A horizons with a high clay content for Vertisols.
2. Newly reclaimed areas of sandy, limy or saline origin. Those soils have a very low content of organic mass, micro and macro nutrients. In 2005, three million feddan were reclaimed (1.25 Mha).
3. North western coastal areas and north Sinai: approximately 200,000 ha (500,000 feddan) with enough rainfall.

(Abdel Monem et al 1998, UNDP 2005)

1.1.3. Water Resources

Egypt is completely dependent on water from the River Nile, obtaining 95%-98% of its total water supply from this source. There are nine riparian states along the River Nile, however,

Egypt is the only country that totally depends on its water, and thus depends on other countries for over 90% of its renewable water resources. The average annual yield of the river is estimated at 86 x $10^9 m^3$ at Aswan, in the South of Egypt (Haddadin 2002, Korb et al 2000, Ragab & Prudhomme 2002, Abdel Gawad 2007). According to the agreement regarding the full utilization of the Nile water established between Egypt and Sudan in 1959, Egypt's share is 55.5 x $10^9 m^3$. The Aswan High Dam, in operation since 1968, is the major regulatory facility on the river, ensuring Egypt's control over its water share and guiding its full utilization (Abdel-Gawad 2007, Wolff 1988).

Agricultural lands in Egypt are almost 100% irrigated since the mean effective rainfall over the entire country is near zero, with the only exception being a small area along the North Coast with enough rainfall. Almost all of the irrigation water is obtained from the River Nile (Kotb et al 2000, Abu Zeid 1994).

Agriculture uses around 90% of the available water and about 12.3 x $10^9 m^3$ of drainage water, mostly from irrigated agriculture, and including the freshwater released during the winter closing, is disposed annually into the Mediterranean Sea (DRI 1994). An amount of approximately 4.6 x $10^9 m^3$ is officially recycled, in particular in the Nile Delta. In order to prevent seawater intrusion into the northern strip of the Nile Delta, ca. 10 x $10^9 m^3$ must be disposed yearly into the Mediterranean Sea. The groundwater reservoir in the Nile Valley and Delta is comparatively insignificant but serves as a basin to recycle deep percolation irrigation water. About 2.6 x $10^9 m^3$ is pumped annually by means of shallow wells (Kotb et al 2000). Desalinated water amounts to approximately 25 x $10^9 m^3$, re-used, treated wastewater to approximately 200 x $10^9 m^3$, which is a total of 0.41% of the total water withdrawal (FAO 1999). Fresh groundwater resources contribute to 20% of the total potential of water resources in Egypt (Allama et al 2002).

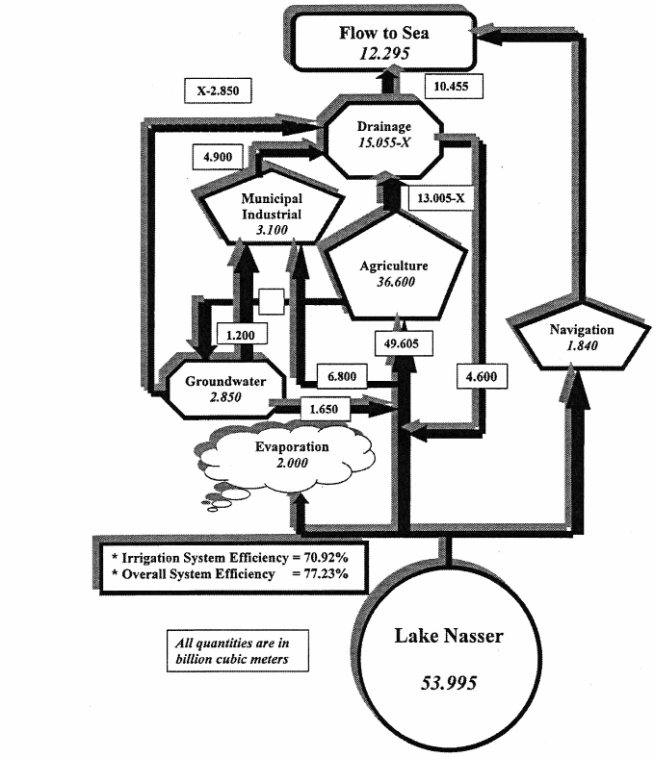

Figure 1.1.2: National water balance of Egypt, 1989/1990, from Kotb et al 2000

Water is, however, a limiting factor. Table 1.1 gives an overview of the water balance of Egypt in 1995 and a conservative estimate for the year 2017.

Table 1.1.2: Water balance of the year 1995/96 and estimate for the year 2017. All values x 10^9 m^3 (JICA 2002)

Category	1995/96	Forecasted 2017
Water Supply		
Nile River	55.50	57.50
Groundwater in Nile Valley & Delta	4.8	7.5
Recycling of agricultural wastewater	12.92	16.92
Recycling of domestic wastewater	1.14	13.62
Recycling of industrial wastewater	0.70	1.70
Rains and floods	1.00	1.00
Loss due to evaporation in the water network	(3.00)	(3.00)
Total of supply	73.06	95.24
Water usage		
Agriculture	60.73	75.53
Industry	7.53	15.44
Domestic	4.54	6.82
Navigation	0.26	
Total of water usage	73.06	97.79
Supply of usage	0.00	-2.55

Kotb et al (2000) describes the water quality of the River Nile as follows: *"Although all the agricultural drains in Upper and Middle Egypt discharge their flow (ca. 2.3 x $10^9 m^3$) into the River Nile, the river-salinity level has not been significantly affected. The concentration of the total dissolved solids (TDS) is ca. 150 mg l^{-1} at Aswan, the upstream point of the system, and ca. 250 mg l^{-1} near Cairo, 950 km downstream. This small increase of TDS relative to the long distance is ascribed to the high dilution effect of the River Nile. However, the situation at the northern part of the Nile Delta is not that positive. The two river branches, Damietta and Rosetta, are vastly contaminated by industrial effluents close to their outlets into the Mediterranean Sea. Water is conveyed from the river to irrigated lands through a complicated network of canals of different orders. Currently, there is no comprehensive monitoring of the salinity level in canal waters, however, there are some representative figures measured by the Water Management and Irrigation Systems Research Institute (WMISRI) at the off-takes of some selected canals."* Measurements from the year 1995 show that different channels in different parts of Egypt show differences in maximum salinity. Measurements at El-Mansouraya canal in Middle Egypt show that the maximum salinity during December was 570 mg l^{-1}, and at Bahr Mouice canal off-take, at the East of the Nile Delta, the recorded salinity was 310 mg l^{-1} during May (Kotb et al 2000).

The salinity of the groundwater aquifers is mainly below 1500 mg l^{-1} over the entire country and in some regions near the Mediterranean coast it can reach concentrations of up to 5000 mg l^{-1} (RIGW 1992).

1.1.4. The Aswan High Dam

The high dam on the Nile was built to support the reclaiming of new lands, to ensure a constant supply of water to urban and rural communities (and for irrigated agriculture), as a protection against floods, river navigation and for the generation of electrical energy.

In 1861, a system of modern irrigation along the Nile was started with a barrage constructed below Cairo, marking the start of controlling the Nile Delta and which ultimately led to five of the seven arms of the river in the delta drying up. Then, a first dam downstream from Aswan in the south of Egypt was built in three stages (1902, 1912 and 1933) close to the First Cataract, only to become enlarged in 1934. In 1962, the 114m high and 3,600m long High Dam was started several kilometres upstream, some 11km from the town of Aswan, and finished in 1971. Lake Nasser, a 500 km long artificial lake, with a surface area of 5,000 km^2, is one of the largest in the world, reaching a maximum depth of 70m with a storage volume of 157 km^3 (the equivalent of two years' flow of the Nile) and reaching well into the northern Sudan (El-Shafie et al 2007, Mainguet 1999, Sauer 1996, Pearce 1994).

Among the benefits of the High Dam are:

- The hydroelectric power installed, with a production of $2.1x10^6$ kW/year (White 1988)
- Avoiding devastating floods as well as nullifying the effects of episodic droughts
- Improvement of shipping
- Stored water offers potential for irrigated agriculture (Tushka project, please refer to chapter 1.1.8 for further explanation), and made two to three harvests upstream possible (Kim & Sultan 2002, Pearce 1994)
- Up to three harvests instead of a single one are possible

Among the negative consequences of the project are:

- Destabilization of the riverbanks and the lowering of the downstream riverbed up to 100km from Aswan
- The lack of load which contributed to building up the delta and the Mediterranean coastline causing the Nile Delta to recede by 100 to 200 m annually in some parts. In the upper delta, due to its water being held back at the level of the reservoir, the reduced discharge of the river is accompanied by a rise of the salt-water table, leading to damage to agriculture because of salinisation (Mainguet 1999)
- In addition to the losses by evaporation exceeding $10x10^9$ m^3/year (aggravated by the strong and constant winds over the lake), there is a strong infiltration into the ground. The geological investigations had not predicted the presence of large amounts of evaporates in the ground, which may contaminate the infiltrating water with salts, which is then used for irrigation. In the early 1970s the salinity of the shallow aquifers had already risen to 36 g/l (Mainguet 1999).
- Due to the permanent cultivation, the disappearance of fallow periods and the increased use of fertilizers, the drainage of the salts is no longer assured and more salt reaches the delta, leading to a salinisation of the soils and the aquifers.
- The loss of nutrient rich Nile Waters from seasonal flooding into the sea effectively eliminated oceanic fishing which had been a major protein-rich food source for the Egyptian population. Thus, aquaculture development intensified in the lagoons and lakes comprising Nile Delta wetlands (Siegel 1995).

Due to the construction of the High Dam, the Nile no longer has an actively prograding delta, but rather an eroding coastal plain. While the Nile delta is eroding at the coast, a new Nile delta, about 200km long and in most part subaqueous, is forming between Dal Cataract in Lake Nubia, Sudan and Abu Simbel in southern Lake Nasser, Egypt, as a response to the suddenly reduced velocity of the Nile as it enters the reservoir behind the dam (Stanley & Wingerath 1996).

In general, the effects of the construction of the Aswan High Dam on soil fertility in the Nile Delta have been discussed, controversially, since its construction. It is a given fact that the loam and silt that used to be spread over the sandy soils downstream are now held back in Lake Nasser, upstream of the dam. It is estimated that the total solid load of the Nile is 50-3.000 x 10^6 t p.a., of which only 5-10 $x10^6$ t p.a. are believed to reach the Delta today. The silt that used to be deposited in annual layers of about a millimetre onto the Nile flood plain (an estimated 10-15 tonnes a year) is now accumulating in layers of about a metre a year in the southern half of Lake Nasser. Critics of the High Dam argue that the loss of the silt is one of the reasons for the high increase in chemical fertilisers. It is clear that the deposited silt was very important for soil development and formation, but might only be playing a secondary role when it comes to the availability of nutrients in the soils. The multiple cropping that replaced the single crop per year resulted in shorter fallow periods, and the amount of soil nutrient declined due to intensive cultivation practices coupled with a lack of systematic nutrient replacement, as well as the loss of the alluvium deposits (McManus 2002, Mainguet 1999, Sauer 1996, Lenney et al. 1996, Pearce 1994, Wolff, personal information).

1.1.5. Soil Resources of Egypt

According to the UNCCD (2005), soil resources could be identified according to climatic features, terrain landform characteristics, land use patterns and anthropogenic implications, as follows:

I. The Nile Valley and Delta Zone:
This is the area in which agricultural production in Egypt is mainly concentrated, and consists of 26.4 million m^2. The soils are recent Nile alluvium; fluviomarine and lagoonal deposits are located next to the northern lakes and the coastal plain in the very north of the Nile Delta. These soils are mostly affected by sea water intrusion into the cultivated lands, as well as over utilization, mismanagement (leading to water logging, salinisation and alkalisation) and soil pollution.

II. North Coastal Zone
This area can be divided into two parts, the north-western coastal areas and the north coast of Sinai. The north-western coastal area covers an area of approximately 10,000 km^2 and consists of young soils. The north Coastal area of Sinai consists of loamy sediments and fine textured soils.

The biggest part of this area is used as rangeland but vast, discontinuous areas are under rain fed cultivation, where cereal crops, following a long fallow period (May-October) are grown during rainy seasons. The cultivated area reaches approximately 1.2 million m^2.

III. Inland Sinai and Eastern Desert Zone

This zone is characterized by a hot-dry desert climate and consists roughly of four major landforms:
- Southern Sinai, with moderately deep and gravely coarse textured soils
- Soils of the central part of Sinai, which consist of calcareous soils, ranging from gravely coarse-textured , moderately fine-textured to gravely coarse over fine-textured soils.
- Soils of the alluvial coastal plains
- Soils of the marshy land and sabkhas
- Soils moderately fine textured, sometimes over sandy deposits with salts and gypsum contents in wide ranges.

About 34 million m^2 are planted with vegetables, fruit trees and some cereal crops, using ground water for irrigation. Other land uses in this zone are mainly mining activities and oil exploitation.

IV. The Eastern Desert
The soils of the Wadis of the Eastern Desert are mainly shallow to deep coarse or moderately fine-textured with variable content of gravel.

V. The Western Desert
In the Western Desert, several natural depressions of variable areas are scattered and include the famous oases of Siwa, Bahariya, Farafra, El Kharga and Dakhla, that are distinguished with artesian wells. There are also several remote areas which are put under reclamation and utilization, e.g. Toshka.
Soils of the oases are mainly ascribed to the erosional patterns, source of parent materials, sedimentational environment and soluviation-deposition of salts, carbonate and gypsum. Therefore, these soils show differences with regard to their texture, mineralogy content, depth to water table or bedrock and numerous types of

morphopedological features such as the accumulation of salts, carbonate and gypsum, shales and iron oxides.
These soils have some limitations that reduce their agricultural potentials, which are mainly due to rough topography that can lead to water and wind erosion; shallow soil depth to bedrock or to permanent water table; salinisation,alkalisation and sand dune encroachment.

1.1.6. Land Degradation and Desertification

Soil degradation might be defined in general as a reduction of the current and/or future capability of soil to produce, in terms of quantity, quality, goods or services. Soil degradation can be both quantitative: loss of soil due to erosion, mass movement and solution, or qualitative: decline in fertility; reduction of plant nutrients; structural changes; changes in aeration/moisture content; change in trace elements, salts, alkaline compounds; pollution with some chemical compound; change in soil flora or fauna. Soil degradation can be a natural phenomenon, or anthropogenic (Barrow 1991).

Agriculture in arid areas is linked to soil degradation due to the fragile condition the soils are in. Rain-fed agriculture in dry lands is threatened by water and wind erosion, irrigated agriculture by water logging and salinisation. As all agricultural land in Egypt, except a small part of land in the very north of the country, is irrigated, the latter are the predominant threats and are described in more detail later on.

Soil degradation is a consequence to all forms of degradation and in particular to that of the vegetation cover. When the soils become degraded production plummets to virtually zero, which brings along a whole array of socio-economic problems (Mainguet 1999).

According to the Intergovernmental Convention to Combat Desertification (ICCD), the term desertification is defined as: *“land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climate variation and human activities.”* (ICCD 1994)

According to Le Houérou (1996), many scientists would have preferred to have connotations to irreversibility and desert landscapes included in the definition. In addition there are some scientists that prefer the term “land degradation”, as it does not have emotional connotations. According to Le Houérou (2002) the term desertization can be used, and is defined as the irreversible arid land degradation resulting in desert-like land forms and landscapes in areas where they did not occur in a recent past. The term “irreversible’” is understood as under total protection from humans and large animals over a period of one human generation or 25 years (Le Houérou 1996, Le Houérou 2002).

The direct causes of desertification and arid land degradation stem mostly from drastic reduction or destruction of the perennial plant cover and simplification of the vegetation structure. Soil surface not protected by permanent vegetation becomes subject to erosion by water and wind, crusting by raindrop splash, trampling by animals, salinisation by evaporation and water logging in topographic depressions since water is no longer extracted by permanent vegetation. The causes are mainly:

- A reduction in the organic content of the soil due to a lower permanent biomass and decreased production of litter.
- Decreased organic matter reducing the stability of soil aggregates and leaving the soil structure more fragile and prone to destruction.
- Unstable and poorly developed structure results in higher apparent density (compaction), lower porosity, lower permeability to air and water, lower water storage and reduced oxygenation.

- Lower permeability, water intake and storage resulting in increased edaphic aridity and therefore reduced productivity.
- Reduced organic matter and a fragile structure which leads to soil surface crusting by raindrop splash which may increase runoff by 30-50% or more. This in turn reduces water intake in the same proportions, which again increases edaphic aridity.
- Decreasing organic matter content in the soils lead to a lower biological activity from micro-, meso- and macroflora and fauna, symbionts in particular. This in turn reduces the turnover of nutrients, causing reduced fertility and therefore productivity
- Lower water and nutrient availability causes lower fertility and productivity, i.e. lower biomass production and plant cover. This is where the self catalytic spiral of land degradation/desertification is set in motion.
- Additionally, a biological crust of cyanobacteria and/or lichens and mosses may form, which drastically reduces soil permeability and boosts runoff, leading to lower water availability and further erosion.
- Greater runoff results in more frequent and more devastating flooding in topographic depressions, which leads to more water logging, more salinity and more encrusting salinity.
- Destruction of the permanent vegetation cover, particularly shrubs and trees and/or perennial grasses, reduces the shading of the soil surface and increases its temperature so that more evaporation takes place. (In dry areas, the soil surface temperature can rise to over 70°C)
- Reduction or destruction of the plant cover also decreases the rugosity of the landscape resulting in higher wind speeds at the soil surface and higher rates of evapo-transpiration and increased aridity.

All these combined causes and processes, as well as others, constitute a complex and intricate process of depletion that is not yet fully understood. Indirect causes are human activities that reduce or destroy vegetation cover, therefore provoking soil surface denudation for prolonged periods of time, which triggers or expands water and wind erosion. This is not just applicable for arid areas, but is globally valid, and is caused by over-cultivation, continuous overgrazing and overstocking, water logging, salinisation and sodization due to faulty irrigation, poor drainage etc. (Le Houérou 1996, Mainguet 1999, Verrecchia et al. 1995).

1.1.6.1. The United Nations Convention to Combat Desertification (UNCCD)

The United Nations Convention to Combat Desertification (UNCCD) was one of the first international environmental agreements to follow the lead of Agenda 21 principles and advocate an explicitly participatory and inclusive approach to address global problems of desertification, land degradation and drought. The convention was adopted in June 1994 and became open for signatures in October 1994. Egypt signed in October 1994, ratified the convention in 1995, and it came into force in 1996.

The objective of the convention is:

To combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification, particularly in Africa, through effective action at all levels, supported by international cooperation and partnership arrangements, in the framework of an integrated approach which is consistent with Agenda 21, with a view to contributing to the achievement of sustainable development in affected areas.

Achieving this objective will involve long-term integrated strategies that focus simultaneously, in affected areas, on improved productivity of land, and the rehabilitation, conservation and sustainable management of land and water resources, leading to improved living conditions, in particular at the community level.

The main principle of the convention is the participation of the public, small communities, NGOs etc. This interdisciplinary approach poses some challenges, due to the structure of society in affected countries (UNCCD 2008, Stringer et al. 2007).

1.1.7. Causes of Desertification in Egypt

According to the Egyptian National Action Program to Combat Desertification (UNCCD 2005) the major causes of desertification in Egypt can be outlined as follows:

- Land loss due to the spreading of urban and peri-urban areas into the fertile land, especially within the Nile Valley and Delta (where most of the big urban agglomerations are located).
- Poor water management due to the inefficiency of the traditional gravity irrigation system still in place in most of the agricultural land; the inadequate maintenance of irrigation and drainage networks; the over abstraction of ground water, particularly in the reclaimed areas, and the seawater intrusion in the coastal areas.
- Unsuitable agricultural practices, particularly under the conditions of frequent and intensive cropping in the Nile Valley and Delta, which resulted in salinity, water logging, depletion of soil fertility and excessive use of pesticides, fertilizers as well as inappropriate time and machines of tillage which led to problems of physical and chemical desertification (e.g. compaction and pollution).
- Depletion of plant cover and conversion of range areas to other uses including the shifting and/or expanding cultivation of field crops, especially of winter crops followed by fallow summer, causing considerable degradation of the natural ecosystem, as well as overgrazing and fuel wood collection.

(UNCCD 2005)

Agricultural productivity in Egypt is limited by the extent of arable lands and by the soil quality of these lands. Especially in the Nile Delta, productivity has been partly restricted by high soil salinity levels and by the encroachment of urban settlements onto previously productive lands (Lenney et al. 1996).

Below follows a description of the main processes involved in land degradation in Egypt, as outlined by the UNCCD (2005), with a special focus on processes leading to soil degradation.

1.1.7.1. Urbanization

Urbanization is one of the most extreme forms of land degradation because it means irreversible loss of soil function and causes sealing of agriculturally productive land. From 1978 to 1984, the annual expansion rates of some selected cities and towns located on highly productive land within the Nile Valley and Delta ranged between 5.3 to 30.8% of studied sites. Over 30% of the soils most suitable for agriculture are under urban land cover. The illegal dereliction of agricultural land with the objective of diverting its use to dwelling purposes and other forms of encroachments poses another threat. Another problem associated with urbanization is the skimming of the fertile soil surface layer of the agricultural land, up to one meter depth, for the brick industry, which is predominant in areas with a high population growth. The total loss is estimated at about 16% of the total irrigated agricultural land (Lawrence et al. 2002, UNCCD 2005).

The Middle East in general has a relatively urbanized population, with more than 20% of the people of the region living in urban agglomerations of over one million people, the biggest being Cairo, with 12 – 16 (some estimates go as high as 20) million inhabitants, currently the world's tenth largest mega-city. Cairo's urban structure and its public facilities were laid down for 2 million inhabitants. Much of the land converted to urban use was highly productive

agricultural land. The loss of this resource between 1981-1988 alone was 340 km^2. Moreover, farmland has often been replaced by development along major transport routes in a ribbon-like fashion, particularly in areas outside the Greater Cairo Metropolitan Region. Along with the loss of arable land, the problem of fast and unplanned growth of cities (in the case of Cairo, there was no officially adopted development plan until 1992) lies in the (atmospheric) pollution (due to the availability of leaded gasoline, the large numbers of older cars and a high level of particulate matter in the atmosphere), as well as the expansion of water supply and sanitary services, which affects ground water quality in a negative way. Another problem, that especially affects Cairo, is the inadequate infrastructure, the rapid and widespread environmental degradation, and growing social inequities. There seems to be significant gaps in the research on urban growth, environment and economic development in the Middle East, and the problems related to urban growth are too multifaceted to be discussed in detail here (Stewart 2002, El Araby 2002).

Urban encroachment on agricultural lands is taking place at a higher rate than that of reclamation. The rate of conversion of agricultural lands in non-agricultural use was more than twice that of reclamation in the Nile Delta. Surveys of land cover type and land cover change in Egypt have focused primarily on the Nile Delta and the narrow Nile Valley for obvious reasons including the fertile soils, dense population and rapid growth in the region. Land loss in other areas seems to be more affected by salinisation rather than urbanization (Masoud & Koike 2006, Lawrence et al. 2002).

In the Nile Delta, the area occupied by urban development increased by 60% between 1972 and 1990, estimates for the year 2007 predicted another increase of 100% for that period, which would mean 12% of the total area of the Nile Delta in the year 2010. Even though growth is pronounced around the main cities (e.g. Cairo, Tanta), it is the growth around the thousands of small villages that poses the largest threat to the agricultural productivity of the Nile Delta. In a study of 31 cities or large villages, compared to smaller villages, the cumulative growth rate for the cities and large villages between 1972 and 1990 is 37%, whereas that for the small villages is 77% for the same period of time. Therefore, stricter enforcement of laws prohibiting urban encroachment onto agricultural land, especially around villages, is needed to preserve the Nile Delta and Nile River banks. Stricter law enforcement is necessary, as estimates show that there was a great increase of land loss after 1984, when the Egyptian government issued an edict prohibiting urban development (Sultan et al. 1999).

1.1.7.2. Salinity

Soil salinisation implies the excessive enrichment in it of soluble salts (like chlorides, sulphates and carbonates etc) and of sodium, magnesium or calcium. When the cations of the salts are essentially sodium, it is called alkalinization or sodization. A soil is considered as salinized when its content in soluble salts is above 1-2% in the topmost 20cm (WMO 1983). When a soil has a texture favouring capillary action (i.e. rich in clays), and when an aquifer occurs at rather shallow depths, salts, bases and sodic compounds are easily deposited in the root and soil layer between the water table and the surface. This process has been referred to as *secondary salinisation*, when caused by human activities (Mainguet 1999).

Approximately 0.1% of land under irrigation is being lost annually due to secondary salinity, sodicity and water logging, globally (Kovda 1983). Land degradation through salinity, water logging and faulty irrigation practices, albeit common in dry-lands and developing countries, is by no means restricted to arid countries. Land desertification by secondary salinisation or sodization, although representing a small percentage in absolute terms, is economically important, because these are initially among the lands having the highest production potential, and which, in addition, have undergone heavy investments (Le Houérou 1996). It should be taken into account, that aridity of the climate also increases the salinity of the

water in reservoirs behind dams as well as that of the water transported over longer distances in the canals built for irrigation purposes and in the natural water-courses. In the Nile below Aswan the dissolved solids increased from 110 – 180 to 120-230 mg/l. 30% of soils in Egypt are considered salt affected (Abdel Monem et al.1998, Mainguet 1999).

Globally, it is estimated that approximately 100 Mha of irrigated land suffers from water logging and salinity, 20% of which is severely affected. Approximately 2-3 Mha of potentially productive agricultural land are taken out of production due to salinisation alone. It is unknown how much of that land is reclaimed. (Ali et al. 2001). In Egypt, approximately 30% of the irrigated land is considered salt affected (Kijne 2006). It is estimated that 60% of the Northern cultivated land and 20% of both the Middle and Southern Delta regions are salt-affected soils. In the Nile Valley (Upper Egypt), salt affected soils represents about 25% of the cultivated areas. Many areas of the reclaimed desert land adjacent to the Nile Valley and Delta as well as in Sinai and Oases suffer from water-logging and high salinity (UNCCD 2005).

According to the UNCCD (2005), the process of salinisation is due to:

- Excessive application of irrigation water
- Irrigation with poor-quality water, e.g. using low quality mixed drainage water and increased use of low quality ground water
- Inadequate salt leaching practices
- Inefficient or impaired drainage conditions
- Evaporation from the water-table, especially when it is within 2m, significantly contribute to root-zone salinity
- Poor land levelling with consequent localized redistribution of salts can often cause salinity problems of significant magnitude.

Salinity is closely linked with water shortage. Irrigated agriculture concentrates salts because a growing crop takes up water while most of the salts are left behind in the root zone. Proper management must ensure that the salts are concentrated outside the root zone, and away from future water supplies for irrigation and for domestic or industrial use. Water shortage often interferes with this action of leaching the salts from the root zone, because the water needed for leaching is seen as a waste of water that could be used better to satisfy evapotranspiration by the crop. No adequate drainage beyond or below the root zone leads to rising water tables and waterlogged conditions. Use of fertilizers enhances the problem (Kijne 2006).
Saline/sodic soils contain either elevated levels of Ca or Na or both; those having high NA levels (sodic soils) may have pH values 8.5 or above. When soil pH is as high as 8.5, a number of micronutrients such as Fe, Mn, Cu and Zn become deficient and crop growth is adversely affected (Prashad & Power 1997). Salinisation in genera,l and sodicity in particular, have adverse affects on soil structure. High values of the exchangeable sodium percentage (ESP) in the soil can cause the hydraulic parameters, such as percolation rate and infiltration rate, to decrease significantly. Salinized soils accumulate sodium on the exchange complex causing poor physical and chemical properties, which adversely affect water infiltration, soil tilth, plant growth and yield. This accounts especially for soils with more than about 20% clay content (UNCCD 2005, Prashad & Power 1997).

Excess exchangeable sodium in soils adversely affects plant growth, as the soil tends to become deflocculated and soil permeability is considerably reduced. Excess exchangeable Na^+ increases soil pH, which lowers the solubility of Ca and Mg carbonates, and these nutrients in turn may become deficient, as well as increasing the availability of Mo and Bo, which may reach toxic levels; and decreases the availability of Zn, which may limit plant growth. Excess exchangeable sodium results in dispersion of surface soils, reduced aggregation and infiltration rate, and increased soil resistance and crusting (Prashad & Power 1997).

Sodic soils exhibit structural problems created by certain physical processes, like slaking, swelling and dispersion of clay and specific conditions like surface crusting and hardsetting, which in turn might affect water and air movement, plant-available water holding capacity, root penetration, seedling emergence, runoff, erosion and tillage and sowing operations. In addition, imbalances in plant-available nutrients in salt- affected soils may affect plant growth (Qadir & Oster 2004, Qadir & Schubert 2002, Quirk 2001)

Crops differ in their sensitivity to sodicity. In general, cereals (other than rice and barley), cotton, sugarcane, and forage legumes such as *Trifolium alexandrinum* are less sensitive than other crops (Prashad & Power 1997).

There is a difference between the problems in the Nile Valley and the Nile Delta:

In the Nile Valley, flood basin irrigation without establishing an adequate drainage system has been used for centuries. The soil became water logged as the water table rose quickly from excess irrigation and/or an insufficient drainage system, while the prevailing high temperatures during summer were causing rapid evaporation at the soil surface, leaving salts to accumulate in the top soils (Kotb et al. 2000). A water logged area is defined by a groundwater table at a depth less than 80 cm below surface for a period more than two months during the winter season (Attia & van Leeuwen 1994). Improper land levelling, an effect of a less impermeable plough sole, seepage of drainage water from higher newly reclaimed areas at the fringes of the valley to down slope sites and frequent re-use of (salty) drainage flow or the use of salty ground water have added to the problem (Kotb et al. 2000).

In the Nile Delta, especially the northern part, the excessive rate of groundwater withdrawal has resulted in a large drop in the water table and, as a consequence, seawater intrusion into the aquifers (GARE 1992). Additionally, the lower water quality (and higher content of salts) in the Nile water, compared to the Nile Valley increase the amount of salt in the soils. An insufficient drainage system and an often shallow groundwater table lead to an upward movement of water containing salts, and evapotranspiration lead to a salt accumulation in the top soil (Kotb et al. 2000).

There are several ways to reclaim saline or sodic soils. The reclamation of saline soils centres on removal of excess salt from these soils, which includes scraping, flushing, leaching and drainage. As scraping (i.e. the mechanical removal of salts) and flushing (flushing water over the surface) have limited applicabilities, the predominant methods used in Egypt have to do with leaching and drainage (Prashad & Power 1997, Kijne 2006, Ragab et al. 2005).

In sodic soils, the aim is to reduce the exchangeable Na^+ to the extent that it does not degrade soil physical properties or interfere with the plant growth.
How critical the content of Na^+ in a soil is, can be seen in the following table

Table 1.1.3.: Exchangeable Sodium Percentage (ESP) and Sodicity Hazard (Abrol et al. 1988)

ESP	Sodicity hazard
>15	None to slight
15-30	Light to moderate
30-50	Moderate to high
50-70	High to very high
>70	Extremely high

Possible techniques to reclaim sodic soils include the use of gypsum, sulphur and pyrite. Reclamation of sodic and saline-sodic soils is done by providing a source of Ca^{2+} to replace excess Na^+ from the cation exchange sites. The replaced Na^+ is leached from the root zone through excess irrigation, a process that requires adequate flow of water through the soil. In

many sodic soils, calcite ($CaCO_3$) can be found at varying depths, as a Ca^{2+} source. At a partial pressure of carbon dioxide present in the atmosphere, calcite is not sufficiently soluble to affect soil reclamation. More soluble $CaCO_3$ minerals, such as vaterite, aragonite or $CaCO_3$ hydrates, are not commonly found in soils or observed to form pedogenically. Therefore, sodic soils are usually reclaimed through the application of chemical amendments that supply Ca^{2+} directly to the soil which then replaces excess exchangeable Na^{+} while others help increase dissolution rate of calcite in calcareous sodic soils. This way of chemical amelioration has become costly for subsistence farmers in developing countries. In addition, the low quality of amendments such as mined gypsum and difficulties in its availability in some areas add to the problem. Another way to reclaim sodic soils is through vegetative bioremediation, which relies on enhanced dissolution of native calcite within the root zone to provide adequate levels of Ca^{2+} for an effective Na^{+} - Ca^{2+} exchange at the cation exchange sites. Some grasses, namely Ghab (Phragmites communis) and Nisela (Panicum repens), have reduced salinity and alkalinity in soils in Lower Egypt (Qadir & Oster 2004, Qadir et al. 2001, Ghaly 2002, Suarez & Rhoades 1982).

A careful management of irrigation water is paramount as well as proper crop selection taking into consideration climate and rainfall, leaching to control soil salinity, drainage and amendment applications, (if necessary) to control sodicity. Another possibility to combat salinisation would be the increase of the efficiency of crops, i.e. more crop per drop of water (Ragab et al. 2005[1], Ragab et al. 2005[2]).

In order to combat salinisation, a lot of research has been carried out in Egypt to leach salts out of soils, which favours the cultivation of rice, which in turn uses a lot of water. Rice cultivation has grown dramatically over the years, as it is favoured by farmers as a cash crop. Therefore, rice cultivation is hard to control for the Egyptian government. Due to the high amount of water needed for rice cultivation, soluble salts are leached out of the top layers of the soils. With the increased re-use of drain water in the Nile Delta, it is not clear if rice cultivation would bring a long term effect on soil quality. In order to save some water, short-season rice varieties could be used instead. Rice cultivation in the Nile Delta and the subsequent burning of rice straw in October pollutes the already extremely polluted air in Cairo; rice cultivation is also forbidden in the areas outside the Nile Delta, due to the high amount of water needed (Kotb et al. 2000, Oad & Azim 2002). The way forward, which is heavily supported by the Egyptian government, is the improvement of irrigation methods and an improvement of the drainage system, which amounts to an additional 50,000 ha drained every year, making the Egyptian drainage project one of the largest water management interventions in the world. The total investment amounted to about US$ 1 billion, and since 1985 part of the investment has been used for the rehabilitation of old drainage systems, which led to a substantial decline in the area of salinity affected lands and a yield increase, after drainage has been installed. These processes take about 4 years depending on the availability of leaching water (Kijne 2006, Ali et al. 2001, El Shorbagy 2000, Moustafa 2000).

1.1.7.3. Pollution

Chemical degradation of water and land resources, defined as the combined negative effects of the chemicals and chemical processes on the aquatic system and the properties that regulate soil function, plays an important role in desertification processes. The UNCCD (2005) sees the root of such problems in the mismanagement of water and agricultural land as well as the poor implementation of pollution control regulations.

There are many toxic compounds other than salts or alkali compounds that may build up in soils naturally or as a consequence of development. B and Se are naturally abundant in some soils and ground waters. Human activity may bring them to the surface or increase the level of contamination, e.g. by using poor-quality irrigation water. B, heavy metals, pesticides, herbicides, disease and pest organisms, radioactive compounds and many other contaminants may degrade soil following human activities.

Another problem is the incorrect use of agrochemicals such as chemical fertilizers, pesticides, herbicides, fungicides, etc, that bring slow, cumulative changes in soil chemistry, structure and population of soil micro-organisms (Barrow 1991).

There are three major sources of land and water pollution in Egypt:

1. The discharge of industrial effluents and agricultural drainage water and navigation activities into the Nile, main canals and drains contaminating surface water resources.
2. The underground absorption and discharge in drains of latrine fills and waste water, due to missing sanitary facilities of 75% of the rural population (45% of the total population).
3. The excessive use of fertilizers due to the frequent and intensive cropping patterns, whose rate reaches, on average, 319 kg/ha of basic nutrients (N, P and K), which in turn leads to nitrate pollution of the water table and drainage water. Excess residues of pesticides and herbicides (importation of which is now controlled) in both surface and shallow water table are reported to have serious impact on public health and environmental risk for communities in the rural area (UNCCD 2005).

Organic pollution

A first biological assessment of organic pollution (chemistry and invertebrate fauna) of Nile water showed that the Nile Delta seems to have many grossly polluted areas. There is an urgent need to monitor, assess and improve water quality as it presents a health risk from water-borne diseases such as diarrhoea, cholera and typhoid which thrive in such conditions (Fishar & Williams 2008).

Pesticides

At a global level, the use of pesticides has proved to assist solving many problems facing human health and food production. Such usage has often been accompanied by hazards to man and the environment. Many of the banned or withdrawn pesticides from developed markets are still produced and sold in developing country markets, either by domestic companies or by some multinationals acting through subsidiaries or joint ventures. These include DDT and other persistent organochlorine (OC) insecticides. Data for Egypt suggests that organophosphates and carbamates dominate insecticide use there, primarily on cotton, but also on corn, rice, sugarcane as well as many different varieties of vegetable and fruit crops. For approximately 25 years, the use of DDT in agriculture has been officially banned in Egypt. In 1962, toxaphene was cancelled from recommendations due to the development of resistance of cotton leafworm, *S. littoralis* to this insecticide. The use of other pesticides (e.g. aldrin, dieldrin, chlordane, heptachlor, lindane, parathion, parathion-methyl, leptophos) were then gradually restricted in the country. Most, if not all, of the banned or severely restricted pesticides have since been used in Egypt. Human exposure to pesticides in Egypt may be excessive, especially those working on cotton fields (and spraying three to five times each season, without protective clothes and masks) and many thousands of children collecting egg masses of the cotton leaf worm daily for about 40 days each season. Some of the pesticides could be found in the tissues of farm animals. Chlorinated pesticides, especially DDT and its degradates, DDD and DDE were detected in surface water in the north coast of Egypt, either because they are still in use or due to their persistence against degradation and the resulting accumulation in the environment (Mansour 2004, Abbassy 2000).

Fertilizer use

Since the 1960s the Egyptian fertilization pattern was characterized by excessive N, moderate P, rare K and no micronutrients, leading to low yield as compared with other

countries. For crops, more than 350 kg ha^{-1} is applied to 2.2 crops/year. Low cost of subsidised fertilizers was one of the reasons for excessive N application, and insufficient information on the balanced plant nutrition concept and its positive environmental dimension formed another reason for neglecting K and micronutrients.

According to data from 1996, on most of the alluvial soils of Egypt, crop plants on one ha are provided with 50 kg N from soil, 30 kg N from the preceding legume crop (clover) and 10 kg N if adding 20 m^3 of farmyard manure. Thus, 90 kg N ha^{-1} are usually available to summer crops grown after clover and manured. Due to the excessive use of N-fertilizers, both drainage water and ground shallow water used for village drinking are heavily polluted with nitrate, especially in summer (El.Fouly & Fawzi 1996).

A possible way out of the excessive use of fertilizers is to use crop rotation patterns in a way that is most beneficial to the amount of nutrients in the soil. A possible crop rotation practice that involves intensive farming can be seen below – especially the rotation with paddy culture helps to leach soils and consequently, to control soil salinity to a considerable extent, but which uses a lot of water (Kotb et al. 2000).

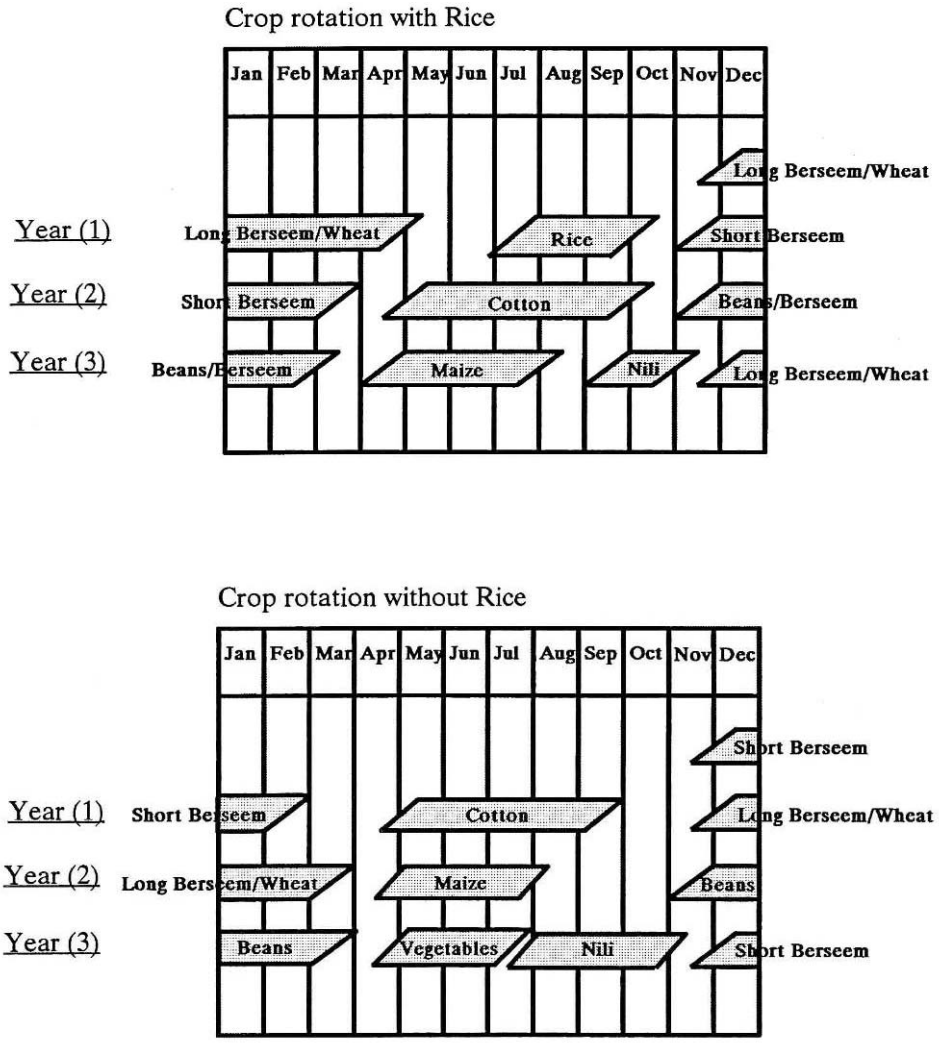

Figure 1.1.3. : Crop rotation patterns in Egypt, in order to reduce the amount of fertilisers used and to decrease soil salinity. (Kotb et al. 2000)

Regional differences in pollution

Upper Egypt

The Construction of the Aswan High Dam in 1961 and increased human activities in the Nile Valley have drastically changed the chemistry and mineralogy of the river flux. The total dissolved solids have increased by approximately 33% (measured in Cairo), even though the Nile has the highest dissolved salt content of any of the major African rivers (Martins &Probst 1991, Dekov et al. 1997).

In Upper Egypt (between Sohag and Aswan), the Nile waters are enriched in Na, K, Ca, Cl, F, Al, Sr, Fe, Mn, Cr, Ni, Co, Pb, V, U, Cd, As, Sb, Se, Hg, Au, HCO_3 and SO_4 (the only exception being Mn, Cu and Zn) compared to the world average river dissolved matter. The high contents of Pb, V, U, As and Ni could result from anthropogenic influence, i.e. industrial and urban activities (Aswan-Cairo highway and complexes of industrial plants), either by direct release or through atmospheric contamination. The content of major ions in this area (except Ca) in ground water is higher than in river water. The elevated content of cations and anions is mostly due to the hot climate and intensive irrigation, which accelerate the chemical weathering and therefore the release of elements in dissolved forms (Dekov et al. 1997). The ground water in Aswan, further upstream, showed good quality for different uses (drinking and domestic uses, irrigation and industrial purposes) (Soltan 1998).

Lower Egypt

83% of heavy industry in Egypt is located along the Nile Delta in Cairo and Alexandria metropolitan areas. In a study from 2007, in which 360 main industries were categorized, and their production, water use, wastewater discharge and main chemical characteristics were measured. From the 360 industries, 36 discharge directly into the Nile and its branches, 41 into the irrigation canals, 4 via wells directly into the groundwater, 9 into the sea (Mediterranean Sea and Gulf of Suez), 1 to Lake Mariut and the rest into the public sewer system and the drains (Abdel-Azeem et al. 2007). The sub-basin clay-size sediment in the lagoons of the northeast Nile Delta (Lake Manzalah, Ginka sub-basin) is a sink with significant metal loading (Hg, Pb, Zn, Cu, Sn, Ag). The metals originate from industrial wastes discharged with sewage. Food fish cultivated in this area bioaccumulate the metals as well as pesticides like DDT and their metabolites and pass them up the food web to humans (Anwar 2003, Siegel 1995, Ali et al. 1992).

Sewage waste and refuse contain high levels of micronutrients that may serve to correct plant deficiencies. Prolonged use of sewage effluent for irrigation usually results in an accumulation of some elements in the soil to toxic levels, and may be introduced into the food chain by means of animal feed or human food. A long term use of sewage water for irrigation enhances the accumulation of trace elements in the soil and may contribute to contamination in low-lying areas. Studies in Egypt showed a significant increase of total and available forms of Pb, Cd, Zn and B. The elements tended to accumulate in the surface layer, with the exception of B, which increased at lower depths (El-Hassanin et al. 1993).

Pb, which is predominant in soils contaminated by automobile exhausts (due to the high number of very old cars in use in Egypt), can be absorbed by plants only to a small extent. Lead mobility and bioavailability are controlled by several soil factors such as pH, redox potentialorganic matter and the chemical form and species of lead. The phytotoxicity of inorganic Pb is relatively low compared with other trace metals, and a very high concentration of the bioavailable Pb in soil is required to cause toxicity. However, organo-lead compounds, e.g. alkyl lead, are highly toxic, even when they occur at very low concentration, and have been reported to occur in soils and street dust, and can be found close to roads in Egypt (Elsokkary et al. 1995). It seems that the major threat for soil

degeneration, even in the area of the highest industrial density (Helwan, south of Cairo) is still sodication and soil salinisation (Melegy 2005).

1.1.7.4. Soil Fertility Depletion

Extensive and frequent cropping in the Nile Valley and Delta, under the conditions of unsustainable irrigation water management and improper agricultural practices described in this chapter, have resulted in depletion and deficiency in many nutrient elements. This situation has been exacerbated following the construction of the High Dam, which sharply decreased the annual additions of the fertile sediments to the soils. Consequently, all Egyptian soils are poor in their content of organic matter, total nitrogen and other nutritive elements. This is especially true for the Lower Nile Delta (Stanley & Warne 1993, UNCCD 2005).

1.1.7.5. Erosion and Sand Encroachment

There will be erosion of a soil when the mechanical loss from its uppermost layer (by water or wind or human activity) exceeds its formation rate in volume. There are four prongs of degradation: mass movement, Aeolian erosion, erosion by water and removal in solution. The last three are especially predominant in dry ecosystems. Soil erosion is the most traumatic and frequently irreversible stage in the degradation of lands (Barrow 1991, Mainguet 1999).
Once the topsoil is removed, the subsoil may be more or less vulnerable to erosion. Often the lack of organic matter in subsoil makes a protective vegetation cover more difficult to establish, and unless the subsoil is clay-rich there is less to bind particles together. The amount of erosion that will occur in a given circumstance is determined by:

1. Erosivity, i.e. the capacity (potential) of precipitation to cause erosion, which is determined by the climate. Erosivity is a function of intensity, duration, timing, and the amount of precipitation.
2. Erodibility, i.e. the vulnerability of soil to erosion which depends on soil properties, i.e. how easily particles are detached and then transported away. Erodibility is dynamic, as circumstances can change, e.g. soil can vary in moisture content and resistance to erosion; as well as vegetation cover alters and thus erodibility of a soil.
3. Cover, i.e. natural vegetation, crop or covercrop that protects the soil.
4. Management, i.e. land use, crop, cropping method, cropping pattern, tillage method and use of mulch.

2, 3 and 4 can alter at various times of the year, or over a period of time. Vegetation cover is still the best protection against erosion by wind and water, and it also plays a role in the distribution of nutrients and in the humidity in the soil. Any human activity exploiting vegetation cover entails the exacerbation of the erosion as a consequence (Barrow 1991, Mainguet 1999, Frede 1986).

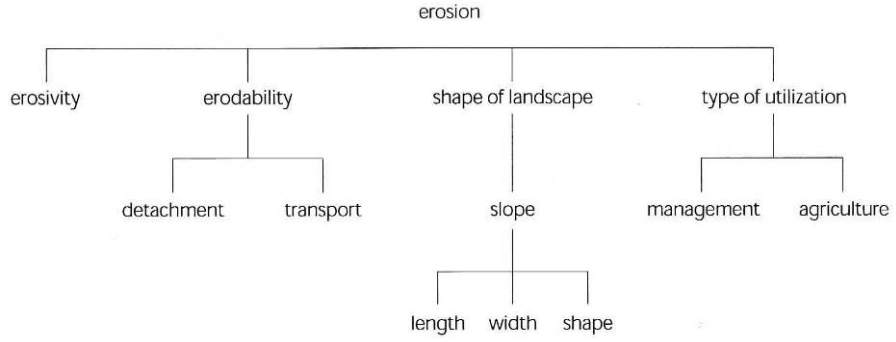

Figure 1.1.4. : Factors contributing to soil erosion (Barrow 1991).

In general, erosion by wind and water can be divided into three phases:

- solution from soil surface
- transport
- deposit

The first two phases need kinetic energy; the mechanisms of erosion by water and wind differ (Frede 1986).

Wind Erosion

Particles of 100 to 150µm diameter are especially susceptible to wind erosion. They are either put in motion by the direct influence of the wind, or are hit by other particles and thus hurled upwards and then caught by the wind (Frede 1986).

There are different kinds of wind erosion, namely:

Deflation: removal and transporting away of loose soil, especially sands, sandy soil, light peaty soils or loess. This typically leaves localized hollows. Deflation can remove much valuable agricultural land in times of drought.

Abrasion: Wind, charged with fine rock or ice debris damages plants, erodes rock, equipment, buildings and blows away the loosened material (Barrow 1991).
Wind erosion is one of the major processes of land degradation in Egypt, and is especially dominant in the Western and Eastern desert and inland Sinai. In inland Sinai, agro-ecological zones are mostly sand-textured and thus especially susceptible to wind erosion. Wind erosion also occurs in the coastal zone where coastal sand dunes dominate. The major reasons for desertification by wind erosion are the fragility, vulnerability and nature of the soil, aridity, scarcity of natural vegetation and the advancement of sand dunes. In the rainfed areas of the northern coastal zone, destruction of plant cover, overgrazing, ploughing and extending cultivation to the shallower and less suitable soils accelerate wind erosion. The average rate of soil loss via wind erosion in the Western desert Oases has been estimated at5.5 ton/ha/year (UNCCD 2005).

Water Erosion

Water causes erosion in three different ways:

- the impact of water drops on soil particles
- runoff of soil surface water
- the impact of drops in surface water, causing turbulences and thus increasing transport capacities of the water.

The pressure caused by the impact of raindrops on soil surface also causes compaction of the surface, destruction of structural elements and an increase in erodable particles, as well as sideway hurling of particles (Frede 1986).

There are different types of soil erosion caused by water:

Sheet (Sheetwash) Erosion: Rain and overland flow of water removes soil particles, which can happen either slowly or rapidly.

Rill erosion: Flowing water concentrates into rivulets and carves small channels

Gully erosion: Where rainfall cannot infiltrate the soil and, where slopes are sufficient, water will flow and become concentrated. This can be triggered or aggravated by trampling or vegetation damage.

Streambank collapse and removal: Stream/river undercuts bank, material slides into river and is transported away.
(Barrow 1991)

Water erosion is among the major processes of land degradation in the northern coastal zone of the country where abrupt and intense rainstorms cause excessive runoff and considerable soil loss. Similar processes influence the coastal plains, hilly and mountain slopes of the Red Sea, as well as the southern parts of Sinai and many wadis in the Eastern Desert. The annual soil loss via water erosion in rainfed areas has been estimated between 0.8 and 5.3 ton/ha/year (UNCCD 2005).

A prediction for the evolution of the coastal part of the Nile Delta says that erosion in this area will further increase, as more sediment leaves the delta system than enters it (due to the sediment being held back at Aswan High Dam). Thus, the shoreline will be cut back at promontories, and lagoons will be infilled on their seaward margin with storm washover sand. In some places, accretion will occur, widening strandplains with increased development of coastal dunes (Stanley & Warne 1993).

Sand Encroachment

Sand dunes and other sand forms in deserts are very vulnerable to wind erosion and deposition; consequently they constitute a serious threat to agricultural development, rural and urban settlements, road traffic and public health. Approximately 16% of the total area of Egypt consists of Aeolian sand deposits, which are exposed to wind erosion phenomena. There are several areas in Egypt characterized by serious sand dune encroachment. West of the Nile Delta sand dunes with an orientation towards the western and south-western sides of the cultivated land in the Nile Delta cover an area of 255 km^2. In the western side of the Nile Valley linear sand dunes cover 350 km^2 and are actively encroaching on fertile cultivated land. Several Oases as well as the area around Cairo are also threatened by advancing sand dunes (UNCCD 2005, Moursy et al. 2002).

1.1.8. Land Reclamation in Egypt

In order to meet the demands of a growing population and limited resources, land reclamation has been an important issue in Egypt since the 1950s. Land reclamation includes the development of infrastructure necessary for production, village infrastructures as well as increasing soil fertility to the so called positive marginal productivity (Wolff 1993).

In the 1950s, following the revolution of 1952, the main target was to provide land and to increase the standard of living of the ever growing part of the population that did not own land, whilst increasing agricultural production was regarded as less important. New, “modern” forms of society were aimed for, so co-operatives were created, that took over the distribution of land and products as well as the purchasing of goods needed for production and their marketing. A complete non-commercialisation of agriculture was not achieved, though. However, approximately 35,000ha of land were reclaimed until the end of the 1950s (Voll 1980, Wolff 1993, Hopkins et al. 1988).

Until the war with Israel in 1967, desert reclamation made substantial progress. The construction of the High Dam was a positive impact. However, not enough emphasis was put on turning reclaimed land into agriculturally used land. In general, it was believed that big, state-owned enterprises were better for agriculture and that fruits and vegetables should be cultivated as cash-crops. Only areas of 2ha were leased to farmers, and very rarely was ownership of those areas transferred to farmers. Reclaimed areas that were not leased to farmers got lost. The aim of desert reclamation at this time was to extend agricultural production and to gain profits. Until 1966, an additional 307,300 ha of new land was reclaimed in all parts of the country (Wolff 1993).

In the 1970s already existing programmes were finished. As those areas cultivated by small farmers were more productive, large co-operations were split into smaller areas that were then leased to farmers. From 1978 to1988 an area of 242,634 ha was reclaimed. In 1986, the so called “Land Master Plan” was laid out, and 1,092 million ha of land was identified as reclaimable (Wolff 1993).

In 1996 the Toshka project was initiated as part of the South Valley Development Project Plan. The goals of this project include reclaiming up to 336,000 ha of desert land and establishing new communities that will relieve population pressure in the Nile Valley and Delta. Private investors are expected to establish large farming operations that will specialize in horticultural crops for export to European markets. As water for this project will be obtained from a new canal originating at Lake Nasser this will increase the demand for Nile River water substantially when all of the canals and pump stations have been completed. The establishment of new industrial and agricultural societies, new settled communities, a network of basic and peripheral roads to serve the area as well as airports, the transport of agricultural and industrial products, and the infrastructure for tourism in the area, (that encompasses many prehistoric Pharaonic, Greco-Roman and Islamic monuments) will be necessary. The total investment is estimated at over 50-90 billion US$ in the 20 years leading up to 2017, provided by private investors. The Sheikh Zayed Canal (which is named after Sheikh Zayed Bin Sultan El Nahajan, the president of the United Arab Emirates, one of the mayor investors) is currently under construction: approximately 50 km of the main channel, as well as two of nine smaller canals have been finished. The main channel is open, 6m high, 30m wide at the bottom and 54m wide on surface level. The onset of the channel at Toshka is 20m high and the pumps of the Mubarak Pumping Station are constructed to pump up to 25 Million m^3 of water daily into the canal. The project will affect the Nubian aquifer, one of the largest aquifers of the world (covering 2 million km^2 in Sudan, Libya, Chad and Egypt, with reservoir capacity of $7.5x10^4$ km^3), largely formed of the non-renewable fossil groundwater recharged during previous, more humid climatic conditions during Quaternary. Simulations have shown that many of the proposed irrigation areas, especially those with small aquifer thickness, will become fully saturated with introduced water, resulting in potential flooding and salinisation (UNDP 2005, Wichelns 2002, Kim & Sultan 2002).

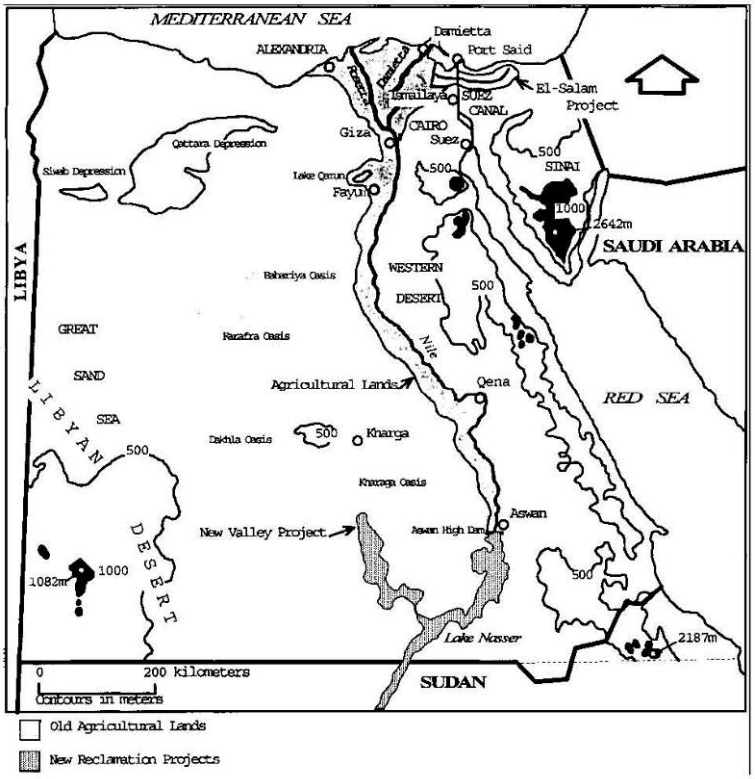

Figure 1.1.5.: Land Reclamation in Egypt (Kotb et al. 2000)

Another current project, the Northern Sinai Agricultural Development Project is designed to reclaim up to 250,000 ha in the eastern Nile Delta and on the northern portion of the Sinai Peninsula. Thus, the El-Salam Canal, which originates in the Delta and siphons under the Suez Canal, will carry a blend of Nile River water (50%) and drainage water from the Delta. The estimated annual water requirement for the 90,000 ha that will be reclaimed on the Sinai Peninsula is 1.7 billion m^3 (Wichelns 2002).

Apart from the high costs for reclamation projects which include the construction of infrastructure, one of the major uncertainties for the success of the projects is to what extent agriculture in these fragile areas will be sustainable. It is unclear yet whether the people willing to relocate to these remote areas will be farmers, or simply full of good intentions. Agricultural practices as well as proper irrigation and use of fertilizers will be crucial for the long term success of the program (Wolff 1993).

1.2. Assessing Soil Quality

Soil quality has different meanings according to the perspective of the person: for the land manager or crop advisor, it may mean sustaining or enhancing productivity and maximizing profits, while maintaining the soil resource for future generations; for the conservationist, it may mean protecting the environment and sustaining the soil resource for future generations; for consumers of agriculture products, it may mean plentiful, healthful, and inexpensive food for present and future generations; and for the environmentalist, it may mean a holistic interconnected view of soil in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling, and biomass production. Each perception of soil quality and the scale of concern impacts how it is measured and assessed (Mausbach & Seybold 1998).

Soil quality is concerned with some measure of a property or function of a soil. There are numerous definitions of soil quality. Simply put, soil quality is *the capacity of a soil to function* (Pierce & Larson 1993). According to the Soil Science Society of America (SSSA) it is defined as: …*the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation* (Karlen et al. 1997). Inherent soil characteristics are those determined by the soil-forming factors of climate, parent material, time, topography and biota, whereas the dynamic or use-dependent soil properties are those influenced by the management practices imposed by humankind. Both are very important in regard to sustainability, and they are complementary.

In general, the concept of soil quality focuses on the interactions among physical, chemical and biological properties and processes occurring within the soil, and thus overlaps with issues associated with soil fertility, soil health, soil productivity and response to soil management (Karlen et al. 2004). Proposed measures of soil quality employ the use of soil quality indicators that reflect the capacity of the soil to function. The functions of a soil could be defined as

1. sustaining biological activity, diversity, and productivity;
2. regulating and partitioning water and solute flow;
3. filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition;
4. storing and cycling nutrients and other elements within the earth's biosphere; and
5. providing support of socioeconomic structures and protection for archaeological treasures associated with human habitation (Karlen et al. 1996).

Soil quality indicators should

- encompass ecosystem processes and relate to process oriented modelling,
- integrate soil physical, chemical, and biological properties and processes,
- be accessible to many users and applicable to field conditions,
- be sensitive to variations in management and climate
- where possible, be components of existing soil databases
- be easily measured and measurements must be reproducible,
- indicators should be sensitive enough to detect changes in soil as a result of degradation (Mausbach & Seybold 1998)

The following is a description of the main soil properties that play a role in assessing soil quality, how they interact and their importance for a soil “to function”.

1.2.1. Physical properties of soils

Soil physical parameters, such as soil texture, soil structure, bulk density, pore volume or soil temperature directly influence soil moisture, soil aeration, nutrient supply, susceptibility to erosion, and activity of soil organisms.

1.2.1.1. Soil texture and soil structure

Soil solids, comprising inorganic and organic components, form the matrix or the body of most soils. This matrix, or the visible part of the soil, is the storehouse of water and nutrient elements.

Except in the case of organic soils, most of a soil’s solid framework consists of mineral particles of different sizes, varying from coarse (over 2mm) to very fine (less than 2µm). There are two types of soil particles, primary and secondary. Primary particles are discrete units that cannot be subdivided, and are also called soil separates, secondary particles consist of primary particles and can be subdivided into its separates by chemical or mechanical dispersion. The particular separate that is present in larger amounts determines the group of the textural classes, and the nature of the soil. Three broad groups of textural classes are recognized: sandy soils, clayey soils, and loamy soils that occur in gradual sequences within each group. The proportions of particles in these different size ranges is called soil texture, and consists of three major size classes, namely sand (2.0-0.05 mm), silt (0.05 – 0.002 mm) and clay (< 0.002 mm). Sand and silt constitute the skeleton of the soil body, whereas clays constitute the reactive fraction of the soil. Because the size of mineral particles in a soil is not readily subject to change by soil management practices (it can only be altered by adding large amounts of soils of different textures brought in from an external source), the soil texture (texture class) is an important and permanent characteristic of a soil and gives a general picture of the soil’s physical properties such as density, porosity consistency, water holding capacity, shrink-swell behaviour, plasticity, soil strength, chemical absorption and tilth. Soil texture affects total porosity, pore size, and surface area. The inorganic primary and secondary minerals in soils are the original source of most of the chemical elements essential for plant growth (Prashad & Power 1997, Brady & Weil 2002, Lal & Shukla 2004).

Soil mineral particles are bound together by oxides and hydroxides of iron, organic substances excreted by plant roots, root pressures, decomposition products of plant residues, microbial cells and fungal hyphae, and excretory products of microorganisms and gelatinous substances secreted by earthworms. Particles are thus aggregated into larger units of different sizes and shapes (platy, columnar/prismatic, blocky, granular/crumb) that determine the soil structure. There are two broad categories of aggregates that vary greatly in size and stabilization mechanisms. Microaggregates are less than 250µm in diameter and are directly stabilized by soil organic matter, exchangeable cations, Fe and Al-oxides, and

$CaCO_3$. In contrast, the formation and stabilization of macroaggregates (>250 µm) are the result of a combination of mechanisms related to plant roots and the activity of soil fungi and fauna (Carter 1996, Paul & Clark 1996). Soil structure, like soil texture, determines how water and air move in soils, and influence the suitability of soils for the growth of plant roots (Brady & Weil 2002, Prashad & Power 1997). Activities such as timer harvesting, grazing, tillage, trafficking, drainage, liming, and manuring impact soils largely through their effect on soil structure, especially in he surface horizons (Brady & Weil 2000).

Soil texture determines bulk density of a soil, which is defined as the mass of a unit volume of dry soil, which includes both solids and pores. Fine textured soils such as silt loams, clays, and clay loams generally have lower bulk densities than do sandy soils. The solid particles of the fine-textured soils tend to be organized in porous granules, especially if adequate organic matter is present. In these aggregated soils, pores exist both between and within the granules. This condition assures high total pore space and a low bulk density. In sandy soils, organic matter contents generally are low, the solid particles are less likely to be aggregated together, and the bulk densities are commonly higher than in the finer-textured soils. While sandy soils generally have high bulk densities, the packing arrangement of the sand grains also affects their bulk density. The bulk density is generally lower if the sand particles are mostly of one size class (i.e. well sorted sand), while a mixture of different sizes (i.e. well graded sand) is likely to have an especially high bulk density. In the latter case, the smaller particles partially fill in the spaces between the larger particles. The densest materials are those characterized by both a mixture of sand sizes and a tight packing arrangement. Bulk density excludes water from consideration. Soils with a low proportion of pore space to solids have a higher bulk density than those that are less compact and have more pore space (Brady & Weil 2000, Gisi et al. 1997).

1.2.1.2. Porosity

Infiltration of water into the soil, its movement through the profile both laterally and vertically and the total store and availability of water to plants all depend on the presence and the size frequency distribution of the pores. Soil porosity may be divided into textural and structural components. Textural porosity is the minimal porosity resulting from the irregular distribution of the inorganic soil fragments; structural porosity is that component of porosity due to the generally-larger interconnected pores. Pores are classified on the basis of their equivalent cylindrical diameters (ECD) although the boundaries of the size classes are somewhat arbitrary. Micropores are defined as those pores sufficiently small (less than approximately 30µm in diameter) to retain water by capillarity and these contrast with the larger macropores which do not.

Mesopores are 0.2 to 30µm in diameter, are textural pores, and the water retained by these pores has been referred to as plant available water. They are less strongly influenced by management (particularly tillage and traffic) and exhibit less temporal variation than macropores (Kay 1997).

Micropores are usually filled with water in field soils, and even when not water-filled, they are too small to permit much air movement. Water movement in micropores is slow, and much of the water retained in these pores is not available to plants. Fine-textured soils, especially those without a stable granular structure, may have a preponderance of micropores, thus allowing relatively slow fas and water movement, despite the relatively large volume of total pore space. Aeration, especially in the subsoil, may be inadequate for satisfactory root development and desirable microbial activity. Ultra-micropores (=Cryptopores) are too small to allow the entry of bacteria. Macropores are of particular importance in determining soil aeration and rapid water entry; they also accommodate plant roots and animals inhabiting soils. Large macropores created by the biota are known as biopores and functionally effective, near-vertical pores are created in almost all soils by root growth and decay,

earthworms, termites, ants, and other burrowing invertebrates (Lavelle & Spain 2001, Brady & Weil 2000).

In agricultural terms, a well-.developed soil structure implies the presence of porous, water stable aggregates and is considered important both in protecting the soil surface against erosion and in promoting a satisfactory level of plant growth. The favourable effects of well developed structure on plant growth are achieved by facilitating aeration and water flow into and through soils. In terms of agricultural production it is advantageous to have most pores in the size range 0.2 to 30µm to maximise water storage, but for 10% of the soil volume to be in pores larger than 30µm, to promote aeration. It is also important that aggregates exposed to raindrop impact and surface water flow are stable in water since their slaking and dispersion may lead to excessive erosion of surface soils, the blocking of soil pores and the formation of surface crusts (Lavelle & Spain 2001, Dexter 1988).

1.2.1.3. Temperature

Another physical fator of importance is soil temperature. In general soil temperature affects the velocity of chemical and biological activity, for every 10°C rise in temperature, microbial respiration and organic matter decomposition can double. This is of importance in warm regions, where it has implications for the decomposition of soil organic matter and therefore the cycling of the nutrients they contain and thus indirectly for soil structure. Soil temperature can alter the physical structure of a soil by alternate freezing and thawing processes Sanchez 1976, Brady & Weil 2002).

1.2.1.4. Soil colloids, minerals, and organic components

Soil colloids are important for the quality of a soil, as they play an important role in determining soil structure as well as for nutrient availability.

The clay and humus particles in soils are referred to collectively as the colloidal fraction because of their extremely small size and colloid-like behaviour. A colloid is a state of matter consisting of very fine particles that approach, but never reach, molecular sizes. The upper size limit of a colloid is 0.2µm, and the lower size limit is approximately 50 Å (5nm), the size of a molecule. The colloids can exist as a gel or a sol. A gel is defined as a colloid that exhibits the properties of a solid. Sols, on the other hand, are colloids that behave as liquid. Plant and soils contain large amounts of solid material that is in a colloidal state. Such material exhibits chemical and physical properties that depend on the colloidal condition. Clay comprises all inorganic solids smaller than 2µm in effective diameter and is considered a soil colloid. Soil organic matter and plant solids also occur in the colloidal state. Many chemical and biological reactions occur at the solid-liquid interfaces. Adsorption takes place at the interface, desorption is the release or removal of materials that were adsorbed (Tan 1993).

Clay minerals are made up of layers of Si-tetrahedra and Al-octahedra, including in some cases Mg and Fe, and are therefore known as layer silicates. Broadly, there are two major kinds, minerals having one layer each of Si-tetrahedra and Al-octahedra (1:1 layer silicates) and those having one layer of Al-octahedra and two layers of Si-tetrahedra (2:1 layer silicates). Of the 1:1 layer silicates, Kaolinite is the most common member, a dioctahedral 1:1 layer silicate that contains Al^{3+} in the octahedral and Si^{4+} in the tetrahedral sites, and is formed in soils by weathering of 2:1 layer silicates and other minerals such as feldspars. Hallyosite is a 1:1 layer silicate, in which layers are separated by a layer of H_2O molecules. It is usually found in soils formed from volcanic deposits, and easily weathers to kaolinite (Prasad & Power 1997).

2:1 layer silicates have one octahedral layer sandwiched between two tetrahedral layers. The most widespread group of minerals is smectites, which include montmorillonite, beidellite,

nontronite, etc. These minerals have a great capacity to adsorb water and swell in the vertical direction and are therefore known as expanding clay minerals. 2:1 layer silicates include pyrophyllite and talc (which are rare in soils), micas (which weather to other minerals, particularly to vermiculites and smectites, with K^+ as an important source for plants released by weathering), vermiculite (which are very common in soils), smectites, chlorite (infrequent in soils), palygorskite and sepiolite (mostly found in soils of arid and semiarid environments) (Prasad & Power 1997).

Noncrystalline silicate clays (noncrystalline silicates) include allophanes and imglolite. They are hydrated aluminium silicates and are amorphous in nature and occur as a major constituent of young soils formed from volcanic ash. They do not exhibit ordered, crystalline sheets. They have high amounts of both positive and negative charge, and high water-holding capacities, and they strongly adsorb phosphate and other anions, especially under acid conditions. Soils containing much allophone may have a very high water content, but they do not swell on wetting or shrink on drying. Loss of water is irreversible (Brady & Weil 2002, Prasad & Power 1997).

Oxide minerals (oxides and hydroxides of Fe, Al, Mn, Ti, and Si) are found in many soils, but are especially important in the more highly weathered soils of warm, humid regions, especially in ultisols and oxisols. The high oxide content of these soils gives them the colours and names such as yellow soils, red soils, terra rosa, krasnozenes, etc. Some, like gibbsite (an Al-oxide) and goethite (an Fe-oxide) consist of crystalline sheets. Other oxide minerals are noncrystalline, often occurring as amorphous coatings on soil particles. They are relatively low in plasticity and stickiness, and their net charge ranges from slightly negative to moderately positive (Prasad & Power 1997, Brady & Weil 2002).

The organic components of soils originate from the biomass that is characteristic for an active soil, and is often divided into nonhumified and humified materials. Nonhumified substances are the compounds in plants and other organisms with definite characteristics, e.g., carbohydrates, amino acids, protein, lipids, nucleic acids, and lignins). These compounds are usually subject to degradation and decomposition reaction. The humified fraction is known as humus or humic compounds, and is considered the end product of decomposition of plant material in soils. Organic (humus) colloids are important in nearly all soils, especially in the upper parts of the soil profile. Humus colloids are not minerals, nor are they crystalline, but consist of convoluted chains and rings of carbon atoms bonded to hydrogen, oxygen, and nitrogen. They are among the smallest of soil colloids and exhibit very high capacities to adsorb water, but almost no plasticity or stickiness. Humus has high amounts of both negative and positive charge per unit mass, but the net charge is always negative and varies with soil pH (Tan 1993, Brady & Weil 2002).

1.2.1.5. Cation Exchange

Since clay colloids carry negative charges, cations are attracted to the clay particles. These cations are held electrostatically on the surface of the clay. Most of them are free to distribute themselves through the liquid phase by diffusion. Different rates and orders of adsorption are known among the cations, since the adsorption reaction depends on the surface potential, valence, and hydrodynamic radius. As surface potential increases, more of the divalent ions will be adsorbed, trivalent cations to an even stronger extent. When a mixture of monovalent and divalent ions is present in a soil solution, adsorption is usually shifted in favour of the divalent ions. Specific adsorption of cations is also affected by the hydrodynamic radius, whereas the crystalline radius only plays a minor role. Generally, ions with smaller hydrated sizes are preferably adsorbed (Tan 1993, Brady & Weil 2002).

Adsorbed cations can be exchanged by other cations, hence the cations are also called exchangeable cations. Adsorption and cation exchange are of great practical significance in nutrient uptake by plants, soil fertility, nutrient retention, and fertilizer application. Adsorbed

cations are generally available to plants by exchange with H^+ ions generated by the respirations of plant roots. Nutrients in the soil are retained by the colloidal surfaces and are temporarily prevented from leaching. The cation exchange capacity (CEC) of soils is defined as the capacity of soils to adsorb and exchange cation, and is related to the surface area and surface charge of the clay. In general, 2:1 layer silicates are attributed to permanent charges, whereas 1:1 layer types of clays show variable charges (Prasad & Power 1997, Tan 1993).

1.2.1.6. Anion Exchange

Two types of adsorption of anions by soil colloids are recognized: negative and positive adsorption. Negative adsorption of anions occurs at a colloidal surface with a positive charge, to which cations are attracted and concentrated at the colloid surface. Thus, anions are expelled from the double layer formed on the negatively charged surface, which is termed negative adsorption. Therefore, the bulk solution contains more anions than the solution in the interface. Negative Adsorption of anions is approximately 1-5% of the CEC, and can amount to 15% in saline soils. Positive adsorption of anions is the adsorption and concentration of anions on the positively charged surfaces or edges of soil colloids. The anion exchange capacity (AEC) of soils is usually smaller than the CEC. It is dependent on changes in electrolyte levels and on soil pH, and limited to special types of clays (Bolt 1976, Tan 1993).

1.2.2. Chemical properties of soils:

1.2.2.1. pH

Soil pH expresses the activity (concentration) of H^+ ions present in solution, and describes whether a soil is acid, neutral, or alkaline. The degree of soil acidity of alkalinity, expressed as soil pH, affects a wide range of soil properties – chemical, biological and indirectly even physical. It influences the availability for root uptake of many elements, including nutrients as well as toxins, as well as the activity of soil microorganisms.

Soil acidity controls the solubility and precipitation of chemical compounds of all essential plant nutrients and is therefore a deciding factor on their availability (see figure 1.2.1.). Soil acidity strongly influences soil fertility and plant growth, as some nutrients become deficient or reach toxic limits, depending on soil pH. The same accounts for alkaline soils. In mineral soils the pH for the greatest availability of the most nutrients is 6.5, while in organic soils (peats and mucks) the optimum pH is about 5.5. In strongly acidic soils (pH < 5) Al-toxicity poses a serious problem. Measurements of soil pH are important criteria for predicting the capability of soils to support microbial reactions. A bacterial cell contains about 1000 enzymes, many of these are pH dependent and associated with cell components, such as membranes. The pH optimum of enzymes is affected by adsorption phenomena. In the soil matrix, adsorption of enzymes to the soil humates moves their pH optima to higher values. Most of the known bacterial species grow within the pH range of 4 to 9 or within smaller segments of that range, with some species growing below that. Fungi as a group are moderately acidophilic; their optimal growth usually in the pH range of 4 to 6. Some bacteria are extreme alkalophiles, capable of growth at pH 13, being halophilic at the same time. pH also affects the abundance of earthworms, with populations growing gradually from pH 4 (less abundant) to pH 8 (Lavelle & Spain 2001, Prasad & Power 1997, Paul & Clark 1996).

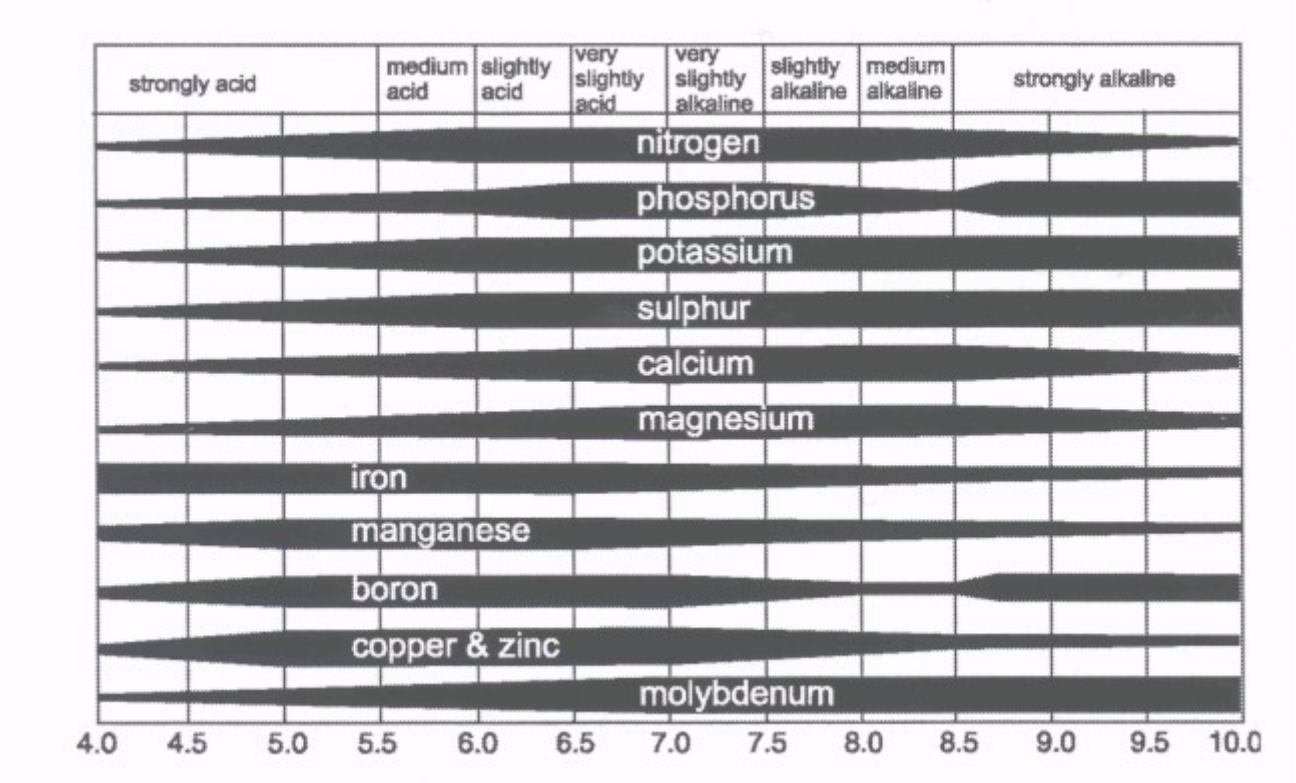

Figure 1.2.1. Effect of soil pH on nutrient availability (Lavelle &Spain 2001)

The buffering capacity of a soil is related to its cation exchange capacity (CEC, see below) and is therefore related to the clay content and mineralogy and to the amount of soil organic matter (see below) present. The larger the amounts of either clay or organic matter, the greater the buffering capacity (Prasad & Power 1997),

There are several factors affecting soil acidity, that include

- the kind of chemical fertilizer used
- the amount of basic cations removed by the crop plants,
- leaching of cations
- organic residues and their decomposition
- nitrogen transformations
- deposition of nitrate, sulphate and acid forming chemicals by rain.

The content of exchangeable Al, especially of Al^{3+} in a soil is the main cause of soil acidity. The acid forming effect of fertilizers is caused by the contained S and Cl, N, and P, even though it seems that N seems to be the one contributing most to soil acidity. The presence of Ca, Mg, K and Na in fertilizers raises the pH of the soil. If NH_4 or NH_4 – forming N fertilizers are applied, due to nitrification, soil pH is also raised. Another cause of acidity of soils is caused by the uptake of exchangeable bases by plants during their growth; for every positive charge taken in on a cation, a root can maintain charge balance either by taking up a negative charge as an anion or by exuding a positive charge as a different cation. When they take up far more of certain cations (K^+, NH_4^+, and Ca^{2+}) than they do of anions (e.g. NO_3^-, SO_4^{2-}), plants usually exude H^+ ions into the soil solution to maintain charge balance. When crops are then harvested, thus partly or completely removed from the soils, the net result is loss of bases from the soil, which leads to the development of soil acidity. Another cause for soil acidity is due to acids brought in by rain. A number of gaseous sulphur and nitrogen compounds, especially SO_2 and NO_2 are emitted into the atmosphere through natural and/or anthropogenic processes. These gaseous compounds are dissolved in rain, and are added to soil by precipitation, the amounts being greatest near industrial towns (Prasad & Power 1997).

Crops differ in their soil pH requirements. The optimum soil pH for crop production is generally considered to be between 6.5 to 7.0, and lime applications (to raise soil pH) are made to that effect (Prasad & Power 1997).

1.2.2.2. Nutrients

Of the 16 essential nutrients, C, H, and O are taken from the air and soil water, while the other 13 are supplied by the soil.

1.2.2.2.1. Macronutrients (N, P, K, S, Ca and Mg)

Macronutrients are divided into two groups, namely primary (N, P, and K) and secondary (S, Ca, and Mg) plant nutrients. Primary nutrients are taken up by crops in the largest amount and are the nutrients most commonly applied almost each crop season unless organic farming is practiced, and are thus the main, sometimes only nutrient contained in fertilizers. Because the criterion for grouping plant nutrients as primary, secondary, or micro is based on their amounts removed by the crop plant, and because in some instances secondary plant nutrients are taken up in higher quantities than primary plant nutrients, they are here grouped as macronutrients, as opposed to micronutrients (Prasad & Power 1997).

Nitrogen (N)

More money and effort have been, and are being, spent on the management on N than any other mineral element, as the world's ecosystems are probably influenced more by deficiencies or excesses of N than by those of any other essential element. In most terrestrial ecosystems N limits plant growth, and thus net primary production, at the same time, several forms of N are also pollutants (Brady & Weil 2002, Robertson & Groffman 2007).

The atmosphere, which is 78% gaseous N (N_2) in content, appears to be a virtually limitless source of this element. Due to the very strong triple bond between the two N atoms, this gas is quite inert and not directly usable by plants or animals, but due to the ability of certain microorganisms (several species of bacteria, several actinomycetes, and certain cyanobacteria) with the ability to break the triple bond, it is available in other N containing compounds. The N content of surface mineral soils normally ranges from 0.02 to 0.5%, a value of about 0.15% being representative for cultivated soils. N takes nine different forms in soil corresponding to different oxidative states. Dinitrogen gas (N_2) is by far the most abundant form of N in the biosphere but is unusable by most organisms, including plants. Biological N_2 fixation, whereby N_2 is transformed to organic N, is the dominant process by which N first enters soil biological pools and then undergoes other processes: *N mineralization*, which is the conversion of organic N to inorganic forms, *N immobilization*, which is the uptake or assimilation of inorganic forms of N by microbes and other soil heterotrophs; *nitrification*, which is the conversion of ammonium (NH_4) to nitrite (NO_2) and then to nitrate (NO_3), and *denitrification*, turning NO_3^- into N_2 and N_2O (Robertson & Groffman 2007, Brady & Weil 2002).

N is an integral component of many essential plant compounds, as it is a major part of all amino acids, which are the building blocks of all proteins (including enzymes), nucleic acids, and chlorophyll. Plants respond quickly to increased availability of N, and it can dramatically stimulate plant productivity. Soil organic N consists of proteins (20 to 40%), amino sugars such as the hexosamines (5 to 10%), purine and pyrimidine derivatives (1% or less), and complex unidentified compounds formed by reaction of ammonium with lignin, polymerization of quinines with N compounds, and condensation of sugars and amines. Part of the organic N is present as clay-humus complexes, which are resistant to decomposition. In general, organic N is largely unavailable to plants and more or less resistant to decomposition. Thus, microbial processes (i.e. mineralization) are needed to transform soil organic N into inorganic

compounds, available for plants. This depends on temperature, C/N ratios, soil pH, aeration, water content of the soil, and clay mineralogy (Prasad & Power 1997, Brady & Weil 2002).

N-fixing organisms can broadly be classified into those that are free-living and those living in association with plants, such as *Rhizobium* species of bacteria living in a symbiotic relationship in root nodules of legumes that are capable of converting atmospheric N_2 gas to NH_3, which is then utilized by the legume to form amino acids and proteins. The rhizobia obtain the energy needed for their growth and for the fixation of N from products of photosynthesis formed in the legume (Prasad & Power 1997).

Plant roots take up N from the soil solution principally as NO_3^- and NH_4^+ ions. NO_2^- can also be taken up, but is toxic to plants; however, NO_2^- hardly ever occurs in larger than trace quantities in soils. Although certain plants grow best when provided mainly one or the other of these forms, a relatively equal mixture of the two ions gives the best results with most plants, also due to the effect on the pH of the rhizosphere, which in turn influences the uptake of other ions, such as phosphates.
Plants deficient in N tend to have a pale, yellowish green colour (chlorosis), have a stunted appearance, and develop thin, spindly stems.

An oversupply of N degrades crop quality, resulting in undesirable colour and flavour of fruits, and low sugar and vitamin levels of certain vegetables and root crops. An oversupply can also cause the build-up of nitrates that are harmful to livestock in the case of foliage and to babies in the case of leafy vegetables. Growth-inhibiting environmental conditions (e.g. drought; dark, cloudy days; cool temperatures)can exacerbate the accumulation of nitrate in tissues because plant conversion of nitrate into protein is slowed. The leaching of excess nitrates from the soil can lead to environmental degradation of downstream water basins (Brady & Weil 2002).

Essentially all N fertilizers are produced from ammonia gas, with the only exception being a small amount of naturally occurring guano (bird droppings from South America) and sodium nitrate deposits. If not taken up by the crop plants or immobilized in soil, fertilizer N applied to crop fields may be lost by surface runoff, ammonia volatilization, nitrate leaching, denitrified as N_2 or N_2O, or lost as ammonia from foliage (Prasad & Power 1997).

Phosphorus (P)

Next to N, P has more widespread influence on both natural and agricultural ecosystems than any other essential element. Neither plants nor animals can grow without phosphorous. It is an essential component of adenosine triphosphate (ATP), as well as deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and of phospholipids, a critical component of cellular membranes (Brady & Weil 2002).

Adequate phosphorus nutrition enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, nitrogen fixation, flowering, fruiting (incl. seed production), and maturation. Root growth, especially development of lateral roots and fibrous rootlets is encouraged by phosphorus, as well as strengthening of structural tissues in cereal crops. Phosphorus deficiency is not as easy to recognize in plants as those of other nutrients, however, a phosphorus-deficient plant is usually stunted, thin-stemmed, and spindly, with dark foliage. Unless a much larger, healthy plant is there for comparison, those symptoms are hard to identify. In severe cases, phosphorus deficiency can cause yellowing and senescence of leaves, some plants are stunted and develop purple colours in their leaves and stems, even though this could also be related to other stresses, such as cold temperature. P deficiency also affects nodulation in leguminous plants, as well as the biological nitrogen-fixation process. Plant roots absorb P dissolved in soil solution mainly as phosphate ions (HPO_4^{2-} and $H_2PO_4^-$), as well as some organic compounds. The availability of P as either HPO_4^{2-} or $H_2PO_4^-$ depends on soil pH, from pH 3 to 7, $H_2PO_4^-$ prevails, whereas

from pH 7 to 12, HPO_4^{2-} dominates. Both anions are available in near-neutral soils (pH around 7) (Brady & Weil 2002, Gisi et al. 1997).

Inorganic P in soil is mostly present as compounds of Ca, Fe, and Al; Ca-phosphates dominate in neutral to alkaline soils, while Fe- and Al-phosphates dominate in acidic soils. When a water-soluble phosphate fertilizer such as super phosphate or ammonium phosphate is applied to soil, immediately after its dissolution the phosphate ions in solution react with Ca, Fe, or Al ions present in soil solution and are precipitated as insoluble compounds, or become adsorbed on the surface of clay particles, and thus very little of the added P is re-extractable with water. Phosphorus in organic molecules constitutes 30-50% of the total P in most soils, ranging from 5% to 95%. Despite the importance of organic P, its chemical nature has not been fully characterized. Organic P occurs in soil principally as phytates or related forms, nucleic acids and their derivatives, and phospholipids. Phytin is synthesized by plants and accounts for roughly 40% of the organic P found in soil. Organic P content depends upon a number of factors such as climate, vegetation, soil texture, land use pattern, fertilizer practices, drainage and irrigation, etc; a number of these factors are interdependent. In general, organic P in surface soils is a smaller fraction of total soil P in the warm regions than it is in the cool regions of the world. High clay soils have a greater percentage of their P in organic form than do sandy soils. In general, organic P tends to accumulate in surface soil because organic P is a part of soil organic matter. In the initial phase of pedogenesis most P in rocks is present as apatite, which is gradually brought into solution by chemical and biological processes, the P coming into soil solution is then reprecipitated as secondary inorganic phosphates or is utilized by microorganisms and plants, which after their death and decomposition make organic P available. Thus as pedogenesis proceeds, organic P accumulates (Plante 2007, Prasad & Power 1997).

There are three major aspects of phosphorus affecting soil fertility, namely (i) the total phosphorus level of soils is low, usually no more than one-tenth to one-fourth that of nitrogen (ii) phosphorus compounds commonly found in soils are mostly unavailable for plant uptake, often because they are highly insoluble, and (iii) when soluble sources of phosphorus, such as those in fertilizers and manures, are added to soils, they are changed to unavailable forms (i.e. fixed) and in time form highly insoluble compounds. Fixation reactions in soils may allow only a small fraction (10 to 15%) of the phosphorus in fertilizers and manures to be taken up by plants in the year of application. Therefore, some farmers apply two to four times as much phosphorus as is removed in the crop harvest, which, if repeated over many years, saturates the phosphorus-fixation capacity and builds up the level of available phosphorus in many agricultural soils. In that case, farmers need to apply little if any phosphorus-containing manure and fertilizers to these soils until soil phosphorus is drawn down to more moderate levels over a period of years. In many developing countries, such overuse of fertilizer P is not the rule, on the contrary, many soils lack the element to an extent that this is the first limiting factor in food-crop production, especially in sub-Saharan Africa (Brady & Weil 2002).

The principal environmental problems related to soil phosphorus are land degradation (caused by too little available phosphorus) and accelerated eutrophication (caused by too much P). Many highly weathered soils in the warm, humid, and subhumid regions of the world have very little capacity to supply phosphorus for plant growth, due to extensive losses of phosphorus during long periods of relatively intense weathering and partly due to the low availability of phosphorus in the aluminium and iron combinations that are the dominant forms of phosphorus in these soils. Another problem is phosphorus lost due to the clearing of intact forests for agricultural use (by timber clearing or fires), and the subsequent P loss in eroded soil particles, runoff water, and biomass removals (harvests). Within a few years, the system may lose most of the phosphorus that had cycled between the plants and the soils; the remaining inorganic P is largely unavailable for plant uptake. As P deficiency also affects the N-fixation in leguminous plants, the resulting N and P deficiency affects plant growth, the small and spindly plants can provide little vegetative cover to prevent heavy rains from washing away the surface soil, and the resulting erosion will further reduce soil fertility and

water-holding capacity. The increasingly impoverished soils can support less and less vegetative cover, and so the degradation accelerates (Brady & Weil 2002).

Potassium (K)

Of all essential elements, K is the third most likely to limit plant productivity. For this reason it is commonly applied to soils as fertilizer and is a component of most mixed fertilizers. The behaviour of K in the soil is influenced primarily by soil cation exchange properties and mineral weathering rather than by microbiological processes. Like P, it does not form any gases that could be lost to the atmosphere. Unlike P and N, it does not cause environmental problems when it leaves the soil system, it is not toxic and does not cause eutrophication in aquatic systems (Prasad & Power 1997, Brady & Weil 2002).

K is not actually incorporated into the structures of organic compounds, instead, it remains in the ionic form (K^+ in solution in the cell), or acts as an activator for cellular enzymes. K is known to activate over 80 different enzymes responsible for energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation in both plants and animals.

K is taken up by plants in large quantities. A portion of this K is leached from plant foliage by rainwater and returned to the soil, and a portion is returned to the soil with the plant residues. Thus, in natural ecosystems most of the K taken up by plants is returned , some is lost with eroded soil particles and in runoff water, and some is lost to groundwater by leaching. In agroecosystems, 1/5 to nearly all of the K taken up by plants is lost due to harvests (Brady & Weil 2002).

At any time, soil K is in primary minerals and nonexchangeable forms. K is present in soils in four different forms:

(i) Primary-Mineral K
K bearing minerals in soils are the feldspars (orthoclase, microcline) and micas (muscovite, biotite, and phlogopite). Primary mineral potassium in soils varies from 0.5 to 2.5% of the total soil K content.

(ii) Nonexchangeable or Fixed K
Nonexchangeable K is held between adjacent tetrahedral layers of micas, and intergrade minerals. Micas have K fixed in the interlayer spaces, the weathering of micas releases K into the soil. Due to the variation in binding strength, the rate of release of K from different micas differs. Because micas have their entire negative charge satisfied by K, the release of K results in the formation of secondary clay minerals such as illite and vermiculite, with accompanying gain of water or OH_3^+ and swelling of the lattice. Once this happens, K changes from a non-exchangeable form to an exchangeable form. Depletion of K from soil solution by plants of by leaching lowers the K concentration in solution and induces the liberation of interlayer, fixed K.

(iii) Exchangeable K
Exchangeable K is held in the exchange complex of 2:1 layer silicates. Thus soils containing smectite have more exchangeable K than those containing illite, which in turn have more than the soils containing kaolinite. The amount of exchangeable K in soils may vary from 40 to 600 mg kg^{-1} soil (Tisdale et al. 1985).

(iv) Soil-Solution K
Soil-solution K is the K present in soil solution. It may vary from 1 to 10 mg K kg^{-1} soil.

There is a continous transfer of mineral K to exchangeable K and fixed K to solution K; the process may reverse to the fixed-K stage under some soil conditions or when heavy K dressings are made. The release of exchangeable to solution K, as well as from nonexchangeable to exchangeable K, varies from soil to soil and depends much upon the dominant clay minerals present.

The amount of K fixed by a soil depends much upon its clay content. In general, the greater the clay content, the greater the K fixation. Illite, weathered mica, vermiculite, smectite, and interstratified minerals fix K, while kaolinite fixes very little. In acid soils, due to the presence of Al^{3+} and aluminium hydroxide cations and their polymers occupying the K-selective binding sites on clay minerals, less K is fixed than in soils with above-neutral pH (Prasad & Power 1997).

Where high yields of agricultural crops or timber are removed from the land, or where the content of weatherable K-containing minerals is low, the levels of exchangeable and solution potassium may have to be supplemented by outside sources, such as chemical fertilizers, poultry manure, or wood ashes. Without these additions, the supply of avaibalble K will likely be depleted over a period of years and the productivity of the soil will decline (Brady & Weil 2002).

Sulphur (S)

S is a constituent of the amino acids methionine, cysteine, and cystine; the vitamins biotin, thiamine, and B1 contain S, as do many protein enzymes that regulate activities such as photosynthesis and nitrogen fixation. S is essential for the three-dimensional shape of proteins that are the key to their catalytic action, as well as S being (with N) essential in the processes of protein and enzyme synthesis (Brady & Weil 2002, Prasad & Power 1997).

S deficiencies are most prevalent in areas where soil parent materials are low in sulphur, due to extreme weathering and leaching. Burning of plant biomass results in a loss of S to the atmosphere. Total S in soils may vary from a few to 1000 mg S kg^{-1} soil (0.1%); higher values can be encountered in problem soils such as saline and acid-sulfate soils. Sulfur in soils is present both in organic and inorganic forms. While inorganic forms are important because most of the S is taken up by plants as SO_4^{2-}, organic forms are important because they often make up the bulk of soil S. As S is an integral part of soil organic matter, total S is generally greater in fine-textured soils (Prasad & Power 1997, Brady & Weil 2002).

Organic S makes up over 90% of the S in surface layers of well drained, nonsaline soils. It is generally associated with proteins in plants and their residue when added to the soil. S is therefore as much an integral part of soil organic matter as N, and the N:S ratio in most non-saline soils falls within the narrow range of 6 to 8:1 (Tisdale et al. 1985).

Inorganic S in most soils is present as SO_4^{2-} ions associated with monovalent (Na, K) and divalent cations (Ca, Mg, traces with Cu, Mn, Zn, and Fe). Sulfate salts in the soil solution (i.e. soluble S) may be adsorbed onto soil colloids, or the salts may be present as insoluble compounds.

The content of soluble S is variable and depends on temperature (i.e. weather), that determines the rate of mineralization of soil organic matter; precipitation and soil water content, as heavy rains can lead to excessive leaching, a high water content decreases the S concentration in the soil solution due to dilution, and due to high evapotranspiration, S from lower soil layers moves upward by capillary action and increases the amount of S in the upper layers of soils; associated cations, as leaching losses are greatest when monovalent cations are associated with S; and the application of S containing fertilizers. A soluble-S content of 5 mg kg^{-1} soil is generally adequate for the growth of most crops (Prasad & Power 1997, Brady & Weil 2002).

SO_4^{2-} can be adsorbed on clay minerals by salt adsorption, 1:1 layer silicates such as kaolinite adsorbing more than 2:1 layer silicates. In calcareous soils, an important fraction of total S is Calcium sulphate coprecipitating with calcium carbonate, which is relatively unavailable to plants. Soils in arid and semiarid regions have large deposits of gypsum ($CaSO_4 2H_2O$). When mined and used for reclaiming sodic soils, gypsum also adds large amounts of S to soils (Prasad & Power 1997).

Calcium (Ca) and Magnesium (Mg)

Calcium and Magnesium are often referred to as secondary plant nutrients. As they are essential for all plants, they are also categorized as macronutrients.

Plants generally use Ca in amounts second only to N and K, it is present in the earth's crust in much larger amounts (3.64%) than Mg (1.93%). Highly weathered, coarse, sandy soils in humid regions may contain 0.1% total Mg and 0.1 to 0.3% of total Ca, while fine-textured, clay soils rich in 2:1 layer silicates may contain 0.7 to 3% total Ca, and often equal quantities of Mg. Values greater than 3% total Ca in soils indicate the presence of $CaCO_3$. Such soils are known as calcareous soils, which may contain less than 1 to more than 25% total Ca (Brady & Weil 2002, Prasad & Power 1997).

Ca in soils is derived from minerals such as Ca-feldspars, pyroxenes (augite), or amphiboles (hornblende). Calcite ($CaCO_3$) is the most important source of Ca in calcareous soils,; when present, dolomite ($CaMg[CO_3]_2$) also contributes to soil Ca. In arid and semiarid regions gypsum ($CaSO_4 2H_2O$) could be an important source of Ca. Magnesium in soils is derived from minerals such as biotite, phologpite, hornblende, olivine, and serpentine. In calcareous soils dolomite, when present, is an important source of soil Mg. In arid and semiarid regions, substantial amounts of mineral epsomite ($MgSO_4 7H_2O$) may be present and may contribute to soil Mg. Both Ca and Mg are present in nonexchangeable and exchangeable forms and in soil solution; the latter two forms remain in a dynamic equilibrium. Both their availability to plants is tied to soil acidity and liming. Exchangeable Ca in soils can range from <25 mg kg^{-1} to more than 5000 mg kg^{-1}, exchangeable Mg in soil solution may range from 50 - 120 mg L^{-1}. Availability of Ca^{2+} and Mg^{2+} depends on the type of clay minerals present (soils having 2:1 layer silicates have higher CEC and can thus retain larger amounts of Ca or Mg); CEC of soils and the saturation of CEC with Ca^{2+} and Mg^{2+}; soil pH (in acid soils, Ca level may be too low to be available to plants); and the ratio of Ca^{2+} and Mg^{2+} to other cations in soil solution (Brady & Weil 2002, Prasad & Power 1997).

Ca is stored in woody tissues in plants, is necessary for cell elongation and division, membrane permeability, and the activation of several enzymes. It is taken up almost exclusively by young root tips. Mg is taken up in smaller amounts than Ca. Mg is a component of the chlorophyll molecule and is therefore involved with photosynthesis in plants. It also plays critical roles in the synthesis of oils and proteins, as well as the activation of enzymes involved in energy metabolism (Brady & Weil 2002).

1.2.2.2.2. Micronutrients

Of the 18 elements known to be essential for plant growth, 9 are required in such small quantities that they are called micronutrients or trace elements. These elements are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni), cobalt (Co) and chlorine (Cl). Despite the terms micronutrients and trace elements, these nutrients are as important for plant growth as macronutrients, the effect of micronutrient deficiency can be very severe in terms of stunted growth, low yields, dieback, and even plant death. The trend toward high-analysis fertilizers has reduced the use of impure salts and organic manures, which formerly supplied significant amounts of micronutrients, thus more attention is paid toward micronutrient deficiencies (Brady & Weil 2002).

Mn is the key element that activates the enzyme system responsible for splitting the water molecule in the photosynthesis process, and is thus ultimately responsible for the presence of oxygen in the atmosphere, and provides O_2 to the poorly ventilated interior soil pores. It also plays an important role in the fixation of N. Fe is also involved in the process of photosynthesis in plants (important for chlorophyll formation), present in several enzymes, and in the oxidation-reduction reactions of soils. Unlike other biological systems, especially animals, Fe is only secondary in importance in soils, compared to Mn (Brady & Weil 2002, Prasad & Power 1997).

Cu, like Fe, participates in oxidation-reduction processes in plants, and is associated with enzymes that can hydroxylate monophenols, oxidizing them to create complex polymers such as lignin and melanin; detoyify superoxides; oxidize amines; terminate electron transfer chains. Zn is involved in a diversity of enzymatic activities such as auxin metabolism, dehydrogenases, phosphodiesterase, proteinase, and peptidase enzymes; promotes growth hormones and starch formation; promotes seed maturation and production. Zn deficiencies are more prevalent than those of Cu and are virtually global in nature. Zn, as well as Cu are phytotoxic over a certain concentration (Alloway 1995, Brady & Weil 2002, Prasad & Power 1997).

Boron activates certain dehydrogenase enzymes; facilitates sugar translocation and synthesis of nucleic acids and plant hormones, and is essential for cell division and development. Mo is present in nitrogenase and nitrate recuctase enzymes, essential for nitrogen fixation and nitrogen assimilation. B is highly mobile in soils (in contrast to being highly immobile in plants). Both micronutrients are taken up by plants as anions (Prasad & Power 1997, Brady & Weil 2002).

Ni is essential for urease, hydrogenases, and methyl reductase; needed for grain filling, seed viability, iron absorption, and urea and ureide metabolism. Co is essential for the fixation of nitrogen and found in vitamin B_{12} (Brady & Weil 2002).

Cl is taken up by plants as the chloride ion (Cl^{-1}), it has biochemical, as well as osmoregulatory, functions in plants. It is involved in the splitting of water molecules in photosystem II of photosynthesis. Several enzymes such as ATBase, alpha-amylase, and asparagines synthetase require Cl^- for stimulation or activation. It is also involved in osmoregulatory functions, and thus in stomatal opening. Cl^- occurs in soils as soluble salts such as NaCl, $CaCl_2$, and $MgCl_2$ (Prasad & Power 1997).

Sources of micronutrients vary markedly from area to area, but they are mostly found, in varying quantities, in igneous rocks, whereas chlorine is added to soils in considerable quantities each year through rainwater or irrigation water. Organic mater is an important secondary source of some of the trace elements, like Cu. Soil pH, especially in well-aerated soils, has a decided influence on the availability of all the micronutrients except chlorine. pH can influence availability to deficiency or toxicity, as well as parent material. Trace elements are common constituents of industrial and domestic wastes that are often applied to soils (Brady & Weil 2002).

1.2.2.2.3. Beneficial Elements

As Paracelsus appropriately stated “Sola dosis facit venenum” beneficial elements have a potentially positive effect on plants, but can be harmful in higher dosages. In addition to the elements considered essential for plant growth (see above, and C, H, and O), a number of other elements have been reported to be essential, or at least beneficial, by way of increased growth or improved resistance to diseases or pests for some species. These elements include Na, Si, La, Ce, V, and Al, and are considered beneficial plant nutrients.

Na is involved in several enzyme reactions; can partly substitute for K in several species; can overcome the impairment of carbohydrate transport associated with Ca deficiency, and is especially important for halophytes, glycophytes, blue-green algae. Si is necessary for the normal growth of some crops, and may decrease the solubility of Al and heavy metals that may otherwise be present in toxic levels. Al, when not present in toxic levels but in abundant amounts, is reported to reduce the toxic level for uptake of Cu, P, and Zn. V is reported to stimulate growth and nitrogen synthesis in some microorganisms. La and Ce in fertilizers have been reported to increase yield and improve crop quality, however, no evidence of essentiality has been produced (Prasad & Power 1997).

1.2.3. Soil organic matter (SOM)

1.2.3.1. Non-living component of SOM

Soil organic matter (SOM) plays an important role in the functioning of the ecosystem. Even though it is a minor soil component, compared to the total soil mass, it has a major impact on obligatory ecosystem processes, like biogeochemical reactions for providing plant nutrients and contribution to the structural development of soils (Tate 1992).

The non-living component of SOM makes up as much as 98% of the total soil organic C. The ultimate source of all soil organic matter is carbon fixed through photosynthetic reactions (CO_2 fixation by plants), a small part is through input from autotrophic soil bacteria. Anthropogenically produced organic substances generally are insignificant from the view of total mass, but their effects on ecosystem function and stability can in many cases be quite dramatic. An organic substance entering the soil ecosystem faces three ultimate fates:

(1) it may be totally mineralized and thereby returned to the carbon dioxide and mineral nutrient pool
(2) it may be assimilated into microbial biomass; or
(3) the organic matter may be incorporated either unchanged or partially modified into the more stable soil humic fraction, i.e. humified.

The rates of these various conversions depend upon the interactions of the soil microbial, nematode, and microarthropod communities, a variety of chemical reactions, as well as the chemical and physical parameters of the given site. In soils affected by desertification, the decline in plant cover leads to a reduced litter production and thus a reduced amalgamation with upper soil particles, which leads to a decline in soil organic matter; this negatively influences soil aggregate stability and leads to a destabilized soil structure, which in turn results in soil compaction, which can lead to completely sterile soils (Tate 1992, Le Houérou 2002, Theng et al. 1989).

The nonliving component of SOM may be subdivided into macroorganic matter and humus. Macroorganic matter is often the smaller of the two nonliving compartments, commonly containing 10-30% of the total soil organic C. It consists largely of plant residues in varying stages of decomposition, capable of being retained on a 250µm sieve. The quantity of organic material retained within the soil matrix is the difference between total biomass production and decomposition, and thus depends on a variety of chemical and physical factors described in this chapter, as well as on the plant material. Essentially, any compound found in living plant and animal cells can be detected in the soil organic fraction, there are materials that consist of readily decomposable components and a fraction that is more resistant to biodegradation. Readily decomposable biochemicals may enter the soil system in exogenously supplied biomass, such as plant or animal remains, or be formed *in situ* through the activity of the microbial community. These substances provide the bulk of the carbon, nitrogen, and energy sources for the microbial community, they may be contained within intact cells or occur free within the soil solution. Variations in the decomposition rate between various ecosystems result from the physical or chemical limitations to the microbial

community. These rates generally correspond to the capability of the soil microbial community to adapt or function in the ecosystem. This microbial activity varies with the soil moisture level, redox potential, pH, presence or absence, or inhibitors, and so on (Tate 1992, Theng et al. 1989).

The dead organic matter remaining after separation of the macroorganic matter or light fraction is commonly referred to as humus and consists of nonhumic and humic substances. The former constituents make up about 30% of humus and comprise well-defined classes of organic compounds, such as carbohydrates, lipids, organic acids, pigments, and proteins. Soil humic substances consist of three major classes of chemicals, generally categorized as humic acids, fulvic acids, and humin. They are differentiated by their solubility in alkaline and acid solutions, due to the difference in molecular complexity of the substances. The definitions of these acids are merely operational in that no sharp boundary exists between these fractions in terms of physico-chemical properties. Soil physical and chemical conditions affect the structure of humic substances contained therein. Both temperature and soil pH affect the chemical composition of the humic acids (Tate 1992, Theng et al. 1989).

Litter also consists of dead plant (and some animal) matter. Because it lies on the soil surface, strictly speaking litter is not a constituent of SOM. Because of its importance in nutrient cycling and humus formation, however, the litter layer is considered an integral part of the soil profile (Theng et al. 1989).

1.2.3.2. Living components of SOM

The living component of SOM, which rarely makes up more than 4% of the total soil organic C, may be subdivided into three compartments: plant roots (5-10%), macroorganisms or fauna (15-30%), and microorganisms (60-80%).

Although roots comprise a minor constituent of the living component, their passage and distribution through soil has greater influence on soil processes than their pool size suggests. Plant roots can affect soil structure. Depending on the diameter of the roots, the length and the lateral and vertical distribution, they can modify the compactness of the soil and exploit different soil pores. Roots with a small diameter can penetrate rigid soil volumes, whereas roots with larger diameter cannot do this. Nutrient availability strongly influences this. At nutrient shortage, the root system is strongly enlarged to enhance nutrient capture whereas when there is a surplus of a particular element in the soil, roots are stunted. (Theng et al. 1989, Marschner 1995, Ernst 2004).

Macroorganisms, soil invertebrates are divided into three size classes: microfauna, which include protozoa and nematoda; mesofauna, such as enchytraeidae and acari; and macrofauna, exemplified by earthworms and termites (Luxton & Petersen 1982). The composition of macroorganisms is strongly influenced by climate. Although some soil invertebrates can digest lignin and polysaccharides of plant origin and so act as primary decomposers, macroorganisms contribute much less than microorganisms to the total soil respiration. Soil fauna does, however, play a primary role in comminuting surface litter, incorporating the fragmented products into the soil, and converting it into excreta. Generally, 20-40% of the annual litterfall is processed in this way. Besides facilitating and accelerating the decomposition of plant residues by microorganisms, soil fauna contribute to nutrient cycling by grazing on the microflora as well as by mixing soil materials within the profile (Theng et al. 1989).

The soil microbial biomass is an easily affected pool of organic matter and comprises approximately 1-3% of total soil organic matter, and consists essentially of bacterial, fungal, algal, protozoan and actionymycete populations. From the view of ecosystem function, the microbial community is a small but highly significant portion of soil organic matter. The soil microbial biomass acts as a source and sinks of the plant nutrients and regulates the

functioning of the soil system. Plant cover influences the quality and quantity of organic matter and thus influences the levels of soil microbial biomass. The benefit of organic matter to the soil ecosystem is primarily derived from the active metabolism of the soil organic matter by the soil microbial community. The nutrients contained within plant biomass entering the soil ecosystem are mineralized for plant assimilation by the microbial community. Nutrients derived largely from the soil mineral formations can be solubilized as a result of the direct microbial metabolic activity or indirect action of microbially synthetsized extracellular enzymes. The specific respiratory activity of soil microbial biomass has been used to analyze the effects of environmental factors, crop management, and organic inputs on the microbial populations. It is sensitive to the changes in the quantity and quality of soil organic matter and ecosystem stability. Therefore, soil management influences soil microorganisms and soil microbial processes through changes in the quantity and quality of plant residues entering the soil, their seasonal and spatial distribution, the ratio above- and below-ground inputs, and changes in nutrient inputs (Kaur et al. 2000, Kandeler et al. 1999, Christensen et al. 1994, Tate 1992).

A fraction of soil enzyme activity is associated with living microorganisms, while other fractions are associated with abiotic components, which are truly extracellular. The latter's enzyme activities produces decomposition and nutrient cycling when under the influence of edaphic factors, such as temperature, moisture and nutrient availability. Temperature and moisture indirectly affect enzyme activities by influencing microbial growth and substrate availability (Li & Sarah 2003). Soil microbial activity and the size of microbial biomass have been shown to depend nutrient availability and is strongly influenced by fertilization and the presence of arbuscular mycorrhizal fungi. Soil microbial respiration and biomass, especially soil enzymes are influenced by the P status of a soil. Phosphorus addition increases microbial respiration in soils with low P contents, but not in soils with high P contents, and can even have an inhibitory effect on microbial respiration and substrate induced respiration in some soils (Raiesi & Ghollarata 2006).

Detailed studies on the effects of single alterations of abiotic soil factors on soil microorganisms are missing as well as on temporal dynamics of microbiological properties. The substantial composition of the solid phase is important for characterizing the microbial habitat, and close correlations between soil organic matter (SOM) and microorganisms have been observed (Lorenz & Kandeler 2006).

1.3. Research concept

As arable land in Egypt is under constant threat of degradation due to environmental as well as anthropogenic influences, and as on the other hand land reclamation projects have become very important in order to meet rising demands due to the increasing population, two sites were chosen for a soil quality assessment. Fields from the Nile Delta, which have been cultivated over the centuries were compared to a site belonging to a land reclamation project in Upper Egypt (Sohag).

1.3.1. Research hypothesis

The following hypotheses were tested:

- Due to the missing floods since the Aswan high dam, and an increase in production, soil quality in the Nile Delta is slowly degrading
- Emulation of previous Nile flooding and sediment deposition in newly reclaimed lands may buffer the impact of land use in comparison, despite the harsher environment.

1.3.2. Research objectives

The general objective of this thesis was to elucidate

- the influence of land use on soil quality properties, combining mineralogical as well as chemical and biological parameters
- how these parameters are biased by aridity and salinity
- and to identify mechanisms and processes facilitating land degradation in order to establish diagnostic tools
- To assess the sustainability of a land reclamation project

To meet this objective a three tiered approach was selected, combining soil physical, soil chemical and soil biological parameters. For a description of methods used, please refer to Chapter 2, Material and Methods.

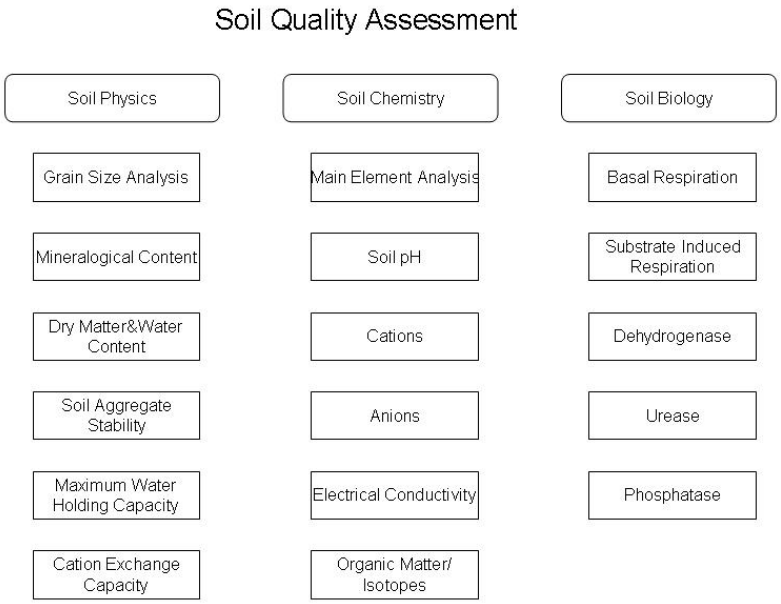

Figure 1.2.2.: Overview of parameters for the assessment of soil quality.

2. Material and Methods

The following chapter provides a description of the two experimental sites (Nile Delta and Sohag), background information on the cultivation of the fields and a description of the analytical methods used. Please note that personal information provided by the farmers is printed in smaller font.

2.1. Sampling Area

In order to be able to compare soils of a land reclamation project with extensively used soils, samples were taken from February – early June 2001 from the site in the Nile Delta, and from November 2001 – March 2002 from the site in Sohag, Upper Egypt. The sites were chosen according to feasibility, accessibility, as well as legal reasons, as access to the Toshka project was denied at the time of the study. The farmers were found through Prof. Abdel Razak of Al-Azhar University, and Prof. Abo-Dahab of Sohag University. Once their permission (as well as that of the local police in the areas) was granted, sites were investigated and chosen due to their choice of crops, which made a comparison of the fields possible.

2.1.1. Nile Delta:

Samples were taken from two fields belonging to Mohamed M., at that time employee of the Regional Centre for Mycology and Biotechnology of Al Azhar University in Cairo as well as a farmer, next to a small town called Kafr Alin, next to the city of Birket El-Sab, in the north-eastern part of the Governorate of Monufia (or Minufeya).

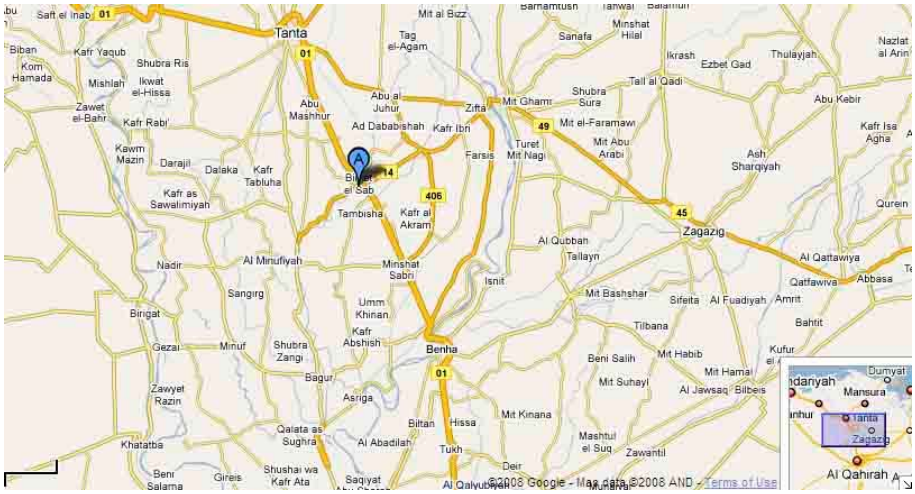

Figure 2.1Map of Monofia Governorate, blue sign indicates Birket el Sab (Birket el Sab, Google Maps 2008)

2.1.2. Upper Egypt – Sohag:

Samples in Sohag were taken from fields at the edge of the fertile Nile Valley, close to the City of Sohag in Upper Egypt

Figure 2.2.: Map of Sohag Governorate, red indicates Sohag city centre (Sohag-Google Maps 2008)

The fields in Upper Egypt were part of a desert reclamation project that had been started in 1991, approximately 10 years before the first sampling took place, the area around the fields consisted of similar fields. New fields were about to be created the same way as the sampling site:

The fields belong to Farmer Omar A., a full-time farmer, who had been cultivating the fields since their creation (see below).

Land Reclamation in Sohag

Soil from building sites along the Nile Bank was first cleared of stones and rocks, then mixed with an equal amount of mud from irrigation channels, and placed in heaps on desert sand. The sand had been flattened in order to provide an even surface, and stones had been taken out mechanically. The soil was then spread in an even layer of approximately 1m in depth, irrigated and ploughed and then planted.

Figure 2.3.: Area about to be reclaimed, close to the experimental site: Soil from building sites close to the Nile bank had been brought to this area, was about to be mixed with mud from irrigation channels and to be spread out evenly.

According to Omar A., the farmer, it had not been necessary to add any more soil since the creation of the fields. According to him, whenever the soil became too muddy, they would add “Red sand”. “Red sand” is very light sand that is transported by wind from the desert mountains that is naturally piled up, collected by the farmers and then spread evenly on top

of the soil surface. According to him, they would use approximately 3-4 m^3 for his 5.5 feddan (5.5 acres).

2.2. Geological Background of Sampling Area

Nile Delta:

At the end of Eocene and during Oligocene, the area was subjected to tectonic disturbances which resulted in the rise of the land and the retreat of the seashore to the north of Cairo. The Mediterranean fault system, as well as the Gulf of Suez and Red sea fault system are a result of that Paleocene tectonic disturbance. During Middle Miocene time up to Tortonian, the northern part of Egypt was an embayment, bordered in the south and southwest by tectonic highs represented by cliff of Cretaceous and Eocene age. A thick sequence of marine shale, clay and mud were deposited by transgression of the sea. A Pre-Middle Miocene uplift continued into late Miocene, after which the sea regressed towards the north beyond the coast of the Delta. As a result of this tectonics, land tilted towards the east, resulting in intense alleviation by streams running from the surrounding highs in the south, SE and west, carrying sediments to the semiclosed basin. During the Upper Miocene, maximum sea regression took place, leaving marginal lagoons spread on the northern part of the present Delta (El Kashouty 2001).

Sohag:

The modern flood plain, consisting of the fertile silt layers of agricultural land, lies on the eastern and western banks of the Nile. Its elevation ranges from about 3 to about 5.5. meters above the modern water level of the Nile (controlled by the Aswan High Dam). The width of the flood plain ranges from less than one kilometre in some parts of the Nile Valley to a few kilometres in the study area of Sohag. Neogene and Quaternary sediments cover low terraces and small hills beyond the cultivated land of the flood plain along the eastern and western banks of the Nile. The classic Upper Cretaceous-Lower Tertiary sequence starts from the oldest rock unit (Nubian Sandstone) in the southern part of the Nile Valley to the youngest rock unit (Thebes Formation) in the northern part (Osman 1996, Osman & Kurzweil 2006)

Quaternary sediments of the Nile valley (after Said 1990):

The Nile trough is filled with alluvial sediments which are divisible into five units each of which is unique with regard to its texture, structure and mineral composition. Each of these units seems to have been formed by a river system which was unique with regard to its sources, competency and regimen. The Nile can be conceived as having passed through five main stages since its valley was cut down in late Miocene time. Each of these stages was characterized by a master river system. Toward the end of each of the first four stages (the last is still extant) the river seems to have declined or ceased entirely to flow into Egypt.

The first of the rivers, the Eonile, was a late Miocene feature which cut its course to a great depth in response to the lowered base level of the desiccating Mediterranean. It formed a canyon longer and deeper than the Grand Canyon, Arizona. In upper Egypt the with of the Eonile canyon ranges from 2 to 20km, and the thickness of the riverine sediments ranges from 170 to 900m. In the delta region, the thickness exceeds 3km in the extreme northern parts. Several water falls seem to have blocked the Eonile; a significant one was at Maghagha which formed a constriction along the path of the Eonile. The deposits of the Eonile are known only in the subsurface in the north Delta embayment. They are made up of a lower unit of coarse-grained sands and gravels derived from the eroded Cretaceous and Eocene rocks of Egypt (the Qawasim) and an upper unit of evaporates (the Rosetta) which is correlated with the evaporate suite recorded beneath the bottom of the modern

Mediterranean. The canyon was transgressed by the advancing Mediterranean as it started filling up during the early Pliocene. There is evidence that this ingression extended inland in the form of an elongate gulf up to the latitude of Aswan. In the north, with the rise in sea level, the waters overflowed the banks of the canyon and covered the peripheries of the Nile and delta (Kom El Sheluf formation). The effect of fresh water on the marine sediments of the gulf increased drastically in late Pliocene time converting it first into an estuary and then into a veritable river channel. The sediments of this river, the Paleonile, consist of a long series of interbedded red-brown clays and thin fine-grained sand and silt laminae which crop out along the banks of the valley and many of the wadis which drain into it. The sediments are also known from the subsurface in practically all the boreholes drilled in the valley and delta (Kafr El Sheikh formation). The Paleonile sediments make about 20% of the section of riverine deposits of the valley and delta. By the end of Paleonile sedimentation, the Eonile canyon was completely filled up and an immense wedge of delta front sediments filled part of the embayment which lay in front of the river. The northern part of the modern delta, therefore, extends beyond the continental margin. It started forming during the late Pliocene in the embayment which lay in the shadow of the elevated southern part of the delta. The lithology and mineral composition of the Paleonile sediments indicate that they must have been derived from areas receiving sufficient precipitation and having an effective vegetation cover. The absence of central African freshwater faunal elements in these beds suggests that these sediments must have been largely derived from Egypt, probably from highlands in the Eastern Desert. This points to extremely wet climates.

The advent of the Pleistocene epoch in Egypt was marked by dramatic events in the most important of which, relative to their impact on the history of the Nile, were those related to climate and tectonism. The advent of the Pleistocene brought to Egypt a pattern of aridity that set the tone of the climate prevailing in Egypt, with minor fluctuations, throughout the Pleistocene. The earliest Pleistocene was an episode of great aridity in which Egypt was converted into a veritable desert. Not only did aridity set over the country, but the Paleonile stopped flowing into Egypt. This long episode of aridity was interrupted by the intrusion of a highly competent river, the Protonile, in the Nile valley. The deposits of this river are made up of cobble and gravel-sized sediments composed of quartz and quartzites (Idfu formation). These sediments seem to have been derived from deeply leached terrain and from local sources.

At a later time during the early Pleistocene a short pluvial occurred during which the conglomerates of the Armant formation were deposited. This was followed by an episode of spring activity and the deposition of bedded and/or massive tufas. These tufas are associated with thick talus breccias which accumulated during an episode of high seismicity along the piedmont slopes of the bounding cliffs (Issawia formation).

The Protonile was succeeded by two other rivers, the Prenile and the extant Neonile. The deposits of each of these rivers are distinct in lithology, stratigraphic relationships and mineral content. They are separated from each other by an unconformity and a long recession. The deposits of the Prenile are made up of massive cross-bedded fluvial sands interbedded with dune sands (Qena formation). The mineral composition indicates that the Egyptian Nile was connected for the first time with the Ethiopian highlands across the elevated Nubian massif by way of a series of cataracts.

This connection seems to have been severed by the middle Pleistocene when the channel of the river was occupied by ephemeral rivers depositing polygenetic conglomerates derived from the uncovered basement complex of the Red Sea hills. During this crisis, which lasted probably more than 200.000 years, a hyperarid phase interrupted this period during which time the Nile flowed from the south depositing silts which are indistinguishable from those of the modern Nile. These silts are named Dandara formation (= α Neonile silts). The conglomerates below and above these silts are called Abbassia I and II respectively. Previously only the generation of conglomerates below the Dandara silts had been

recognised and given the name Abbassia. The Abbassia conglomerates were deposited in a humid interval, the Abbassian I and II respectively. They represent conspicuous horizons in the Nile sequence. The composition, thickness and lithology of the gravels of these conglomerates indicate deposition during short wet intervals when winter-season cyclonic cloud bursts were intense and much more frequent than at present. The Abbassia II conglomerates are rich in archeological materials of Acheulian age.

The deposits of the last of the rivers, the Neonile, which is still extant, are indistinguishable from those of the present-day river. The African connection was resumed. The Neonile is a humble successor of the Prenile. Its harbingers occurred during the arid phase which interrupted the Abbassian Pluvials when the Dandara (α Neonile) silts were deposited. Since that time and for a long period the floods seem to have been erratic; only during a few intervals were the floods high enough to leave behind thin silt terraces. Most of the time the floods were smaller than usual and the Nile was lowered down to levels which cannot be determined. The recessional deposits which followed the Abbassia II gravels, named the Korosko formation, include the deposits of two major pluvials during which great geomorphological changes took place over the valley. In the earlier Pluvial (Saharan I) Mousterian remains become abundant. In the second pluvial, the Saharan II Aterian sites are recorded. Two or more silts occur in the midst of the recessional deposits. This long recessional period was followed by three aggradational phases which were interrupted by minor recessional episodes. The aggradational deposits are named β, γ, and δ Neonile. These younger Neonile deposits are represented by massive structured silts with interfingering dune sand. The lowermost β silt carries late middle Paleolithic artefacts of the Khormusan tradition. It is exposed along the Nubian Nile which has been downcutting its channel since its inception and is buried beneath the modern silts of the aggrading downstream Nile. As the Nubian lands drowned under the rising waters of the High Dam, the only location where it is still preserved is in Wadi Kubbaniya to the northwest of Aswan. The succeeding γ Neonile deposits are recorded in many areas in upper Egypt and form a compley with units are now believed to form one major aggradational cycle with minor recessional intervals. The deposits carry late Paleolithic artefacts and are dated between 21.000 to 12.000 BP. The cycle is known to have been terminated by a series of high floods. The δ Neonile silts are the deposits of the youngest of the aggradational cycles of the Nile. They started to form about 10.000 BP and are separated from the underlying silts by recessional deposits which belong to the Nabtian pluvial.
The α Neonile silts (the Dandara or the older Neonile deposits) lie unconformably over the Abbassia I gravels. Their age is unknown; the archaeology points to a pre-Acheulian age (probably 400.000 BP).

In conclulsion it can be stated that the connection of the Nile with its African sources is new. The earliest Niles derived their waters from local sources, the Red Sea range and the Nubian and southwest Egyptian highs. It was only during the middle Pleistocene that the first African connection occurred. It is almost certain that the Ethiopian connection preceded the equatorial African connection, the White Nile formed a series of interiorly-drained lakes until relatively recently (Said 1990).

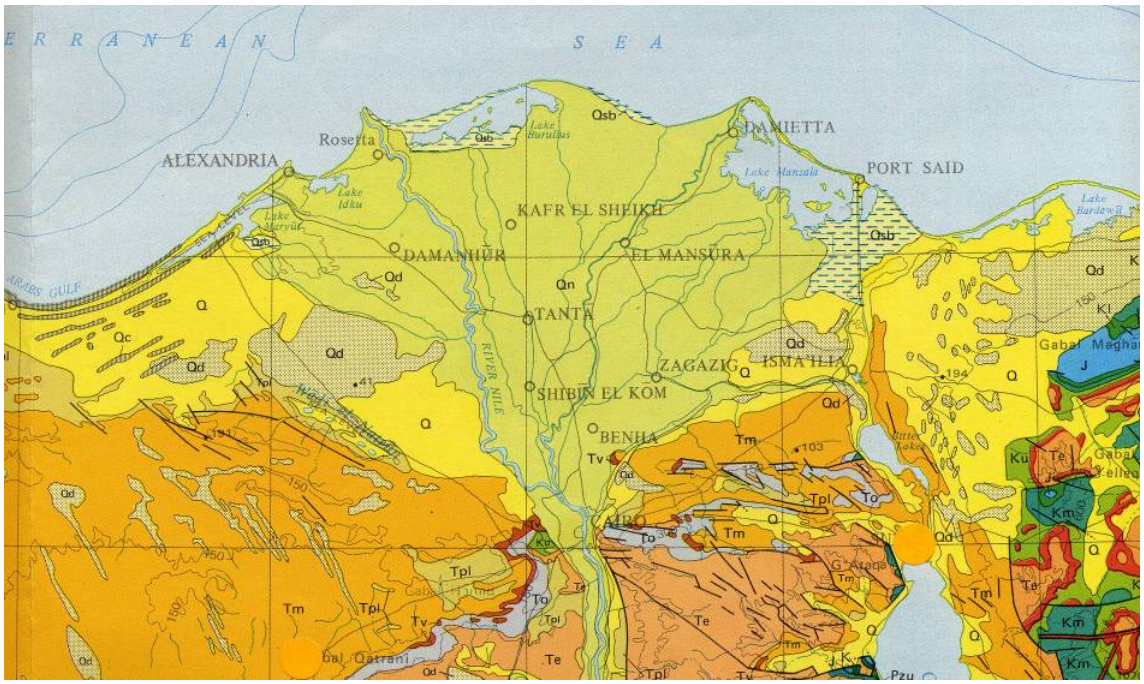

Figure 2.4.: Geological Map of the Nile Delta. Qd - Sand Dunes, Qsb - Sabkha Deposits, Qn - Nile Deposits, Q - Undivided Quarternary - wadi and playa deposits, raised beaches and corals of the Red Sea coast, Qc - Calcarenite Bars - along the Mediterranean coast, T - Tertiary, K - Cretaceous, J - Jurassic, P – Paleozoic, 1:2.000.000 (CONOCO 1987)

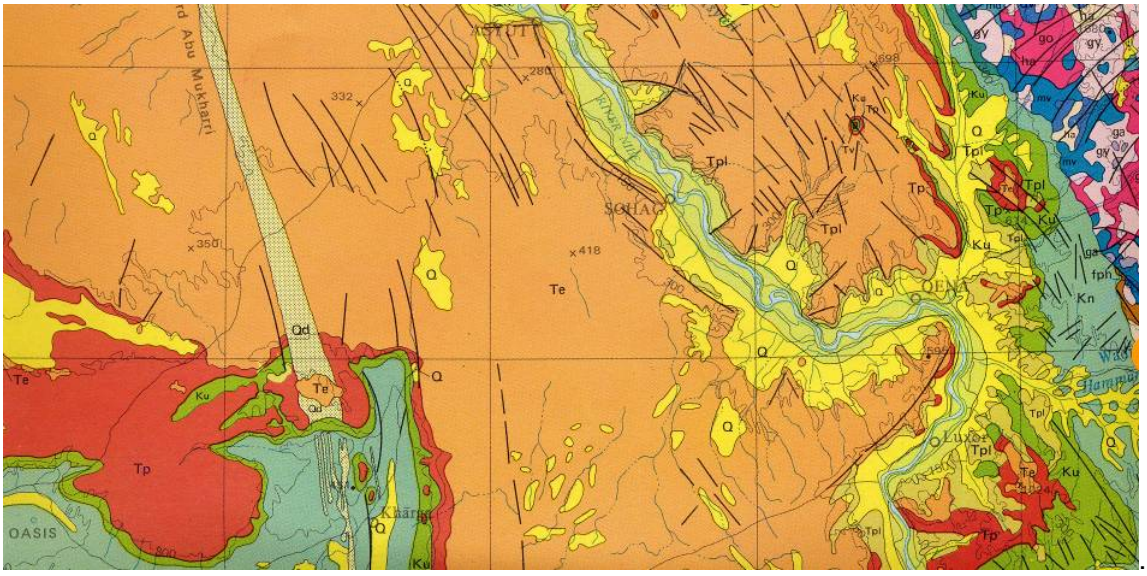

Figure 2.5.: Geological Map of Sohag. Qd - Sand Dunes, Qsb - Sabkha Deposits, Qn - Nile Deposits, Q - Undivided Quarternary - wadi and playa deposits, raised beaches and corals of the Red Sea coast, Qc - Calcarenite Bars - along the Mediterranean coast, T - Tertiary, K - Cretaceous, J - Jurassic, P – Paleozoic, Pr – Precambrian, 1:2.000.000 (CONOCO 1987)

2.3. Climate of Experimental Sites

Nile Delta:

The following graphs show the mean daily minimum and maximum temperature, mean precipitation for the city of Tanta, approximately 10 km north-west of Birket El-Sab:

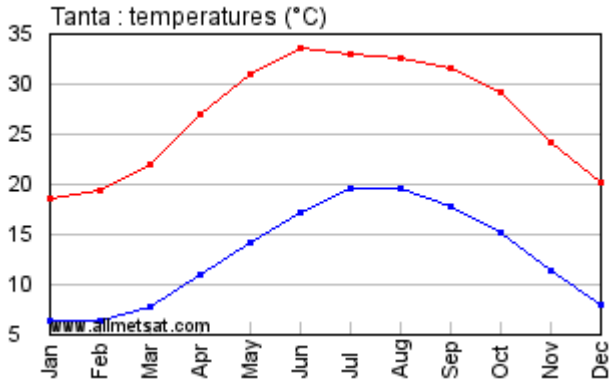

Figure 2.6.: Mean daily maximum (top) and minimum (bottom) temperature from January to December, Tanta, Nile Delta, Egypt (Allmetsat 2008a)

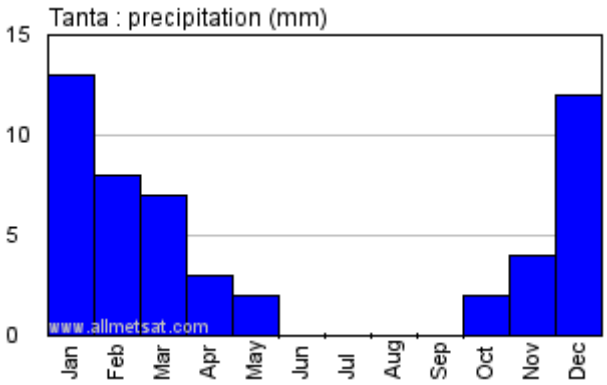

Figure 2.7.: mm precipitation from January to December, Tanta, Nile Delta, Egypt (Allmetsat 2008a)

Climate:

The following graphs show the mean daily minimum and maximum temperature, mean precipitation for the city of Sohag, Upper Egypt:

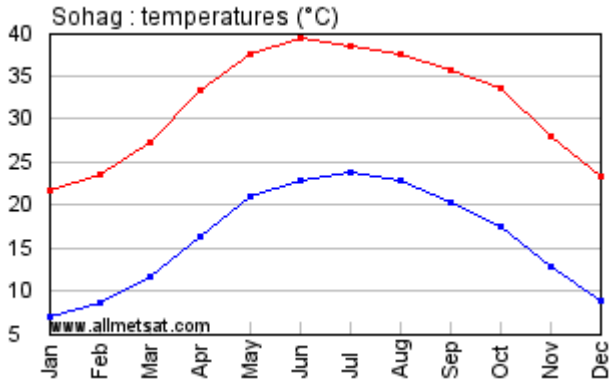

Figure 2.8.: Mean daily maximum (top) and minimum (bottom) temperature from January to December, Sohag, Upper Egypt, Egypt (Allmetsat 2008b)

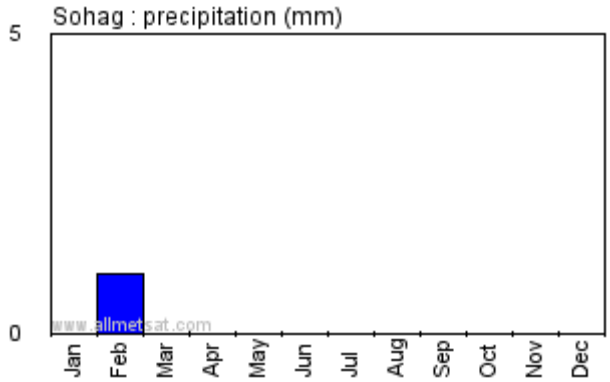

Figure 2.9.: mm precipitation from January to December, Sohag, Upper Egypt, Egypt (Allmetsat 2008b)

2.4. Agriculture

2.4.1. Crops

2.4.1.1. Cotton (*Gossypium sp. L., Malvaceae*)

In nature, *Gossypium hirsutum* is a perennial shrub that grows up to 1.5m height, however, cotton is cultivated as an annual.
Egypt's dry climate and the abundance of water are ideal for cotton production, which started in the early 19th century. Egypt is the biggest producer (next to the U.S.A) of *Gossypium barbadense L.*, a cotton variety of very high quality due to fiber length, fiber stability and spinnability (Krenz 1999).
For the past 150 years, cotton has been planted the same way: trenches are dug, with an elevation of approximately 30 cm, 60-70 cm apart, running east-west, thus providing maximum sunlight for germination. Seeds are planted at the top third of the dykes, so that plants are not affected by the salinisation of the soils due to water evaporation. Fields are irrigated every 2 weeks, by flooding the trenches with water (von Boguslawski 2002).

2.4.1.2. Berseem (*Trifolium alexandrinum L.*, *Fabaceae*)

Berseem clover is a straight growing, non-reseeding annual legume with oblong, slightly hairy leaflets without a watermark. It has hollow stems and a short taproot. Flowers are yellowish white, self-sterile, and clustered in dense elliptical heads about 1 in long. Each floret produces one roughly-spherical yellow seed. The most common varieties of Berseem in Egypt are called Miscawi, Saidi and Fahl, of which Miscawi is the most common one (Graves et al. 1989). Berseem is supposed to be of Mediterranean, Middle Eastern and Indian origin (Duke 1981). It tolerates loam to clay salts and moderate salinity (Graves et al. 1987)

2.4.1.3. Wheat (*Triticum aestivum L., Poaceae)*

The centre of origin of the species is the fertile crescent (Levant) in the Middle East, from where it has spread all over the world. It is a cultivated grass that is cultivated world wide, second only to maize. Wheat is a major annual crop of temperate regions and is considered a primary source of calories for the human race and animals (Snape&Pankova 2007)

2.4.2. Fields

Nile Delta:

The two fields were right next to each other, facing North-East, each field the size of half a feddan (approximately half an acre). According to Mohamed M. the farmer, the crops were planted according to a crop cycle issued by the Ministry for Agriculture, Cairo at the end of the 1990s (Mohamed M. 2001, personal information). The farmer was interviewed with the help of colleagues from the Regional Centre for Mycology and Biotechnology, Al Azhar University, Cairo.

Cotton (*Gossypium sp.*) Field:

According to the farmer, the preceding crop on his cotton field was Berseem (Trifolium alexandrinum). After the harvest, the field was ploughed thoroughly, the soil was then left to dry (he called this procedure “Mix and Dry”), then cotton (Gossypium sp.) seeds were sawn in rows. This took place just before the first sampling (January 2001), by the time of the 5th sampling (10th June 2001), cotton had been harvested, the soil ploughed and left to dry, to be planted with Berseem in due course.

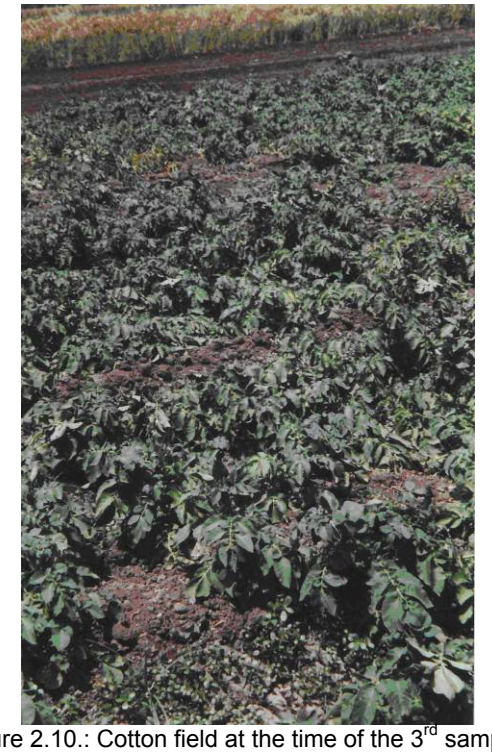

Figure 2.10.: Cotton field at the time of the 3rd sampling

Berseem (*Trifolium alexandrinum*) Field:

The field adjacent to the cotton field was planted with Berseem clover (Trifolium alexandrinum), also called Egyptian clover, a kind of Clover predominantly used as feed for domestic animals (Barzegar et al. 2006). Berseem is cut every 2-3 weeks, in order to feed the animals. Before the first sampling, Berseem had already been planted for approximately 2 months. After the last sampling (June 2001), the farmer intended to harvest all the remaining Berseem, plough, and after letting the soil dry, to plant potatoes.

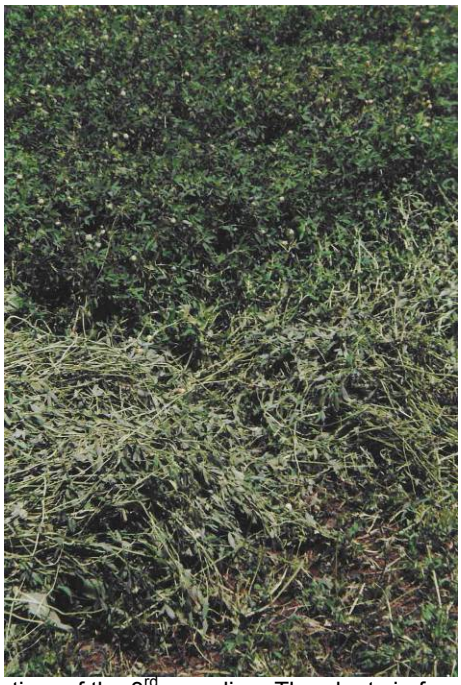

Figure 2.11.: Berseem field at the time of the 3rd sampling. The plants in front had been mowed a few minutes before the picture had been taken.

Sohag:

Berseem (*Trifolium alexandrinum*) field:

Berseem had been planted a week before wheat, in early October 2001, the plants were approximately 10cm high by the time of the first sampling (November 2001). Like the adjacent wheat field, no crops had been planted during the summer months, before that, the farmer had planted onions. Similar to the site in the Nile Delta, Berseem was cut at regular intervals, and harvested after the last sampling had taken place.

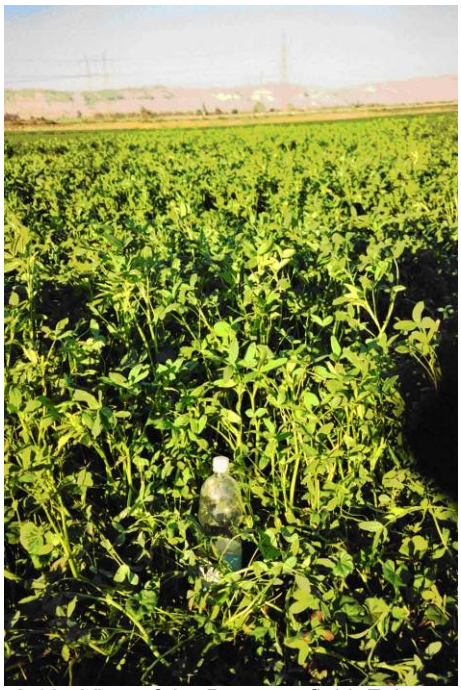

Figure 2.12.: View of the Berseem field, February 2002

Wheat (*Triticum spp*.) field:

Wheat had been planted around Mid-October, before the first sampling in November 2001. By the time of the first sampling, plants were approximately 10cm high, the last sampling took place before the harvest at the end of February 2001. The preceding crop was Berseem, the farmer intended to plant onions in March 2001. During the summer months of 2000, no crops had been planted.

Figure 2.13.: View of the wheat field, February 2002

2.4.3. Irrigation and Drainage

Nile Delta:

According to farmer Mohamed M. fields were irrigated by pumping water from the irrigation channels through the trenches on the fields, until the water was absorbed by the soil. The fields were irrigated every 14 days.
There is an effective drainage system in place, consisting of parallel pipes placed at 20m intervals, approximately 1.5-2m below surface. The pipes are surrounded by a layer of rocks and sand, in order to prevent clogging. Water is absorbed through pores in the pipes, and is then led to water collectors that are placed every 300 – 500m. This waste water is then discharged.

Sohag:

According to farmer Omar A., water from the well, approximately 20m away from the fields was used for irrigation, it was pumped up to surface level and then distributed on the fields using hoses. There were three wells on the farm by the time of sampling, the oldest being 15-20 years old, the other two were built 2-3 years before. The water used was groundwater, which varies between 70 – 110m below surface. According to the farmer, no seasonal changes had been recorded the level depending on current only. A water analysis from Assiut University, undertaken a few years previously, proved drinking water quality.

Unlike the fields in the Nile Delta, no drainage system was necessary, as water not absorbed by the less than 1m layer of soil would be drained by the sand layer below.

Fields were irrigated every 4 days during the summer months (March-October), and every 7-8 days during the winter (November-February).

2.4.4 Fertilisation

Nile Delta:

According to the farmer, the fields were fertilised using Superphosphate, Nitrate and Urea at regular intervals (approximately 2 times per crop until harvest). Natural fertilizer (cow and water buffalo manure) was spread on the fields at no fixed interval, depending on availability.
(All personal information, Farmer Mohamed M., 2001)

Sohag:

Omar the farmer was very consistent in his description of his methods. During his 10 years of experience on this field, he told that he had optimised the use of fertilizers. In the beginning he used natural fertilizer only (cow, chicken and water buffalo manure), then he used industrial fertilizers only, and by the time of sampling he used a mixture of both. Again, no exact amount of natural fertilizers used could be recorded, but he gave clear numbers regarding the use of industrial fertilizers.

All amounts in kg/feddan (acre) per year:

Crop	Fertilizer	Amount (kg/Feddan.a)
Wheat	Urea	75 kg
Berseem	Urea	50 kg

The farmer also gave information on the use of Superphosphate, however, he did not fertilize the fields analysed in this study with Superphosphate, but used it for his tomato fields only. The farmer also used the following mixture for a herbice treatment: 750g Dithane M44 (BASF), 750g Copper 50% (in Oxichloro copper), 200ml Noor Film 50 (Tri Ethanol ammonium dodecyl benzine sulfonate) and 2l Potassium Oxide, with 600l water for an area of 3 feddans. Also he applied the insecticide Dimethioate EC 40 (BASF) with 330 ml in 200l water per feddan. (All personal information, Farmer Omar A. 2001/2002)

2.5. Sampling

Soil sampling took place in spring/early summer of 2001 at the sites in the Nile Delta, and in November 2001 and January – March 2002 in Sohag. Unfortunately, it was not possible to take samples from both sites at the same time, due to complications regarding transportation, permits and the availability of drivers and interpreters. Sampling in Sohag was especially complicated, as it was necessary to obtain a permit from the local police office and depended on the availability of a police officer as an escort. Sohag is regarded as a politically instable area, therefore all foreigners have to be accompanied by a police officer and all visits are recorded by the local police office. The actual sampling times were calculated according to accessibility of the sites, times of irrigation and fertilisation, and crop size.

Table 2.1.: Dates of samplings in the Nile Delta and Sohag

Sampling	Nile Delta	Sohag
1st Sampling	14/02/2001	28/11/2001
2nd Sampling	03/04/2001	04/01/2002
3rd Sampling	23/04/2001	17/01/2002
4th Sampling	16/05/2001	01/02/2002
5th Sampling	10/06/2001	15/02/2002

Samples were taken in the same manner from all four fields, following standard procedures for soil scientific purposes:

6 samples were taken from each field, one from a sector close to each corner, and two from the very middle of the field. Each sample consisted of 5 sub-samples, taken within a square of approximately $1m^2$ that were taken with a commercially available gardening spade, from 0 – 25 cm below surface. At each sampling, great care was taken to draw new samples from the approximately same spot as before.

Soil Profiles:

In order to be able to assess the mineralogical composition of soil and to gain more information regarding soil profiles, additional samples were taken from each site, this time with hollow plastic pipes of 1m length. Those were hammered into the ground, in order to obtain a full profile, reaching 1m in depth. 6 samples were taken in Sohag, 2 from each field (Cores 2-5), and 2 more from the adjacent, ruderal area (Core 1&6).

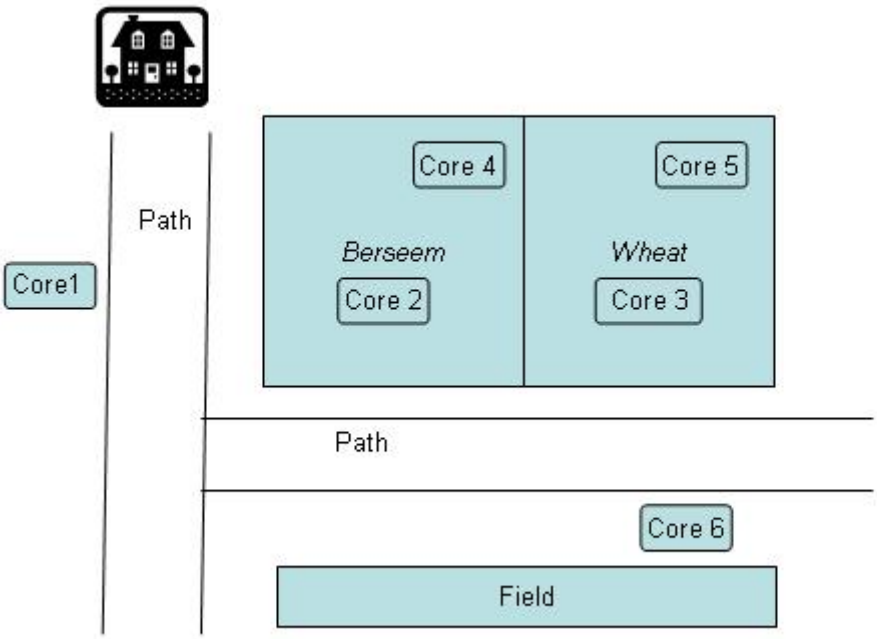

Fig 2.14.: Map of sampling soil cores in Sohag.

In the Nile Delta, 2 samples were taken from the middle of the fields, however, due to the compaction of the soil (due to recent irrigation), profiles from the Delta only reach a depth of approximately 30 cm. As the A-horizon of soils in the Nile Delta is several m deep, it would have been necessary to dig a deeper hole, if possible using an excavator. According to the information of the locals, the only excavator of the area would have only been available after an official request, and only after approximately 12 months. No further sampling was possible at a later time, due to the end of the project.

Figure 2.15.: Mineralogical sampling using a 1m long, hollow plastic tube with caps on both ends. Pipes were pushed into the ground using hammers, then pulled out, and closed for further transportation.

Sample treatment

Single samples were collected in plastic bags, labelled, and transported back to Cairo in a bag containing coolers, and from that time were kept at a temperature of 4°C until they were dried. The untreated field moist sampled were sieved using a DIN sieve with a 2mm mash

size. The <2mm fraction was then used for further analysis, any grains >2mm were disposed of.

After analysing Basal Respiration, Substrate Induced Respiration and Dehydrogenase Activity, as well as pH, dry weight/fresh weight ratio and Water Holding Capacity, the samples were dried at a temperature of 30°C for up to a week, until they were completely dry.

The dried samples were then shipped to Austria, where all other parameters were analysed at the University of Vienna. Cation Exchange Capacity was measured at the University for Applied Life Sciences, Vienna.

Soil profiles:

Soil profiles taken in Sohag and Delta were shipped to Austria separately, still in the plastic pipes, as they could be closed from both ends. The cores were then pushed out of the tubes, laid out on paper, and photographed. After a thorough analysis of the soil colour, they were divided into homogenous segments, put into plastic bags and used for further analysis, using X-Ray Diffraction and X-Ray Fluorescence only. Figure 2.16 shows an example of a profile taken in Sohag. The A-horizon of this anthroposol consists of a layer containing humic substances, and was created by mixing soil/sediment from the banks of the river Nile with mud from irrigation channels. The immediately adjacent C-horizon consists of desert sand.

Figure 2.16.: Example of soil core, taken in Sohag. Numbers indicate cm below surface.

2.6. Analytical Methods

2.6.1. Determination of Soil Physical Parameters

2.6.1.1 Grain Size Analysis:

A representative cross section of dried samples were wet sieved according to ÖNORM B 4412 (1974), using sieves with mash sizes 1mm, 500µm, 250µm, 125µm, 63µm. Silt and clay fraction (<0,063mm) were analysed using SEDIGRAPH 5100. Results were analysed graphically using Sedivision 2.0 as well as using VAS Uni-Korn 2.0 for the determination of soil descriptive parameters calculated using the Method of Moments.
For the determination of soil colour, a Rock Colour Chart (Munsell® Soil Color Chart) was used.

2.6.1.2. X-Ray Diffraction

For a qualitative and quantitative analysis of the mineralogy of the samples, a representative cross section of dried samples of both fields of the first, third and fifth sampling were analysed, as well as samples from the cores. For a semi-quantitative analysis of clay minerals, the <2µm fraction was separated using Atterberg cylinders. For a qualitative analysis, texture-free samples were prepared, for a semi-quantitative analysis (of clay mineral groups), textured samples were prepared. Samples were analysed using a X-ray diffractometer (Philips PW 3710), anode potential 45kV, current intensity 35kV, recording 1° (2 Theta) per minute. Diagrams were analysed according to Moor&Reynolds (1989), the semi-quantitative analysis of clay mineral groups was performed according to Schultz (1964, modified).

2.6.1.3. Dry Matter and Water Content

Soil Samples are dried at 105°C, and dry matter and water content are determined from recording the weight loss (Öhlinger 1996a, modified).

2.6.1.4. Soil Aggregate Stability (SAS)

For the determination of soil aggregate stability (SAS), dried aggregates (1-2mm) are wet sieved in distilled water in a machine providing a mechanical stroke length of 12.7mm to the sieves at a frequency of 42 cycles min^{-1}. After 5 min of wet sieving the mass of stable aggregates is determined. Aggregate stability is expressed as percentage of stable aggregates of the total aggregates (Kandeler 1996a, modified).

2.6.1.5. Maximum Water Holding Capacity (WHC)

Field moist, sieved soil is saturated with water, surplus water sucked off under defined conditions. The remaining water content represents the maximum water-holding capacity (Jäggi 1976, modified).

2.6.1.6. Cation Exchange Capacity (CEC)

500mg of dried soil was added to 35ml of deionised water and dispersed, the suspension then diluted to 50ml. 10ml of 0.01 M Cu(II) trien sulphate solution added, left to react for 3 min, then centrifuged, the extinction measured at 574nm (Kahr & Meier 1996, modified). CEC was only measured at samplings 1, 3 and 5 for all fields.

2.6.2. Determination of Soil Chemical Parameters

2.6.2.1. X-Ray Fluorescence

Soil material was crushed and grounded in an agate swing mill in order to obtain finest powder possible. Approximately 5 grams of material were placed in an oven at 110°C over night, weighed, then put in a muffle furnace at 1050°C for a 3 hour period, then weighed, and the Loss of Ignition (LOI) determined. Major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P) were determined on calcined soil powder fused with lithium tetraborate as flux to form a glass bead.
Trace elements (As, Cr, Cu, Ni, Pb, Zn, Co) were determined directly on the crushed and milled soil powder mixed with polyvinyl alcohol as a binding agent to form a pressed powder pellet. Analysis was performed on a sequential x-Ray spectrometer PHILIPS PW 2400 using a super-sharp end-window tube with a Rh-anode and a 3kW generator, the accompanying software was PANalytical SuperQ, Vers. 4. Ba, Ce, Co, Ga, La, Nb, Rb, Sc, Sn, Sr, Th, U, V, and Y were also determined due to the default setting, but only the above mentioned trace elements were depicted, due to their importance for the topic.

2.6.2.2. pH

pH is espressed as the inverse log of the hydrogen ion concentration. Soil pH was measured in a 1:2.5 soil to water solution and a 1:2.5 soil to 0.01M KCl solution, using a glass electrode (pH meter). Due to technical reasons, pH in KCl could only be measured after the second sampling in the Nile Delta (ÖNORM L 1083, 1989; modified)

2.6.2.3. Cations

1g of a representative cross section of dried samples were diluted in 10ml of distilled (Milli Q) water or 10 ml 1N KCl respectively, shaken, filtered, and then analysed using Atomic Absorption Spectroscopy for K and Na, DCP (Direct Current Plasma) for Ca and Mg, and ICP-MS (Inductively coupled plasma mass spectrometry) for Al, Cr, Mn, Fe, Ni, Cu, Zn, Mo and Pb.

Cationic mobility was assesed by dividing the acid soluble cationic content by the water soluble vontent of the respective cation

2.6.2.4. Anions

Anions were measured directly out of the water extract (see 2.5.3.3.) by HPLC (High Performance Liquid Chromatography).

Column: IonPac AS11, 10µm, 25 cm x 4 mm
Pre Column: Ion Pac AS-11 guard, 13µm, 5cm x 4 mm
Eluent: ternary gradient: 5.0 mM NaOH, 100 mM NaOH, A. dest.
Flow rate: 2mL min^{-1} at 80bar
Temperature: 35°C
Injector: 6-way-valve, injecting volume 10µL
Detector: conductivity detector after chemical suppression (auto suppression mode)

2.6.2.5. Electrical Conductivity

Electrical Conductivity is directly proportional to salinity of the soil solution, and is indicated in µS (it is equal to inverse Ohm). Electrical conductivity was measured according to ÖNORM L 1099 (1989, modified).

2.6.2.3. Soil Organic Matter

Mass Spectroscopy

For the determination of delta ^{13}C, delta ^{15}N, C/N ratio, total C and total N, dried samples were analysed in a mass spectrometer. Soil samples were ground to a fine powder in a ball mill (Retsch MM2000, Haan, Germany). Aliquots of soil material (2 mg) were weighed into tin capsules for analyzing total N, C and $\delta\,^{15}N$ and $\delta\,^{13}C$ by continuous-flow gas isotope ratio mass spectrometry (CF-IRMS). The CF-IRMS system consists of an elemental analyser (EA 1110, CE Instruments, Milan, Italy), a ConFlo II device (Finnigan MAT, Bremen, Germany) and a gas isotope ratio mass spectrometer (Delta^{PLUS}, Finnigan MAT). High-purity CO_2 and N_2 reference gases were run with each analysis. Reference gases were calibrated to V-PDB and atmospheric N international standards using IAEA-CH-6, IAEA-CH-7 for $\delta^{13}C$, and IAEA-N-1, IAEA-N-2 and IAEA-NO-3 for $\delta^{15}N$. The SD of repeated measurements of a working standard was 0.10‰ and 0.15‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively.

The ^{13}C and ^{15}N abundances were calculated as follows:

$\delta^{13}C = ([R_{sample} / R_{standard}] - 1) \times 1000$ [‰ vs. V-PDB])
$\delta\,^{15}N = ([R_{sample} / R_{standard}] - 1) \times 1000$ [‰ vs. at-air])

where R is the ratio of ^{13}C:^{12}C and ^{15}N:^{14}N, respectively. The isotope abundances are referred to the following certified reference materials: Vienna-Pee Dee Belemnite (V-PDB) and atmospheric dinitrogen (at-air).

Determination of Total Organic Carbon (TOC)

Total organic C was calculated by determination of carbonate according to ÖNORM L 1084 (1989, modified), the inorganic C then subducted stoichiometrically.

2.6.3. Determination of Soil Biological Parameters

2.6.3.1. Basal Respiration

Field moist samples are incubated in a closed Greiner cup at 25°C. The CO_2 produced by microbial respiration is absorbed in 0.05M NaOH. After incubation, $BaCl_2$ is added and thus CO_2 precipitated as barium carbonate. CO_2 is then quantified by titration using 0.1 M HCl and Phenolphtalein as an indicator (Öhlinger 1996b).

2.6.3.2. Substrate Induced Respiration

Glucose is added to the field moist samples and incubated in a closed Greiner cup at 25°C for 22 hours. The CO_2 produced is then absorbed in 0.05 M NaOH, using the same method as described for the determination of the basal respiration. (Beck et al. 1996, modified).

2.6.3.3. Dehydrogenase Activity

Field moist samples are suspended in a triphenyltetrazolium chloride solution and incubated for 22h at 25°C. The triphenyl formazan (TPF) produced is extracted with acetone and measured photometrically at 546 nm. Dehydrogenase activity of a soil is the result of the activity of different dehydrogenases , which are an important component of the enzyme system of all microorganisms (enzymes of respiratory metabolism, citrate cycle and nitrogen metabolism). Dehydrogenase activity is thus an indicator of biological redox-systems, and can be taken as a measure for the intensity of microbial metabolism in soils (Öhlinger 1996c, Tabatabai 1982).

2.6.3.4. Phosphatase Activity

Phenylphosphate (sodium salt) solution is added to the dried samples and incubated for 3h at 37°C. Released phenol is coloured with 2,6-dibromchione-chlorimide and determined photometrically at 614nm (Öhlinger 1996d, modified). Phosphorus uptake by plants depends on the mineralization of the organic P-components by phosphatases to orthophosphate (Malcolm 1983). Phosphatases are excreted by plant roots and microorganisms, however, microbial phosphatases dominate in soils (Tabatabai 1982).

2.6.3.5. Urease Activity

An aqueous urea solution is added to the dried soil samples, and incubated for 2h at 37°C. Released ammonium is extracted with KCl-solution and determined by a modified Berthelot reaction. The determination is based on the reaction of sodium salicylate with NH_3 in the presence of sodium dichloroisocyanurate, which forms a green-coloured complex under alkaline pH conditions. Sodium nitroprusside is used as a catalyst, which increases the sensitivity of the method about tenfold (Kandeler 1996b, modified).

2.6.3.6. Cellulase Activity

Dried soil are incubated for 24h at 50°C and pH 5.5, using CM-cellulose as substrate. Reducing sugars are released during the incubation period, because of the reduction of potassium hexacyanoferrate(III) in an alkaline solution. Reduced potassium hexacyanoferrate(II) reacts with ferric ammonium sulphate in an acid solution to form a complex of ferric hexacyanoferrate (II) (Prussian blue), which is determined colorimetrically at 690nm against a blank (Von Mersi & Schinner 1996). Please note: as the first tested batch showed no cellulose activity at all, no results are discussed.

2.7. Statistical analysis

All statistical analysis was performed using Statgraphics 5.0 by Statistical Graphics Corp. Data obtained from soil analysis was subjected to an Analysis of Variance (ANOVA) using Tukey-west for comparison of means. For correlations, Pearson's correlation coefficient was used.

A principal component analysis was then performed, the data of principal components (determined by their component weight) treated as metasyntactic variable, with which another PCA was performed. In order to assess correlations properly, single regression analyses were performed.

3. Results:

This chapter provides a depiction of results. In the accompanying text, a reference to the statistical evaluation is given. For an interpretation of results, please refer to chapter 4. Abbreviations used in this chapter:

CO_D	Cotton Field, Nile Delta
B_D	Berseem (Clover) Field, Nile Delta
B_S	Berseem (Clover) Field, Sohag, Upper Egypt
WH_S	Wheat Field, Sohag, Upper Egypt
Sa 1-5	Sampling 1-5 (for the dates of sampling, please refer to chapter 2)

3.1.Soil Physical Parameters

3.1.1. Grain size Analysis

For the grain size analysis, three samples of each field were analysed, table 3.1 represents means of those three samples.

Table 3.1.: % of fractions of the total sample. All values are means.

Fraction	**Cotton Delta**	**Berseem Delta**	**Berseem Sohag**	**Wheat Sohag**
	%	%	%	%
2-1mm	0,7	1,2	2,3	2,2
1-0.5 mm	4,7	4,0	8,1	7,4
0.5-0.25 mm	16,2	18,9	12,2	10,4
0.25-0.125 mm	17,9	15,0	14,8	15,9
125-63 µm	15,1	11,1	9,5	12,5
63-44.2 µm	2,3	2,0	3,1	3,2
44.2-32 µm	5,8	6,2	6,0	6,2
32-22.1 µm	2,5	2,7	3,3	3,8
22.1-16 µm	2,4	2,8	3,5	4,2
16-11.05 µm	2,7	3,3	4,1	4,6
11.05-8 µm	2,4	2,8	3,6	3,2
8-5.5 µm	2,8	3,2	3,7	3,7
5.5-4 µm	2,7	2,5	3,0	2,9
4-2.8 µm	2,7	2,8	3,2	2,2
2.8-2 µm	3,2	4,0	2,9	3,3
2-1.38 µm	2,2	4,4	4,2	2,4
1.38-1 µm	1,3	2,6	2,5	2,2
1-0.69 µm	2,8	2,5	2,3	2,3
0.69-0.5 µm	3,7	2,7	2,0	1,8
0.5-0.35 µm	2,5	2,7	2,5	2,7
0.35-0.25 µm	1,7	1,7	2,0	2,3
0.25-0.2 µm	1,8	0,9	1,2	0,7

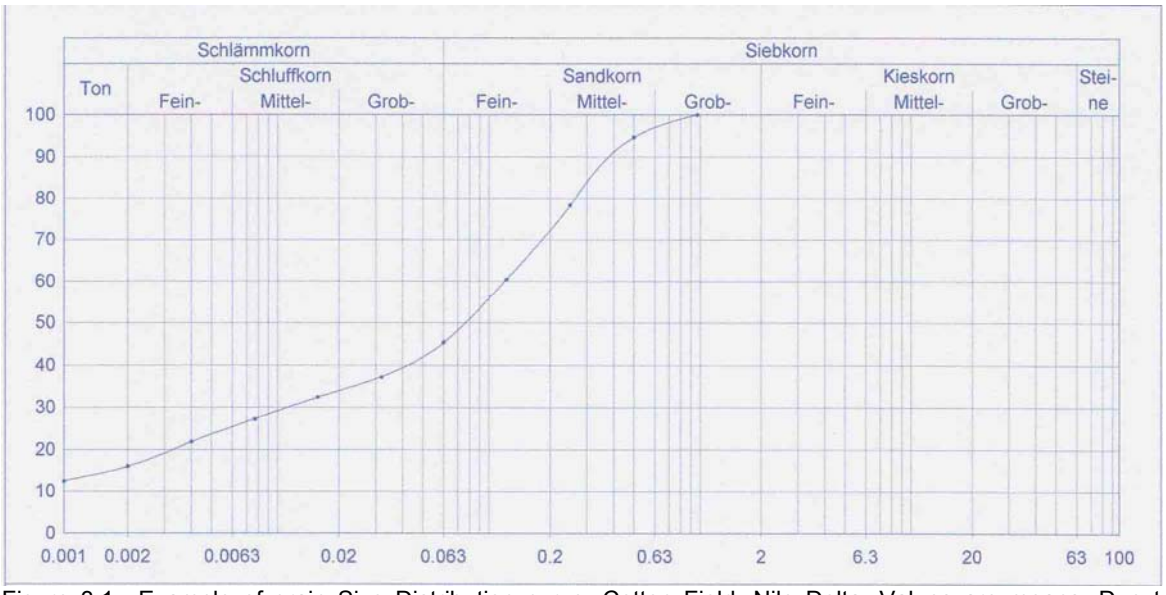

Figure 3.1.: Example of grain Size Distribution curve, Cotton Field, Nile Delta. Values are means. Due to technical reasons, fractions 2-1 mm where added and are depicted as >1mm.

Table 3.2.: % of sand, silt and clay. Values are means.

Field	*%Sand (2mm-63µm)*	*%Silt (63-2µm)*	*%Clay (<2µm)*
Cotton Delta	54.6	29.5	15.9
Berseem Delta	50.2	32.3	17.5
Berseem Sohag	46.9	36.4	16.7
Wheat Sohag	48.4	37.3	14.3

Table 3.3.: Mean, Sortation (Standard Deviation), Skewness and Kurtosis (Moments) of mean Grain Size curves.

Field	*Mean (Φ)*	*Sortation (Φ)*	*Skewness (Φ)*	*Kurtosis (Φ)*
Cotton Delta	4.734	3.308	0.688	2.186
Berseem Delta	4.874	3.335	0.516	1.939
Berseem Sohag	4.885	3.329	0.421	1.965
Wheat Sohag	4.782	3.197	0.522	2.192

Table 3.2. shows the percentage of sand, silt and clay: Soils in Sohag differ slightly: whilst the soil from the Berseem field can be classified as medium-sandy, fine-sandy, clayey silt, soil from the wheat field classifies as fine-sandy, medium-sandy silt (DIN 4022). Soils from the Nile Delta can be classified as fine-sandy, medium-sandy, clayey silt. For an explanation for this difference please refer to chapter 4, Discussion.

The colour of the soils of Sohag were dark yellowish brown (colour 10 R 4/2), the soils of the Nile Delta were darker (5 R 2/2).

3.1.2. Mineralogy

All results derived from X-ray diffractrometry were evaluated using a modified semi-quantitative method described by Schultz (1964). When looking at the results, it is important to bear in mind that differences described are trends rather than fixed values, as there is an uncertainty factor of approximately 5%.

No changes over time were recorded, therefore all values described are the means of samples of several samplings, standard errors are also reported to allow information on distribution of values.

Bulk Samples:

In order to show the similarity of the samples of different fields at different sampling times, a selection of x-ray diagrams is shown in figures 3.2.a-b

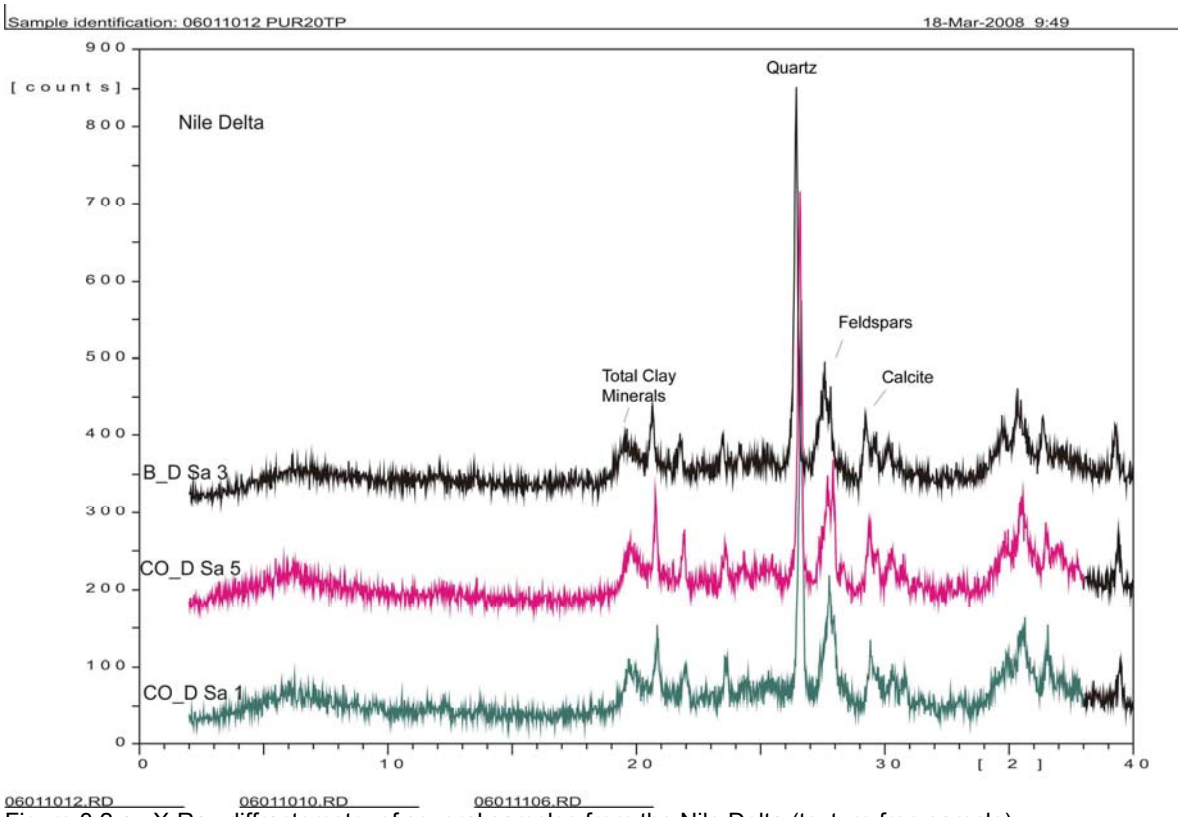

Figure 3.2.a: X-Ray diffractometry of several samples from the Nile Delta (texture free sample)

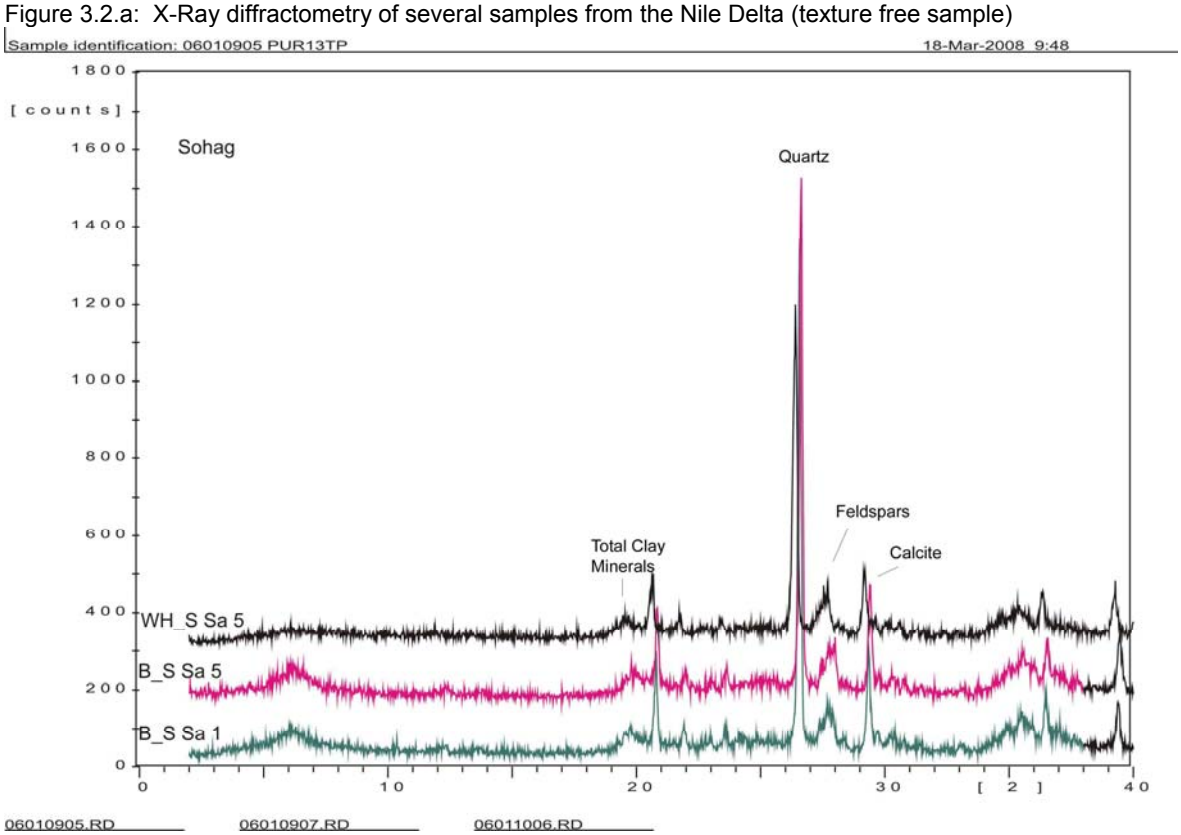

Figure 3.2.b: X-Ray Diffractometry of several samples from Sohag, Upper Egypt (texture free sample)

The two main components of the bulk samples of both experimental sites are quartz and clay minerals. Whilst the main component in the Nile Delta (see table 3.4.) is clay minerals (more than 50%), in Sohag (see figure 3.2.b.) there is more quartz in the Berseem field than clay minerals (37% and 32% quartz, respectively), and as much quartz as clay minerals in the wheat field (over 30%). In the Nile Delta, no difference between the two fields regarding the amount of calcite (5%), gypsum (3%) and NaCl (1%) could be detected, but the amounts of goethite (3% cotton field, 4% Berseem field) and feldspars (10% cotton field, 15% Berseem field) differ.

In Sohag (Table 3.4.), approximately twice the amount of quartz and more than twice the amount of calcite can be found in the samples, compared with the Nile Delta, but 20% less clay minerals. The only difference between the two fields in Sohag is the concentration of feldspars with 12% in the Berseem field, and 14% in the wheat field.

Table 3.4.: Overview of Bulk Mineralogy, Nile Delta and Sohag. All values are means, error=standard error

	Cotton Delta		**Berseem Delta**	
	%	S.E.	%	S.E.
Quartz	19	2	17	1
Calcite	5	1	5	0
Feldspars	10	3	15	2
Clay Mins.	58	4	53	1
Gypsum	3	0	3	1
Goethite	3	0	4	0
NaCl	1	0	1	0
	Berseem Sohag		**Wheat Sohag**	
	%	S.E.	%	S.E.
Quartz	37	2	32	5
Calcite	12	0	12	3
Feldspars	12	1	14	1
Clay Mins.	32	2	34	4
Gypsum	2	1	3	1
Goethite	3	0	2	1
NaCl	1	0	1	0

The quantification of clay minerals in the bulk samples (see table 3.5.) shows that there is a difference between the two sampling sites, but not between the two fields of a site. In general, there is a relatively bigger amount of smectite and kaolinite in the samples from the Nile Delta.

Table 3.5.: Overview of the clay mineralogy of bulk samples. All values are means in % of the total amount of clay minerals, S.E.= standard error.

	Cotton Delta		**Berseem Delta**	
	%	S.E.	%	S.E.
Smectite	42	6	38	0
Mica (Illite)	6	2	5	0
Kaolinite	10	1	10	1
	Berseem Sohag		**Wheat Sohag**	
	%	S.E.	%	S.E.
Smectite	25	2	29	1
Mica (Illite)	3	0	4	1
Kaolinite	3	1	2	2

Bulk mineralogy of the core samples was analysed (see tables 3.6-3.8). As samples were taken at different depths due to circumstances, as well as at different places, all values

shown here are the results of the analysis, not means or medians (please refer to Material and Methods, for a description of sampling and a map).

Bulk mineralogy of core samples (see table 3.6.) of the fields of the Nile Delta varies between the two samples regarding the amount of quartz, which is 4 times higher in Delta II, as well as feldspars, with a higher content in Delta I. Otherwise the samples are very similar to the ones taken from the 0-20 cm samples from sampling 1-5, the only exception being the amount of feldspars, which is higher in the samples taken from the cores.

Table 3.6.: Bulk Mineralogy of core samples of the Nile Delta. All values % of the total amount.

	Delta I	**Delta II**
	%	%
Quartz	3	12
Calcite	4	5
Feldspars	28	16
Clay Mins.	59	60
Gypsum	2	2
Goethite	2	3
NaCl	1	1

Looking at the samples taken in Sohag, there is a difference between the samples taken from rural areas (Sohag I and Sohag VI, table 3.7.) and the ones taken from the fields (table 3.8.) – please refer to Material and Methods for a map and description of sampling. The amount of quartz in samples Sohag I and VI equals that of the one taken from below a field (Sohag IV, 20-60), the amount of quartz in the top layer of the samples taken from the fields (Sohag II to IV) equals the samples from sampling 1-5. Gypsum, goethite and NaCl could only be found in the top layer of sample Sohag I and the sample taken from the top layers of the fields, but none at all in the deeper layers (Sohag I, 20-60cm, Sohag IV, 40-60 and Sohag VI, 0-40). Clay minerals in the discussed bulk samples were below the detection limit. There is no result for Sohag V, as there wasn't enough material left for a x-ray diffraction analysis.

Table 3.7: Bulk mineralogy of core samples in the ruderal area of Sohag, Soh.=Sohag, numbers indicate depth of sample below surface. All values % of total amount.

	Soh. I 0-20	**Soh I 20-60**	**Soh. VI 0-40**
	%	%	%
Quartz	71	80	77
Calcite	15	13	18
Feldspars	8	7	3
Clay Mins.	0	0	0
Gypsum	2	0	0
Goethite	2	0	2
NaCl	1	0	0

Table 3.8.: Bulk mineralogy of core samples of the fields of Sohag, Soh.=Sohag, numbers indicate depth of sample below surface.. All values % of total amount.

	Soh. II 0-40	**Soh. III 0-40**	**Soh. IV 0-40**	**Soh. IV 40-60**
	%	%	%	%
Quartz	35	20	25	77
Calcite	13	8	24	17
Feldspars	10	15	8	5
Clay Mins.	34	49	38	0
Gypsum	3	2	2	0
Goethite	2	3	2	0
NaCl	1	1	1	0

Analysis of the <2µm Fraction:

In order to show the similarity of the samples of different fields at different sampling times, a selection of x-ray diagrams is shown in figures 3.3.a-b. As characteristic reactions after the saturation of the samples with ethylene glycol could be reported (e.g. drift of the smectite grating at 16.6 Å), smectite was clearly identified.

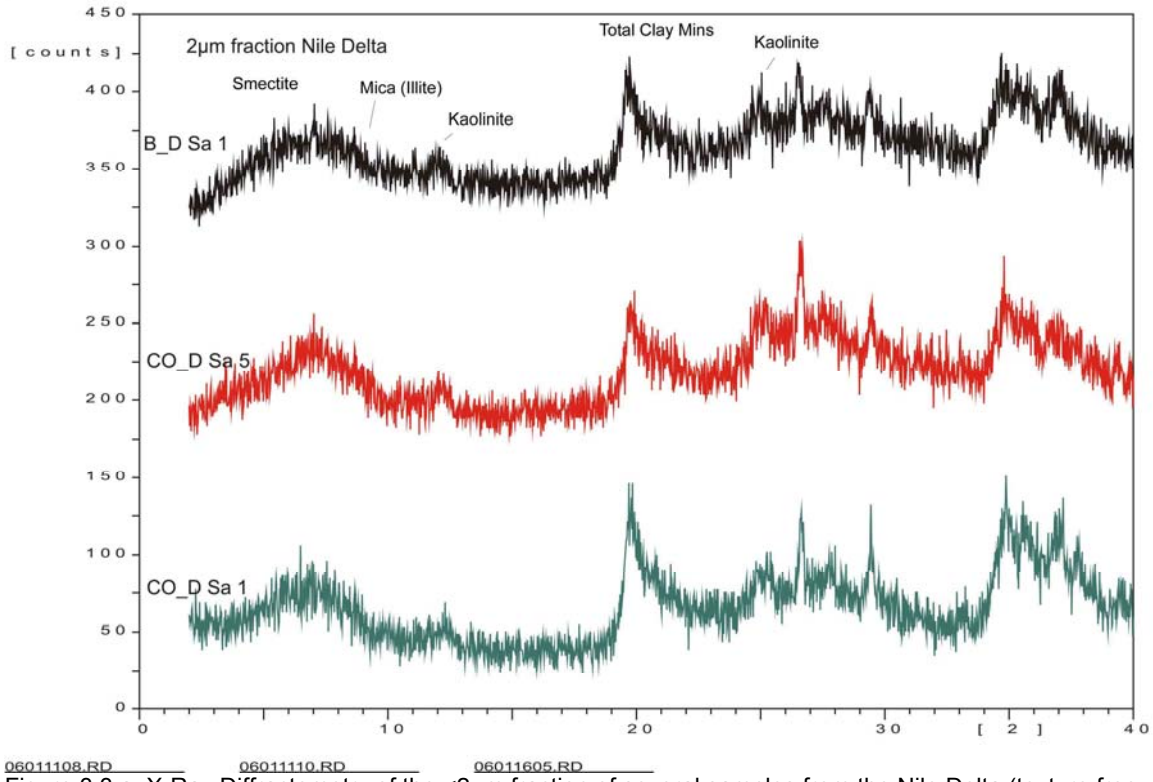

Figure 3.3.a: X-Ray Diffractometry of the <2µm fraction of several samples from the Nile Delta (texture free sample)

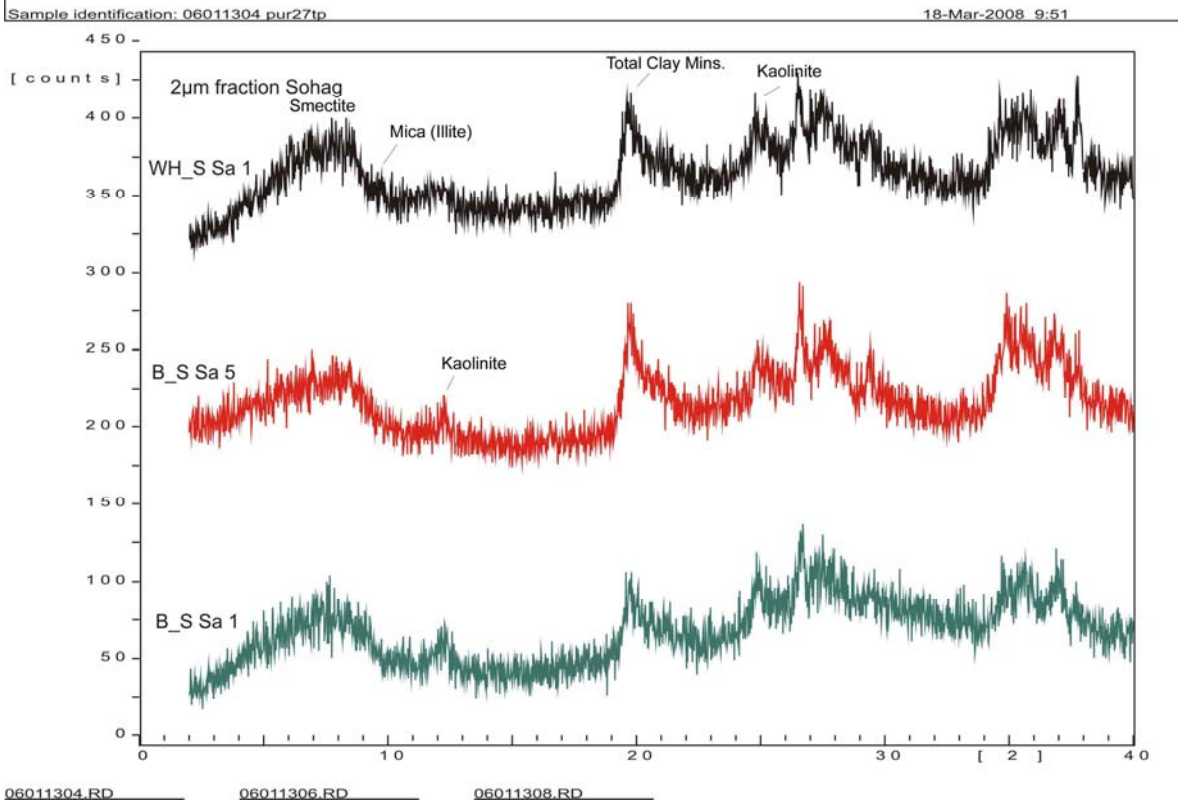

Figure 3.3.b: X-Ray Diffractometry of the <2µm fraction of several samples from Sohag, Upper Egypt (texture free sample)

Looking at the mineralogy of the <2µm fraction of the samples from the fields (see table 3.9.), differences aren't as big as in the bulk samples: In the Nile Delta, a slightly higher amount of calcite can be found in the cotton field (5% calcite in the cotton field, 4% in the Berseem field) as well as a slight difference regarding feldspars (8% vs. 6%). In Sohag, there are no differences between the two fields; in general the values for both experimental sites are very similar, with the only exceptions being the amount of feldspars, of which the concentration is slightly higher in Sohag.

Table 3.9.: Overview of mineralogy of the<2µm fraction. All values are means, S.E. =standard error

	Cotton Delta		**Berseem Delta**	
	%	S.E.	%	S.E.
Quartz	4	1	3	0
Calcite	5	0	4	0
Feldspars	8	2	6	0
Clay Mins.	74	4	79	1
	Berseem Sohag		**Wheat Sohag**	
	%	S.E.	%	S.E.
Quartz	4	0	4	1
Calcite	4	0	3	1
Feldspars	11	0	9	2
Clay Mins.	72	1	73	5

Looking at the quantification of clay minerals of the <2µm fraction of the samples of the fields (see table 3.10.) all four fields are almost identical in their content of smectite, mica, and kaolinite, the only difference is a slightly lower content of kaolinite in the Berseem field in Sohag.

Table 3.10.: Quantification of clay minerals of the<2µm fractions. All values are means, in % of the total amount of clay minerals. S.E.= standard error

	Cotton Delta		**Berseem Delta**	
	%	S.E.	%	S.E.
Smectite	57	0	62	3
Mica (Illite)	6	2	10	2
Kaolinite	12	3	8	2
	Berseem Sohag		**Wheat Sohag**	
	%	S.E.	%	S.E.
Smectite	62	1	59	0
Mica (Illite)	6	1	6	1
Kaolinite	3	0	8	3

The <2µm fraction of the core samples is reported in tables 3.11.-3.13. Even though the total of clay minerals were below the detection limit in the bulk samples of samples Sohag I, and VI, there was enough material to separate enough of the <2µm fraction for further analysis. As values of the following tables show, the dissemination of clay minerals is very similar to the fields.

Table 3.11.: <2µm fraction of core samples, Nile Delta. All values are % of the total amount.

	Delta I	**Delta II**
	%	%
Smectite	52	60
Mica (Illite)	7	7
Kaolinite	15	7

Table 3.12.: < 2µm fraction of core samples, Sohag, ruderal, Soh.=Sohag, numbers indicate depth of sample below surface. All vaules are % of the total amount.

	Soh. I 0-20	**Soh I 20-60**	**Soh. VI 0-40**
	%	%	%
Smectite	58	44	40
Mica (Illite)	6	8	7
Kaolinite	9	19	18

Table 3.13.: <2µm fraction of core samples of the fields of Sohag, Soh.=Sohag, numbers indicate depth of sample below surface.. All vaules are % of the total amount.

	Soh. II 0-40	**Soh. III 0-40**	**Soh. IV 0-40**	**Soh. IV 40-60**
	%	%	%	%
Smectite	57	59	52	56
Mica (Illite)	5	7	7	0
Kaolinite	5	7	9	0

3.1.3. Dry Matter and Water Content

Dry Matter and Water Content varied between the fields of the respective sampling areas and between different samplings in one field. Values between the two experimental sites differed at all times (at the 99.99% confidence level) (see table 3.14). In the Nile Delta, soil of the cotton field differed between each of the samplings (at the 99.2% confidence level), as well as the soil of the Berseem field (at the 99.99% confidence level). The two fields showed a significant difference in dry matter and water content, with values in the cotton field higher than in the field planted with Berseem, with an only exception at the 2nd sampling (here the difference is at the 97.8 % confidence level). In Sohag, there were no differences between the two fields at the second and the fourth sampling, whilst dry matter and water content differed between the two fields at the first, third and fifth sampling, with higher values in the wheat field (differences at the 99.99%, 99.86% and 99.97% confidence level, respectively.

Table 3.14: Dry Matter and Water Content. All values are means (%dry weight of fresh weight (DW%FW)). n=6. Subscript numbers indicate highly significant differences between two fields in one area (read left to right), superscript letters indicate differences at different times of sampling (read top to bottom). Only highly significant differences are indicated (p>0.005).

	Delta		**Sohag**	
	Cotton	Berseem	Berseem	Wheat
Sampling 1	$_1$74.0	$_2$68.6^a	$_1$82,3	$_2$88,5^c
Sampling 2	72.5	70.7^a	83,8	84,5^b
Sampling 3	$_1$81.7	$_2$77.0^b	$_1$77,1	$_2$81,6^a
Sampling 4	$_1$73.4	$_2$79.1^b	82,1	81,1^a
Sampling 5	$_1$75.8	$_2$72.0^a	$_1$78,8	$_2$81,6^a
Mean	$_1$74.4		$_2$81.9	

3.1.4. Soil Aggregate Stability

There is a significant difference in Soil Aggregate Stability (see table 3.15) between the Cotton and Berseem field in the Nile Delta at all times except the third sampling, where the % of stable aggregates (%SAS) declined significantly. In general, there are less stable aggregates in the cotton field.

In Sohag, there is no significant difference at the 95% confidence level in the amount of stable aggregates between the two fields, however, the amount of stable aggregates increased significantly at the 5th sampling in the wheat field. There are less stable aggregates in the soil of the fields in Sohag compared to the fields in the Nile Delta.

Table 3.15: Soil Aggregate Stability (SAS). All values are means (%SAS). n=6. Subscript numbers indicate highly significant differences between two fields in one area (read left to right), superscript letters indicate differences at different times of sampling (read top to bottom). Only highly significant differences are indicated (p>0.005).

	Delta		**Sohag**	
	Cotton	Berseem	Berseem	Wheat
Sampling 1	$_1$29.2	$_2$47.1^{a}	24,8^{ab}	28,8^{ab}
Sampling 2	$_1$31.6	$_2$48.9^{a}	23,5^{a}	25,1^{a}
Sampling 3	33.3	36.7^{b}	33,3^{ab}	26,4^{ab}
Sampling 4	$_1$34.7	$_2$42.7^{ab}	29,8^{ab}	26,0^{ab}
Sampling 5	$_1$30.4	$_2$51.1^{a}	31,1^{b}	31,9^{b}
Mean	$_1$39.0		$_2$28.1	

3.1.5. Maximum Water Holding Capacity (WHC)

WHC (see table 3.16.) differs significantly between the two areas (Nile Delta and Sohag), but not between the two fields of one area.

It increases significantly over time in both fields of the Nile Delta, and is highest at the 5th sampling. Higher WHC values can be found in the field planted with Berseem in the Nile Delta, however, the field planted with Berseem in Sohag shows lower values than the field planted with wheat (these differences are trends only, as fields do not differ at a 95% interval at any point). There is an increase of WHC at the 3rd sampling, with a subsequent decline in WHC in the Berseem field in Sohag over time (at the 98.21% confidence level), the adjacent wheat field showed an increase at the 5th sampling (at the 99.99% confidence level) It is interesting to note that the field planted with Berseem shows the highest WHC at the 3rd sampling, where it is lowest in the field planted with wheat. This difference is significant at the 99.21% confidence level.

Table 3.16: Maximum Water Holding Capacity (WHC). All values are means (maxH_2O/Dry Matter). n=6. Subscript numbers indicate highly significant differences between two fields in one area (read left to right), superscript letters indicate differences at different times of sampling (read top to bottom). Only highly significant differences are indicated (p>0.005).

	Delta		**Sohag**	
	Cotton	Berseem	Berseem	Wheat
Sampling 1	9.3^{ab}	11.5^{ab}	7,8	8,1^{ab}
Sampling 2	7.3^{a}	7.6^{ab}	7,0	8,0^{ab}
Sampling 3	7.5^{a}	7.4^{a}	9,7	3,6^{a}
Sampling 4	6.9^{a}	9.7^{ab}	6,8	7,8^{ab}
Sampling 5	12.6^{b}	12.4^{b}	8,5	9,7^{b}
Mean	$_1$9.2		$_2$7.7	

3.1.6. Cation Exchange Capacity (CEC)

CEC in the Nile Delta does not differ significantly at the 95% confidence level between the two fields (see figure 3.4.a), nor are there any differences between the different samplings (all differences are significant at a confidence level lower than 45%). The same accounts for the fields in Sohag, again there is no difference between the fields or samplings (see figure 3.4.b). There is, however, a significant difference between the fields of the Nile Delta and Sohag, CEC in Sohag is significantly lower (mean=24.3 meq*100g $Soil^{-1}$) than in the Nile Delta (mean=27.3 meq*100g $Soil^{-1}$).

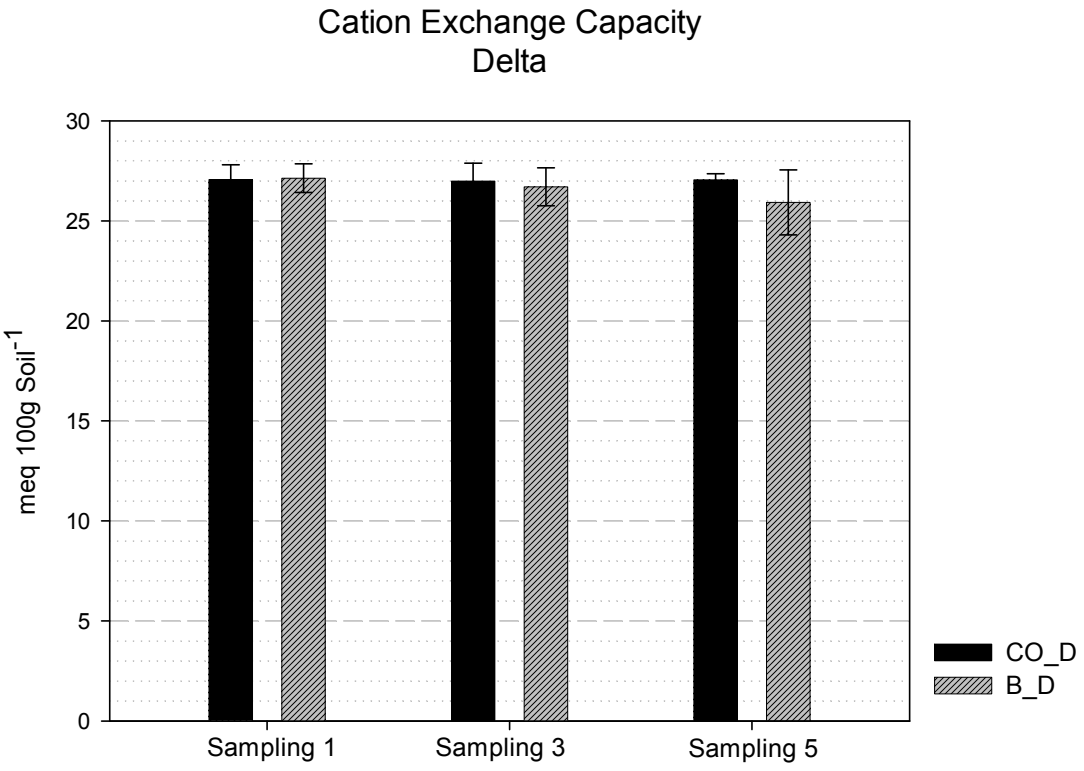

Figure 3.4.a: Cation Exchange Capacity of soils from the Nile Delta, Values are means, error=standard error

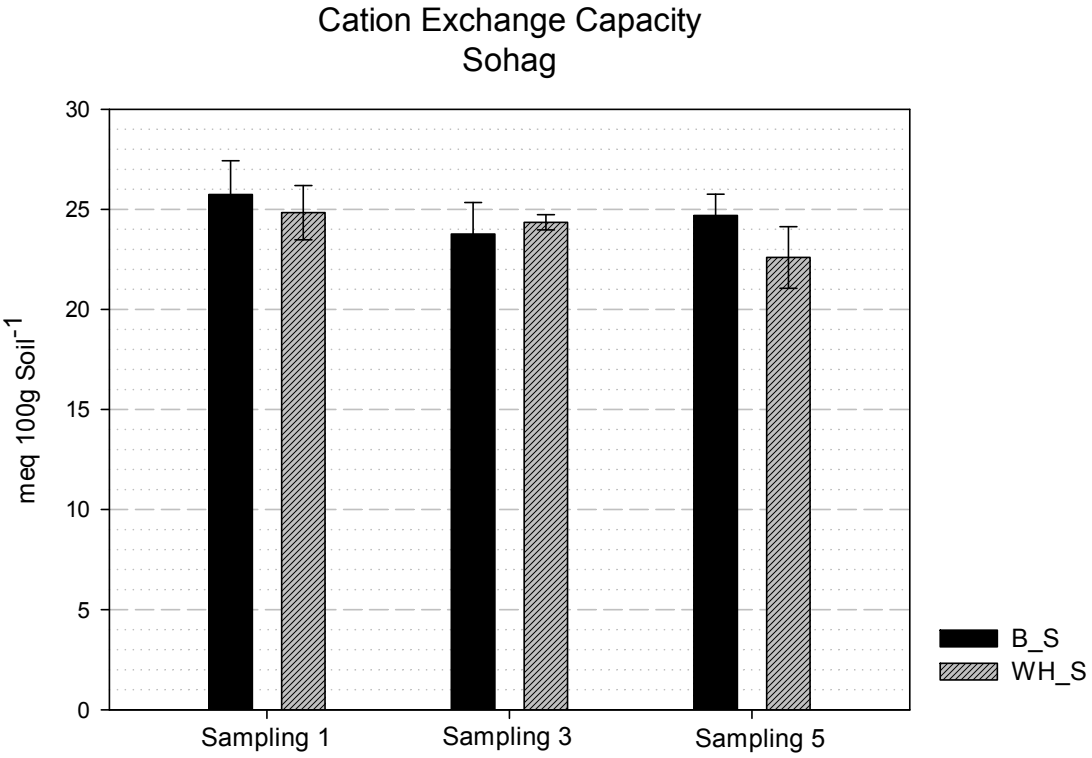

Figure 3.4.b: Cation Exchange Capacity of soils from Sohag. Values are means, error=standard error

Table 3.17 : Cation Exchange Capacity. All values are means, meq refers to meq*100g soil, S.E..= standard error

	Cotton Delta		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	meq	*std. err.*	*meq*	*std. err.*	*meq*	*std. err.*	*meq*	*std. err.*
Sampling 1	27,1	0,7	27,1	0,7	25,7	1,7	24,8	1,4
Sampling 3	27,0	0,9	26,7	0,9	23,8	1,6	24,4	0,4
Sampling 5	27,1	0,3	25,9	1,6	24,7	1,1	22,6	1,5

3.2. Soil Chemical Parameters

3.2.1. Main Element Analysis:

Again, no differences in concentrations of the main components (see table 3.18.) between the fields of an experimental site could be found, the results discussed here are all dealing with the differences between the two sites.

In Sohag, approximately 20% more SiO_2 and more than 30% more CaO can be found than in the Nile Delta. All other components are more abundant in the Nile Delta: The values of TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO for the fields in Sohag, are around 70% of the values found in the Nile Delta, Na_2O around 80%, K_2O around 60% and P_2O_5 approximately 50%.

Table 3.18: X-ray Fluorescence Spectroscopy, Main Components Analysis. All values are means, S.E.=standard error

	SiO2		**TiO2**		**Al2O3**		**Fe2O3**		**MnO**	
	wt %	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*
CO_D	50.6	0.1	1.9	0.0	15.2	0.1	10.4	0.0	0.2	0.0
B_D	50.0	0.1	1.9	0.0	15.2	0.1	10.4	0.0	0.2	0.0
B_S	61.0	0.8	1.3	0.0	10.8	0.3	7.2	0.2	0.1	0.0
WH_S	60.7	0.5	1.4	0.0	10.7	0.3	7.2	0.2	0.1	0.0
	MgO		**CaO**		**Na2O**		**K2O**		**P2O5**	
	wt %	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*	*wt %*	*S.E.*
CO_D	3.2	0.0	4.8	0.0	1.3	0.0	1.6	0.0	0.4	0.0
B_D	3.2	0.0	4.8	0.0	1.3	0.0	1.6	0.0	0.4	0.0
B_S	2.3	0.1	6.3	0.1	1.0	0.0	1.0	0.0	0.2	0.0
WH_S	2.3	0.1	6.5	0.1	1.1	0.0	1.0	0.0	0.2	0.0

Trace elements also did not vary between the fields of the respective experimental sites, however, there are differences between the two sites (see table 3.19.). Again, concentrations of trace elements are lower in Sohag: Cu, Ni and Co are approximately 70%, As 80%, Cr 90% and Zn 95% of the concentration of the fields in the Nile Delta. Only the concentration of Pb was 25% higher in Sohag than in the Nile Delta.

Table 3.19: X-Ray Fluorescence Spectroscopy, Trace Elements. All values are means, S.E. =standard error

	As		**Cr**		**Cu**		**Ni**	
	ppm	*S.E.*	*ppm*	*S.E.*	*ppm*	*S.E.*	*ppm*	*S.E.*
CO_D	4,21	0,28	132,97	0,81	64,69	0,51	74,94	0,27
B_D	4,13	0,40	130,77	0,80	63,10	0,34	74,45	0,38
B_S	3,46	0,36	115,05	2,70	44,21	1,98	53,18	1,95
WH_S	3,35	0,38	120,36	2,48	43,97	1,09	52,98	1,28
	Pb		**Zn**		**Co**			
	ppm	*S.E.*	*ppm*	*S.E.*	*ppm*	*S.E.*		
CO_D	11,85	0,33	110,99	1,14	33,39	0,18		
B_D	11,41	0,15	111,71	0,53	32,85	0,26		
B_S	14,63	1,39	102,96	7,95	23,79	0,75		
WH_S	16,65	1,01	108,68	3,74	23,21	0,61		

3.2.2. pH

In the Nile Delta, pH in a 1:2.5 soil to water solution differs between the two fields at samplings 2 and 3, where pH in the clover field is significantly higher than in the field planted with cotton (see table 3.20). In Sohag, there is no difference between the two fields at any time at the 95% confidence level, pH in the wheat field increased significantly over time.

In general, pH in the Delta was slightly lower than in Sohag.

Table 3.20: pH in a 1:2.5 soil to water solution. All values are means. n=6. Subscript numbers indicate highly significant differences between two fields in one area (read left to right), superscript letters indicate differences at different times of sampling (read top to bottom). Only highly significant differences are indicated (p>0.005).

	Delta		**Sohag**	
	Cotton	Berseem	Berseem	Wheat
Sampling 1	7.4	7.7	7,7	$7,4^{a}$
Sampling 2	$_{1}7.4$	$_{2}7.8$	7,9	$7,8^{ab}$
Sampling 3	$_{1}7.2$	$_{2}8.0$	8,0	$8,1^{b}$
Sampling 4	7.6	7.7	8,0	$8,1^{b}$
Sampling 5	7.4	7.8	7,9	$8,0^{b}$
Mean	$_{1}7.6$		$_{2}7.9$	

There were no significant differences regarding pH in a 1:2.5 soil to 0.01M KCl solution (see table 3.21) in neither field of neither experimental site, except in the Nile Delta where pH is significantly higher in the Berseem field compared to the cotton field. pH in the cotton field at the third sampling is significantly lower as at the fourth and the fifth sampling (at the 99.4% confidence level). pH between the two experimental sites differs at the 99.69% confidence level.

Table 3.21: pH a 1:2.5 soil to 0.01M KCl solution. All values are means. n=6. Subscript numbers indicate highly significant differences between two fields in one area (read left to right), superscript letters indicate differences at different times of sampling (read top to bottom). Only highly significant differences are indicated (p>0.005).

	Delta		**Sohag**	
	Cotton	Berseem	Berseem	Wheat
Sampling 1	-	-	7,4	7,4
Sampling 2	-	-	7,4	7,4
Sampling 3	$_{1}7.0$	$_{2}7.5$	7,5	7,6
Sampling 4	7.4	7.4	7,5	7,5
Sampling 5	7.4	7.4	7,5	7,5
Mean	7.4		7.5	

3.2.3. Cations and Anions:

For the graphic representation of results, cations and anions were divided into macronutrients, micronutrients and heavy metals.

Macronutrients: $NO3^{-}$, PO_4^{2-}, K, SO_4^{2-}, Mg, Ca
Micronutrients: Al, Fe, Mn, Cu, Zn, Na, Cl,
Heavy Metals: Ni, Cr, Mo, Pb

Concentrations of Cr, Mo and Pb were below 1ppb, and are therefore not depicted.

All values are mg/kg soil, therefore ppm. The values depicted in the following graphs are all means and all mg/kg soil, unless stated otherwise.

3.2.3.1. Macronutrients

In general, the concentration of macronutrients (figures 3.5.a-b) is lower in Sohag, compared to the Nile Delta, except for Ca and PO_4^{2-}.

In the Nile Delta (figure 3.5.a), the two fields differ in their content of macronutrients, in the cotton field the changes in the concentration are more substantial: in general, the concentration is much higher at the first sampling, compared to the clover field, then the concentration increases from he first to the third sampling, then decrease to a value similar to that of the adjacent clover field. The most notable changes are the concentrations of NO_3^- and SO_4^{2-}, concentration of both elements increases between the first and the third sampling, then decreases until the fifth sampling in the cotton field. SO_4^{2-} in the Berseem field decreases over time. The concentration of PO_4^{2-} does not differ between the two fields, and increases at the third sampling (in both fields), then decreases again until the fifth sampling. Concentrations of K, Ca and Mg are higher in the cotton field compared with the Berseem field.

In Sohag (figure 3.5.b), the only significant changes over time are in Mg and Ca in the Berseem field, where values increase over time. There are no differences between the two fields.

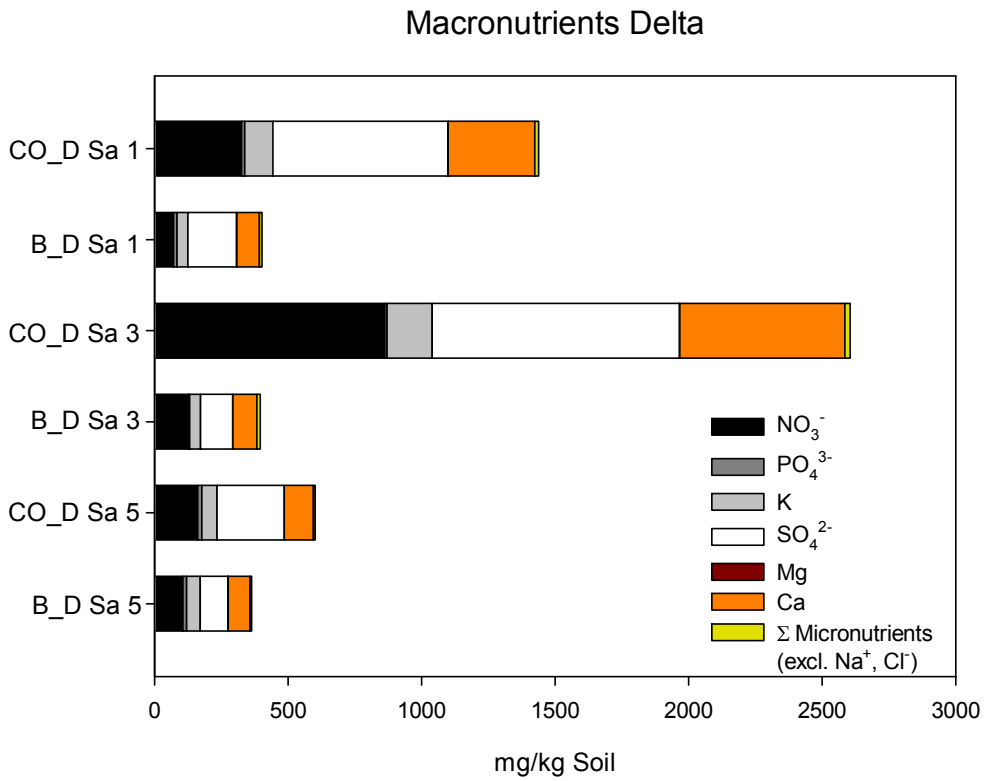

Figure 3.5.a: Macronutrients in the Nile Delta. All values are means. Only differences at a confidence level above 95% are discussed in the text.

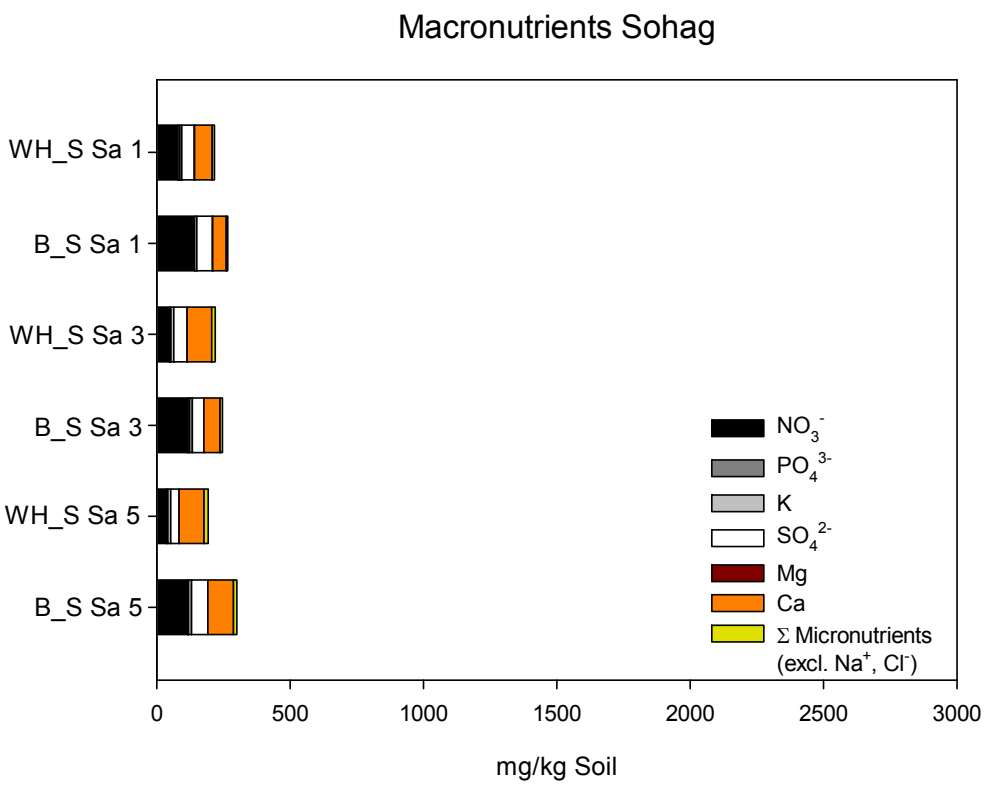

Figure 3.5.b: Macronutrients in Sohag. All values are means. Only differences at a confidence level above 95% are discussed in the text.

Table 3.22.: Macronutrients in the Nile Delta and Sohag. All values are means, S.E.=standard error

Cotton Delta						
	NO_3		PO_4		K	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	325.7	39.1	12.0	2.1	105.7	12.1
Sampling 3	862.2	123.6	8.7	3.3	168.8	32.9
Sampling 5	161.7	25.3	15.5	1.2	57.5	6.5
	SO_4		Mg		Ca	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	655.7	103.2	1.1	0.0	324.0	17.4
Sampling 3	925.6	102.2	1.7	0.4	618.0	133.1
Sampling 5	251.0	28.9	0.4	0.0	108.8	7.3
Berseem Delta						
	NO_3		PO_4		K	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	71.3	14.7	12.6	3.6	41.1	11.2
Sampling 3	126.3	8.6	5.2	1.5	40.8	7.4
Sampling 5	106.6	8.4	13.7	1.8	50.5	9.4
	SO_4		Mg		Ca	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	182.7	22.0	0.4	0.0	84.8	7.1
Sampling 3	120.7	7.4	0.4	0.0	90.4	2.5
Sampling 5	104.8	13.6	0.4	0.0	82.3	6.4

Berseem Sohag						
	NO_3		PO_4		K	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	142.0	24.2	0.0	0.0	8.7	1.4
Sampling 3	116.7	21.5	6.7	2.1	10.6	0.5
Sampling 5	114.3	48.0	5.2	1.6	11.0	2.0
	SO_4		Mg		Ca	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	58.8	10.8	0.2	0.0	51.1	2.4
Sampling 3	42.2	11.6	0.3	0.0	61.3	2.9
Sampling 5	61.0	12.7	0.4	0.0	95.6	6.0
Wheat Sohag						
	NO_3		PO_4		K	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	79.8	10.1	6.5	0.3	7.5	0.9
Sampling 3	48.5	7.5	4.5	2.2	10.7	1.1
Sampling 5	35.5	8.0	5.8	0.8	11.1	1.9
	SO_4		Mg		Ca	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	47.8	7.1	0.2	0.0	66.0	1.1
Sampling 3	50.2	9.0	0.3	0.0	91.9	13.5
Sampling 5	31.0	6.2	0.3	0.0	93.4	11.6

3.2.3.2. Micronutrients

The general overview of micronutrients (see figures 3.6.a-b) show that Na^+ and Cl^-, are the micronutrients that can be found predominantly in the soils of both experimental sites. In the Nile Delta, the concentrations of Na^+ and Cl^- go up to over 1000 mg/kg soil, the total of other micronutrients without Na^+ and Cl^- goes up to a total of 20 mg/kg soil. In Sohag, the difference is not as big, the total concentration of micronutrients (and Ni) reach a total of approximately 200 mg/kg soil, and the total without Na^+ and Cl^- reaches 15 mg/kg soil. In the Nile Delta, Na^+ and Cl^- concentrations increase in the cotton field over time, and are higher in general, compared to the clover field. In Sohag, concentrations of the two elements do not vary over time, and no significant differences between the two fields could be found.

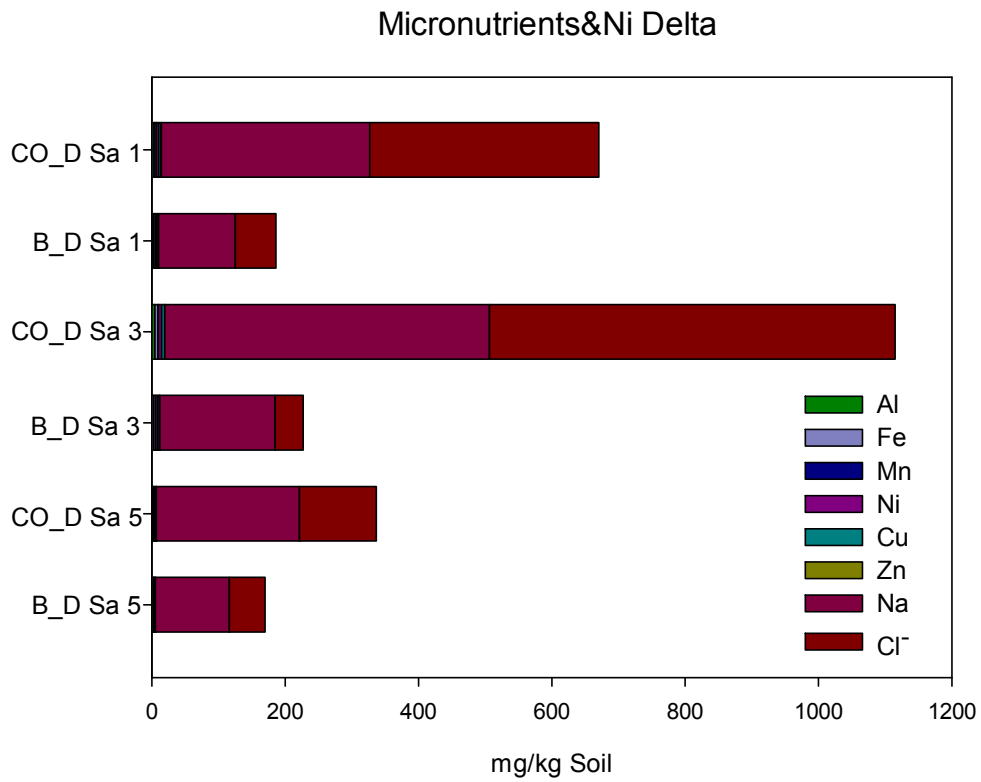

Figure 3.6.a: Micronutrients (and Ni) in the Nile Delta. All values are means. Only differences at a confidence level above 95% are discussed in the text.

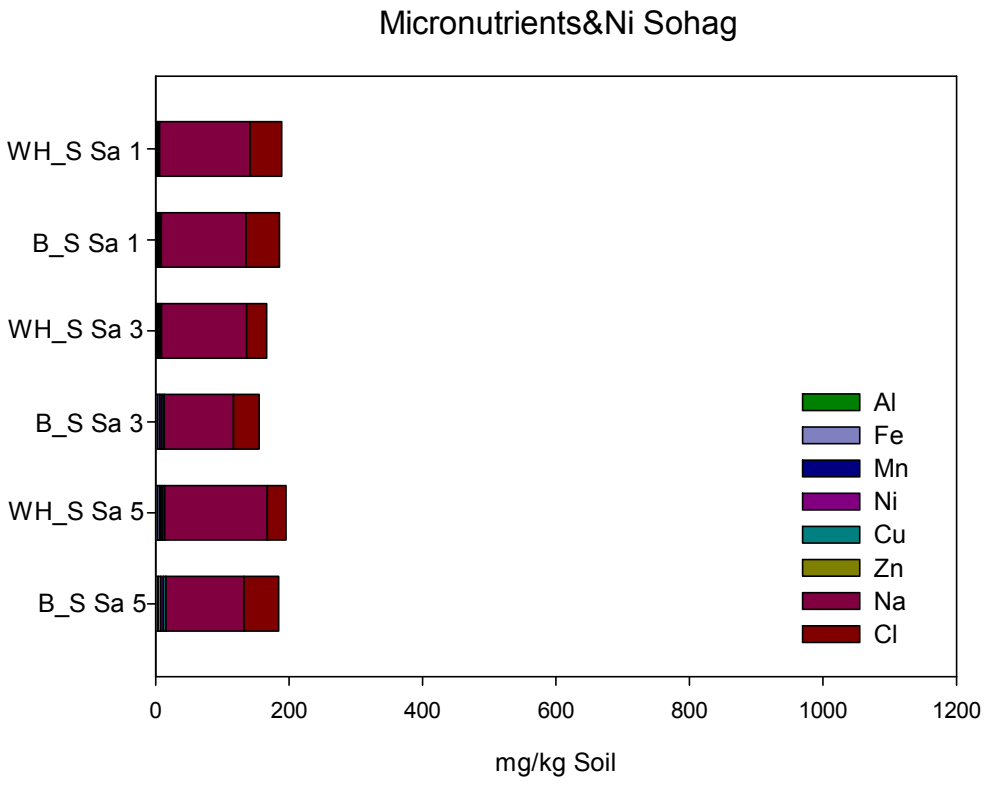

Figure 3.6.b: Micronutrients (and Ni) in Sohag. All values are means. Only differences at a confidence level above 95% are discussed in the text.

Figures 3.7.a-b show the concentration of other micronutrients, without those of Na^+ and Cl^-.

The concentrations of micronutrients are similar in all fields of both experimental sites, with the only exception of a higher concentration of Zn in Sohag. In the Nile Delta, the

total concentration of micronutrients is slightly higher in the cotton field, the only significant difference is a higher Mn concentration in the cotton field. In Sohag, there is a slight increase in the overall concentration of micronutrients over time, both no difference between the two fields could be found.

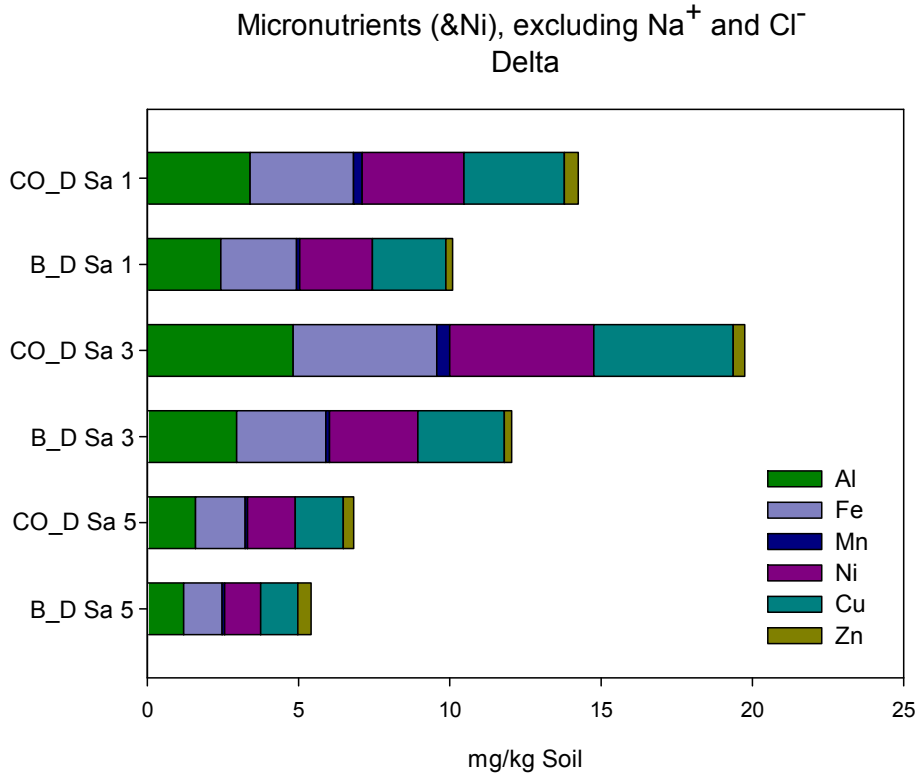

Figure 3.7.a : Micronutrients, excluding Na^+ and Cl^- in the Nile Delta. Values are means. Only differences at a confidence level above 95% are discussed in the text.

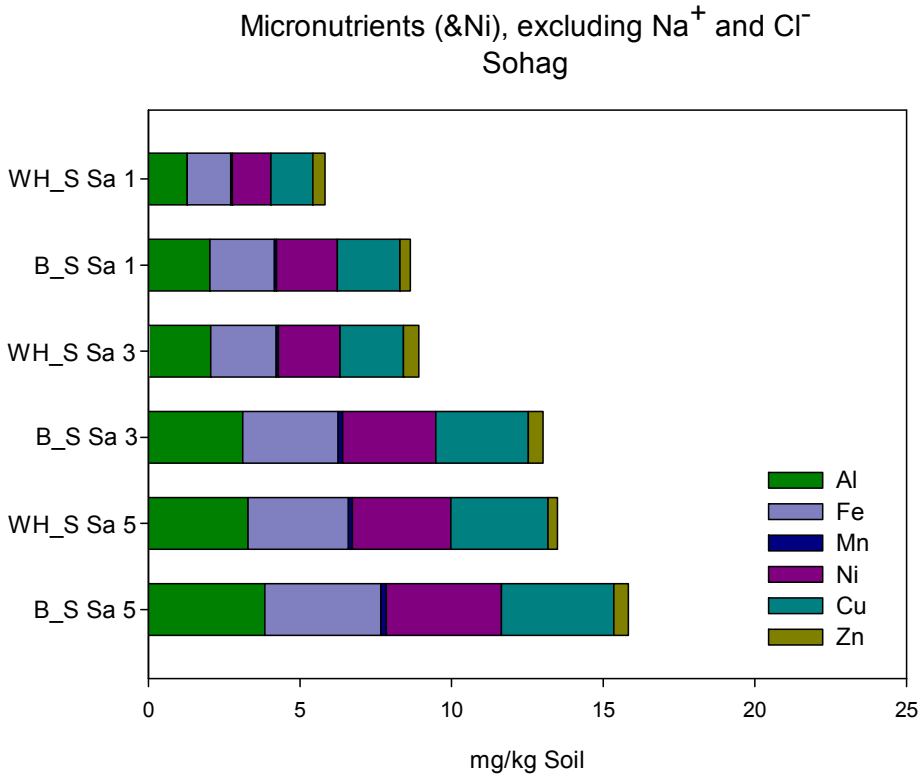

Figure 3.7.b: Micronutrients, excluding Na^+ and Cl^- in Sohag. Values are means. Only differences at a confidence level above 95% are discussed in the text.

Table 3.23: Micronutrients in the Nile Delta and Sohag. All values are means, S.E.=standard error

Cotton Delta								
	Al		**Fe**		**Mn**		**Ni**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	3.4	1.2	3.4	1.2	0.3	0.1	3.4	1.2
Sampling 3	4.8	1.2	4.7	1.2	0.4	0.1	4.8	1.2
Sampling 5	1.6	0.2	1.6	0.2	0.1	0.0	1.6	0.2
	Cu		**Zn**		**Na**		**Cl**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	3.3	1.1	0.5	0.2	312.7	22.0	343.3	42.4
Sampling 3	4.6	1.1	0.4	0.1	486.8	35.0	608.2	120.7
Sampling 5	1.6	0.2	0.3	0.1	214.6	21.9	115.2	11.9
Berseem Delta								
	Al		**Fe**		**Mn**		**Ni**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	2.4	0.3	2.5	0.3	0.1	0.0	2.4	0.3
Sampling 3	3.0	0.5	2.9	0.4	0.1	0.0	2.9	0.5
Sampling 5	1.2	0.4	1.3	0.4	0.1	0.0	1.2	0.4
	Cu		**Zn**		**Na**		**Cl**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	2.4	0.3	0.2	0.0	115.1	20.3	61.0	5.9
Sampling 3	2.9	0.4	0.2	0.0	172.7	12.2	42.0	4.5
Sampling 5	1.2	0.4	0.4	0.1	111.0	20.0	53.7	4.2
Berseem Sohag								
	Al		**Fe**		**Mn**		**Ni**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	2.0	0.3	2.1	0.3	0.1	0.0	2.0	0.3
Sampling 3	3.1	0.4	3.1	0.4	0.1	0.0	3.1	0.4
Sampling 5	3.8	1.7	3.8	1.6	0.2	0.1	3.8	1.7
	Cu		**Zn**		**Na**		**Cl**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	2.1	0.3	0.3	0.0	127.0	25.7	50.2	0.8
Sampling 3	3.0	0.4	0.5	0.1	104.0	13.5	38.2	9.7
Sampling 5	3.7	1.5	0.5	0.0	116.5	16.3	52.3	7.1
Wheat Sohag								
	Al		**Fe**		**Mn**		**Ni**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	1.3	0.2	1.4	0.2	0.1	0.0	1.3	0.2
Sampling 3	2.1	0.2	2.2	0.2	0.1	0.0	2.0	0.2
Sampling 5	3.3	0.5	3.3	0.4	0.1	0.0	3.2	0.5
	Cu		**Zn**		**Na**		**Cl**	
	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.	mg/kg DW	S.E.
Sampling 1	1.4	0.2	0.4	0.0	135.7	7.1	47.7	4.7
Sampling 3	2.1	0.2	0.5	0.0	127.5	8.7	30.2	4.6
Sampling 5	3.2	0.4	0.3	0.1	153.9	30.8	28.0	1.0

In order to be able to assess the concentrations of Na^+, Cl^-, Ca^+ and SO_4^{2-}, results were changed into mEq/kg soil (see figures 3.8.a-d). The concentration of all four elements is highest in the cotton field, with a strong increase of all four elements between the first and the third sampling; concentrations at the fifth sampling are comparable to those in the other three fields. All other three fields show similar concentrations.

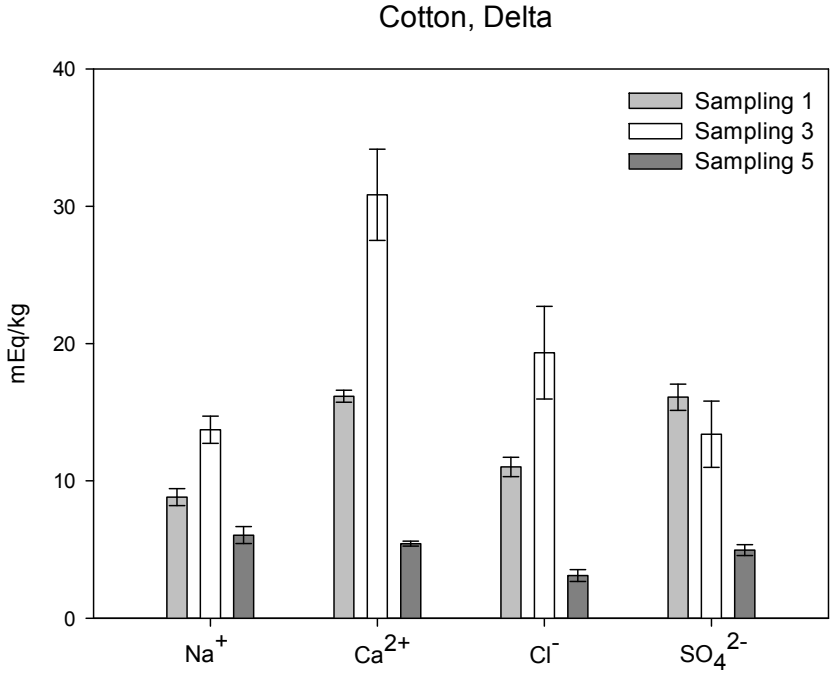

Figure 3.8.a: Concentration of Na^+, Cl^-, Ca^+ and SO_4^{2-} , cotton field, Nile Delta. All values are means, error=standard error

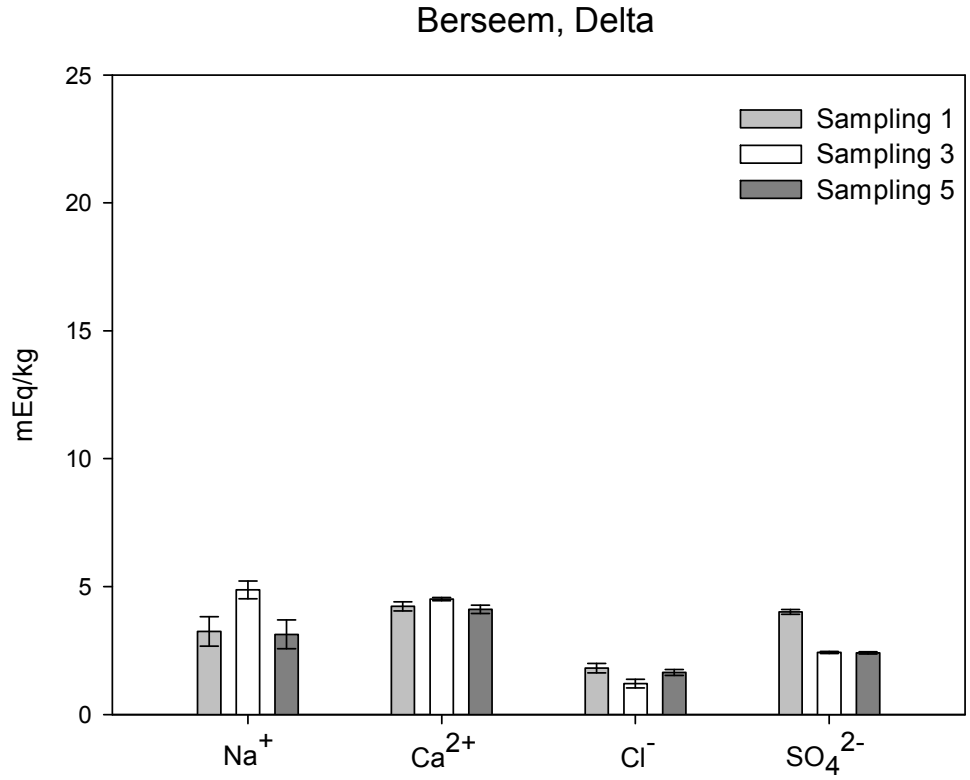

Figure 3.8.b: Concentration of Na^+, Cl^-, Ca^+ and SO_4^{2-} , Berseem field, Nile Delta. All values are means, error=standard error

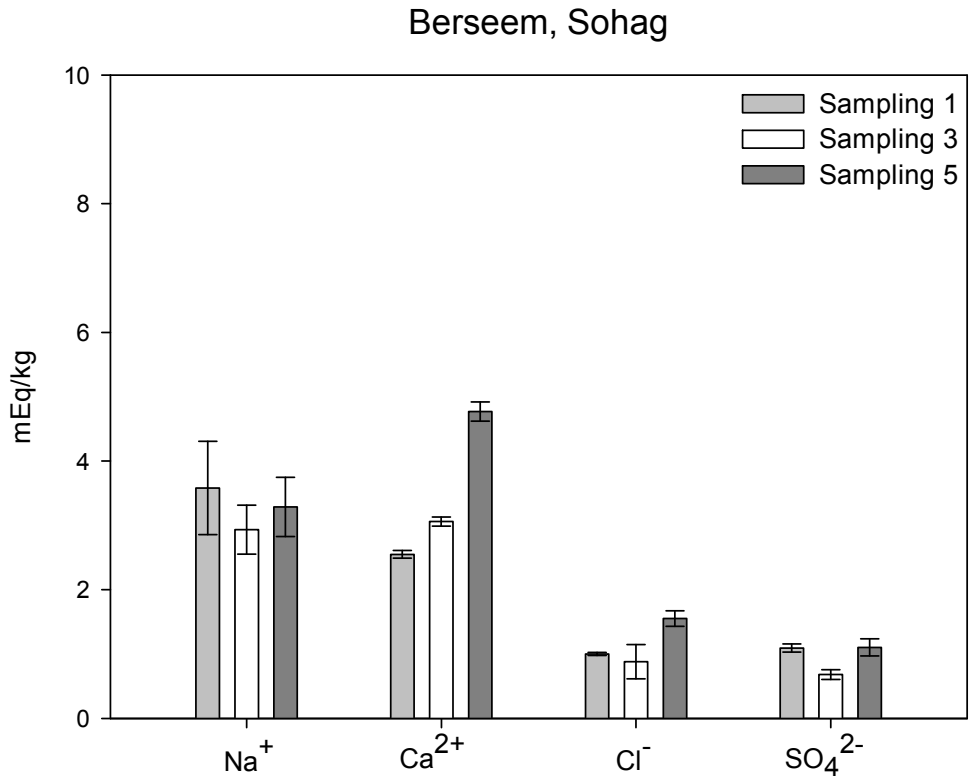

Figure 3.8.c: Concentration of Na^+, Cl^-, Ca^+ and SO_4^{2-} , Berseem field, Sohag. All values are means, error=standard error

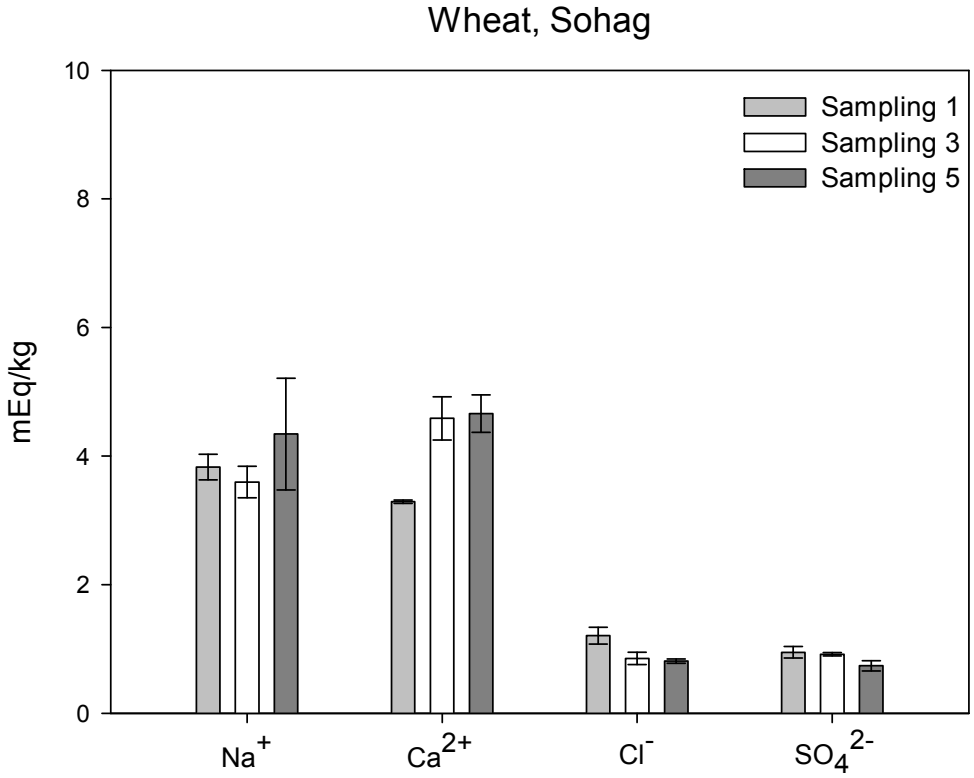

Figure 3.8.d: Concentration of Na^+, Cl^-, Ca^+ and SO_4^{2-} , wheat field, Sohag. All values are means, error=standard error

Cationic Mobility (see figures 3.9.a-d), the percentage of cations dissolved in water of the total amount of cations (in an acidic solution) indicates different trends for both experimental sites and for the respective fields.

Cationic mobility (CM) in the soil of the cotton field of the Nile Delta (see figure 3.9.a) is highest at the third sampling for all cations, the only exception being Zn. The second highest mobility of cations can be found at the first sampling, and the lowest at the 5th sampling, again with the only exception being Zn, which shows a reversed trend. CM of Na is highest, followed by that of K, with almost equal results for Mg, Al, Fe, Ni, Cu and Zn. Mobility for Ca is slightly lower, and that of Mn is lowest.

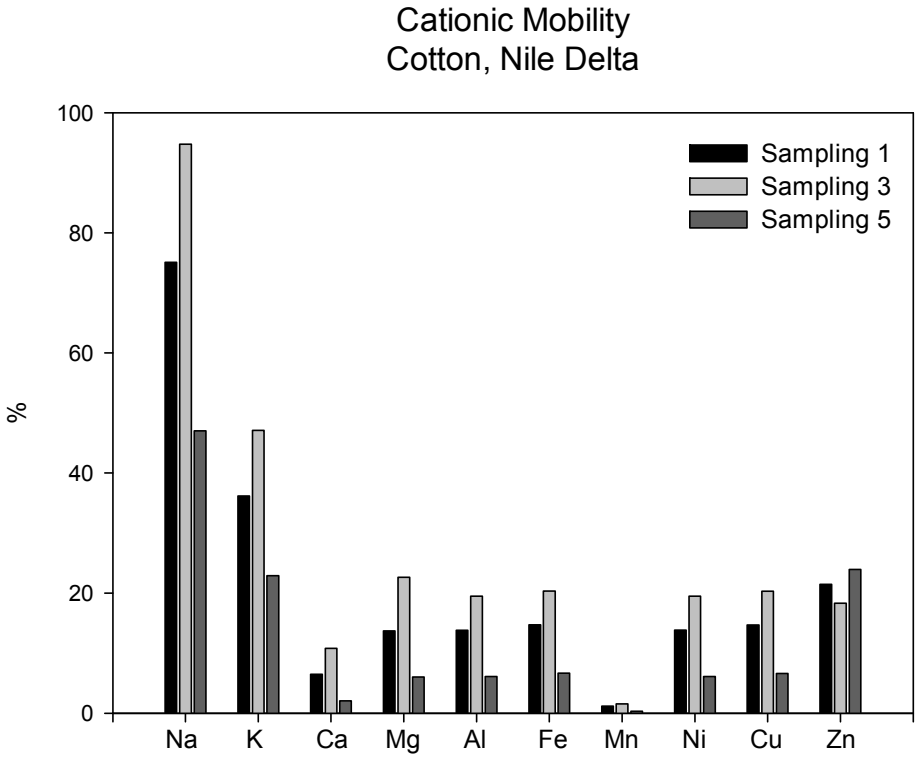

Figure 3.9.a: Cationic Mobility for Cations of the cotton field, Nile Delta. Values are means of cations in water solution in % of cations in acidic solution.

CM for the Berseem field (see figure 3.9.b) in the Nile Delta shows similar results to those of the adjacent cotton field, however, CM is generally lower, and CM is highest at the first sampling for Na, K, Ca, Mg and Zn, and second highest at the third sampling, with the only exception of, where the lowest value can be found at the third sampling. CM is highest for Na, followed by K for the first sampling, and Zn for the first and third sampling, and very similar results for Mg, Al, Fe, Ni, and Cu. CM for Ca and Mn is very low.

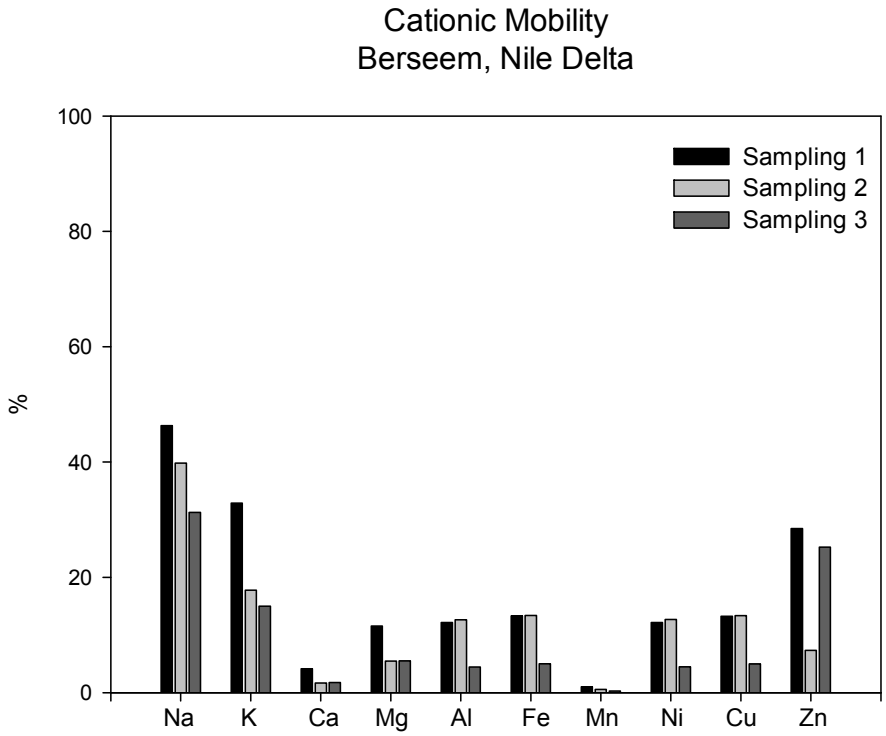

Figure 3.9.b: Cationic Mobility for Cations of the Berseem field, Nile Delta. Values are means of cations in water solution in % of cations in acidic solution.

CM for the Berseem field (see figure 3.9.c) in Sohag shows that CM is highest at the fifth sampling, second highest at the first sampling and lowest at the third sampling, for all cations other than K, Zn and Ca. CM for K and K and Zn is highest at the first sampling and almost identical and the third and fifth sampling, and for Ca it is lowest at the first sampling, then increasing slightly over time. CM for Na is highest in general, but CM for Al, Fe, Ni, and Cu increases strongly at the fifth sampling. Values of CM for K, Al, Fe, Ni, and Cu is comparable for samplings 1 and 3, that for Ca, Mg, Mn and Zn is rather low.

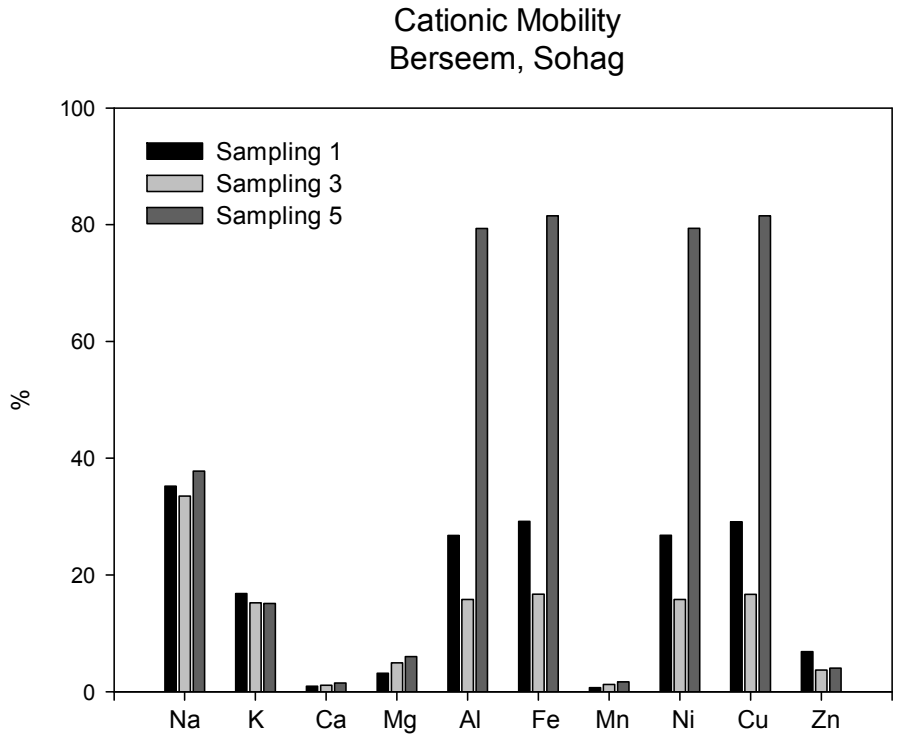

Figure 3.9.c: Cationic Mobility for Cations of the Berseem field, Sohag. Values are means of cations in water solution in % of cations in acidic solution.

CM for cations in the wheat field in Sohag could not be determined for Al, Fe, Ni and Cu, as results for concentration in acidic solution were so close to zero that they could not be taken into account and are marked as n.d. (not determined) in figure 3.9.d. CM for N, K, Ca, Mg, and Mn are comparable to CM of the adjacent Berseem field. CM for Zn differs, as it is low at the first sampling, highest at the third and second highest at the fifth sampling. CM of Ca, Mg, and Mn is lowest at the first sampling and increases over time.

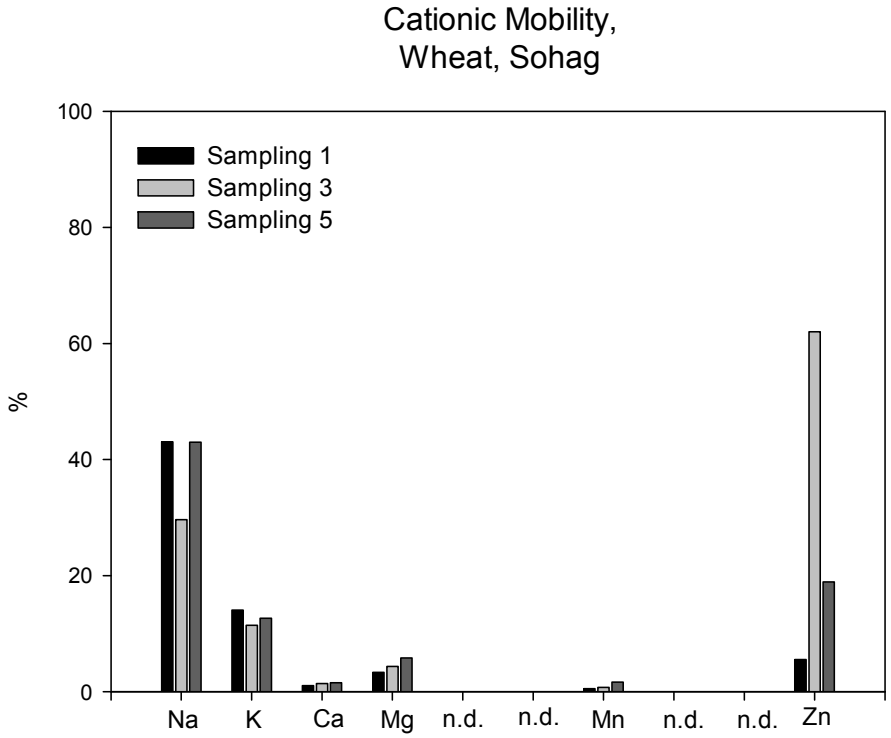

Figure 3.9.d: Cationic Mobility for Cations of the wheat field, Sohag. Values are means of cations in water solution in % of cations in acidic solution.

3.2.4 Salinity

Electrical Conductivity (EC) (figure 3.10) differs between the two experimental sites, with higher values found in the Nile Delta.
EC in Sohag remains constant throughout all five samplings, in the Nile Delta, the most dramatic changes can be found in the cotton field: EC increases between the first and the third sampling, then decreases to a value similar to the second sampling at time of the fourth sampling and then decreases to below the value of the first sampling. At the fifth sampling, EC is still higher in the soil of the cotton field compared to the adjacent Berseem field. Changes in the Berseem field are not as dramatic as in the cotton field, and show a different trend: EC is highest at the time of the first, and lowest at the time of the third sampling.

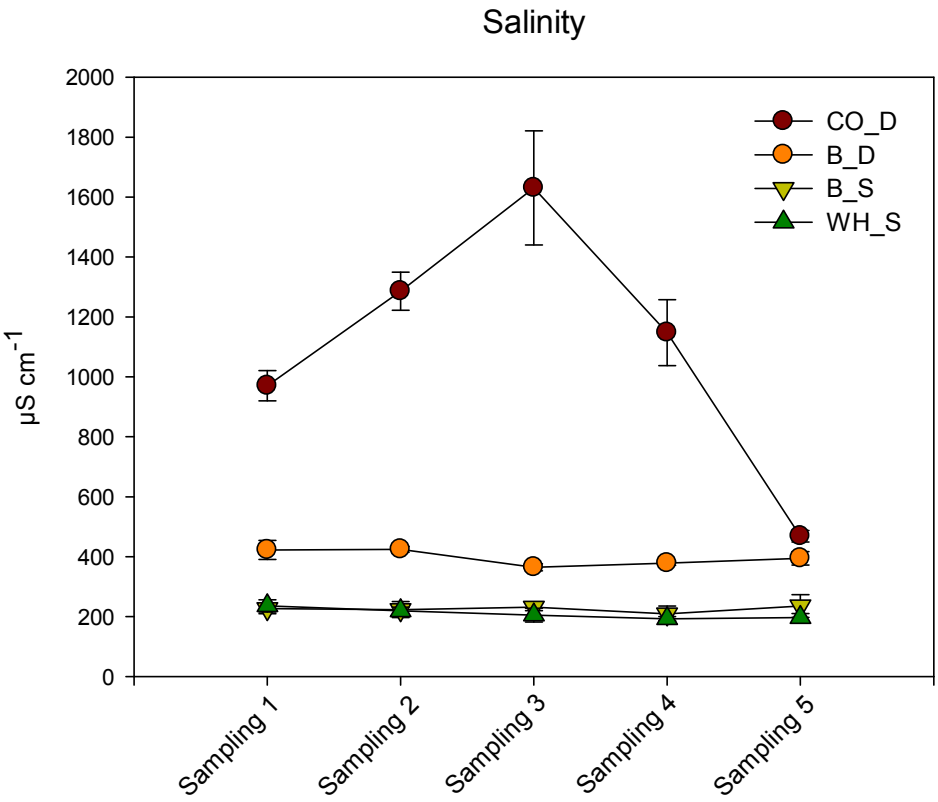

Figure 3.10: Electrical Conductivity (EC) in µS cm^{-1}. All values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.24: Electrical Conductivity (EC). All values are means, S.E.=standard error

	Cotton Delta		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	µS cm^{-1}	*S.E.*	*µS cm^{-1}*	*S.E.*	*µS cm^{-1}*	*S.E.*	*µS cm^{-1}*	*S.E.*
Sampling 1	970,5	50,7	422,0	31,9	226,5	16,9	236,0	20,1
Sampling 2	1286,0	63,6	424,5	9,6	223,5	26,5	219,0	12,3
Sampling 3	1630,5	190,3	364,5	11,9	231,5	11,6	205,0	23,0
Sampling 4	1147,5	110,1	378,0	6,9	209,0	26,1	193,0	7,1
Sampling 5	468,0	19,3	394,5	22,1	235,5	38,0	197,0	13,5

3.2.5. Isotopes/Organic Matter

Δ ^{15}N and δ ^{13}C (see figures 3.11.a-b) show similar trends:
in both cases, values are higher in the Nile Delta than in Sohag.

In the Nile Delta, values remain almost constant throughout time, however, there is a decrease of δ ^{15}N at the fourth sampling in the cotton field, and δ ^{13}C is lower in the cotton field at the first and the fifth sampling, both times compared to the adjacent clover field.

In Sohag, there is a substantial decrease in δ ^{15}N and an increase in δ ^{13}C at the 3rd sampling in the Berseem field. Values for the wheat field remain almost constant for both values, however, generally lower values for δ ^{15}N can be found in the wheat field compared to the Berseem field.

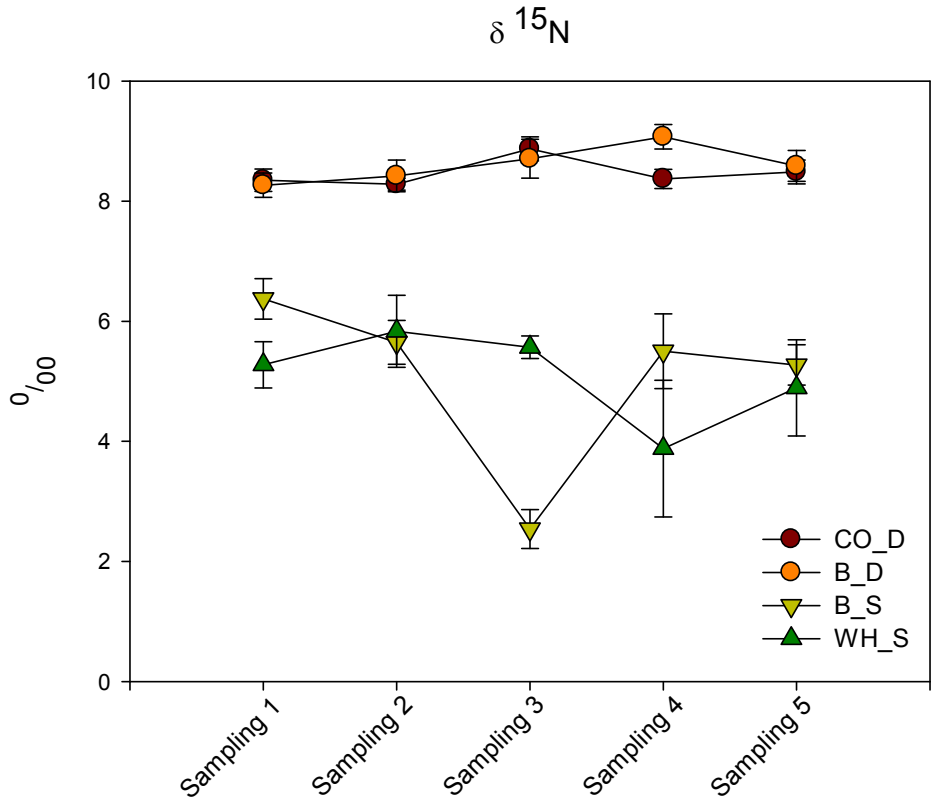

Figure 3.11.a: Δ ^{15}N, all values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

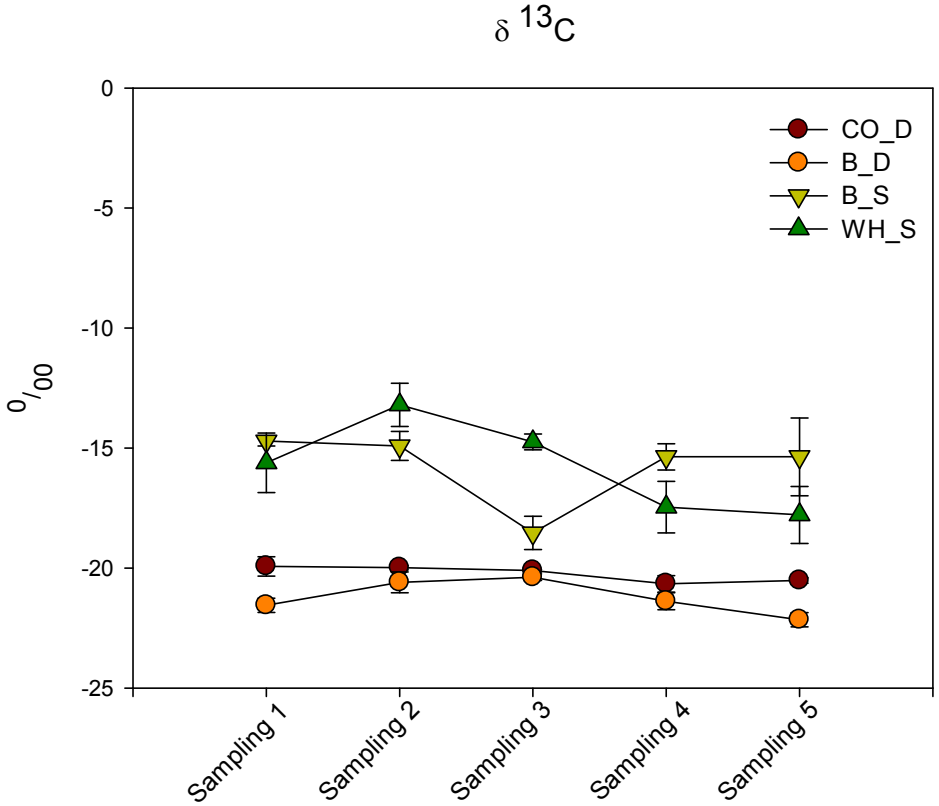

Figure 3.11.b : Δ ^{13}C, all values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.25: Δ ^{15}N and Δ ^{13}C, all values are means. S.E.=standard error

δ *15N*	**Cotton Delta**		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	‰	S.E.	‰	S.E.	‰	S.E.	‰	S.E.
Sampling 1	8,35	0,19	8,27	0,20	6,37	0,34	5,27	0,39
Sampling 2	8,28	0,10	8,42	0,26	5,65	0,36	5,83	0,60
Sampling 3	8,87	0,20	8,71	0,32	2,54	0,32	5,57	0,19
Sampling 4	8,37	0,16	9,07	0,21	5,50	0,62	3,88	1,14
Sampling 5	8,49	0,20	8,59	0,26	5,27	0,34	4,89	0,80
δ *13C*	**Cotton Delta**		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	‰	S.E.	‰	S.E.	‰	S.E.	‰	S.E.
Sampling 1	-19,93	0,40	-21,55	0,30	-14,71	0,21	-15,61	1,24
Sampling 2	-19,99	0,09	-20,59	0,43	-14,91	0,61	-13,20	0,90
Sampling 3	-20,11	0,05	-20,38	0,14	-18,54	0,69	-14,75	0,33
Sampling 4	-20,66	0,34	-21,38	0,36	-15,37	0,54	-17,46	1,07
Sampling 5	-20,52	0,11	-22,15	0,30	-15,36	1,62	-17,79	1,19

Total Organic Carbon (TOC) (see figure 3.12) is significantly higher in the Nile Delta than in Sohag. In Sohag, values remain constant over time, and there are no differences between the two fields. In the Nile DeltaTOC increases over time, and the values between the two fields differ at the 1st, 2nd and 4th sampling, with higher values found in the Berseem field. Total carbon is lower in the cotton field, and decreases at the 4th sampling, whereas values in the Berseem field increase constantly after the second sampling.

Values for Total Inorganic Carbon are 0.37% for the cotton field, 0.42% for the Berseem field in the Nile Delta, 0.81% for the Berseem field in Sohag, and 0.95% for the wheat field. Total Carbon was measured; values for Total Inorganic Carbon were subtracted from the total for the depiction of TOC.

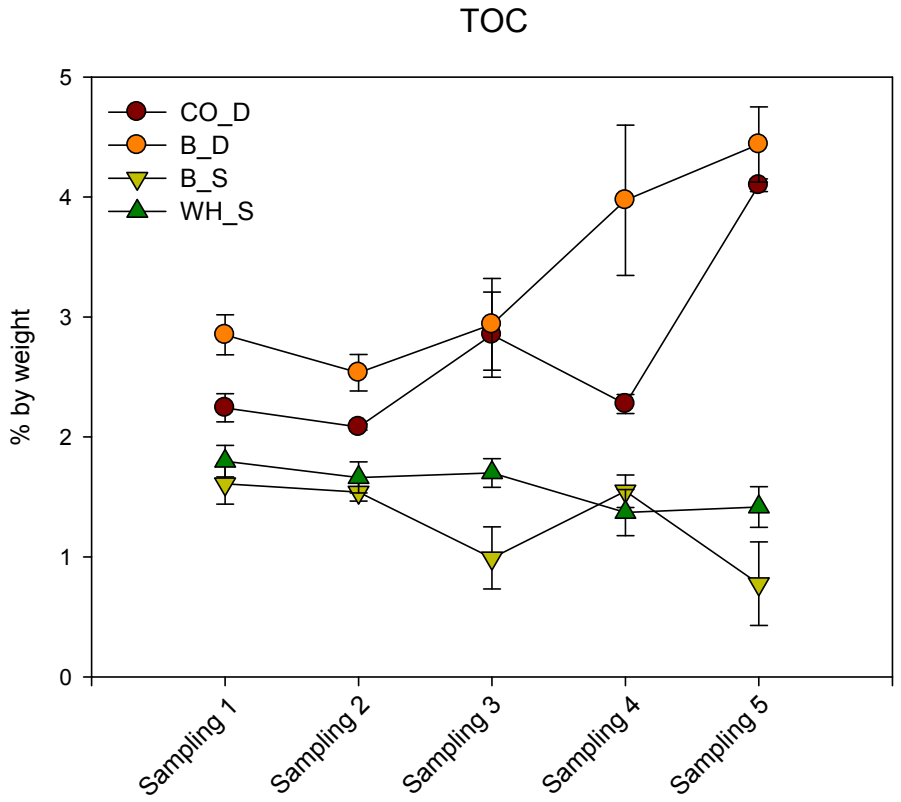

Figure 3.12: Total Organic Carbon. All values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Total Nitrogen (see figure 3.13) remains almost constant over time in all four fields. The only increase is between the 2nd and 3rd sampling at both fields in Sohag. Again, there the two experimental sites differ in their content of total N, with higher values for the Nile Delta soils.

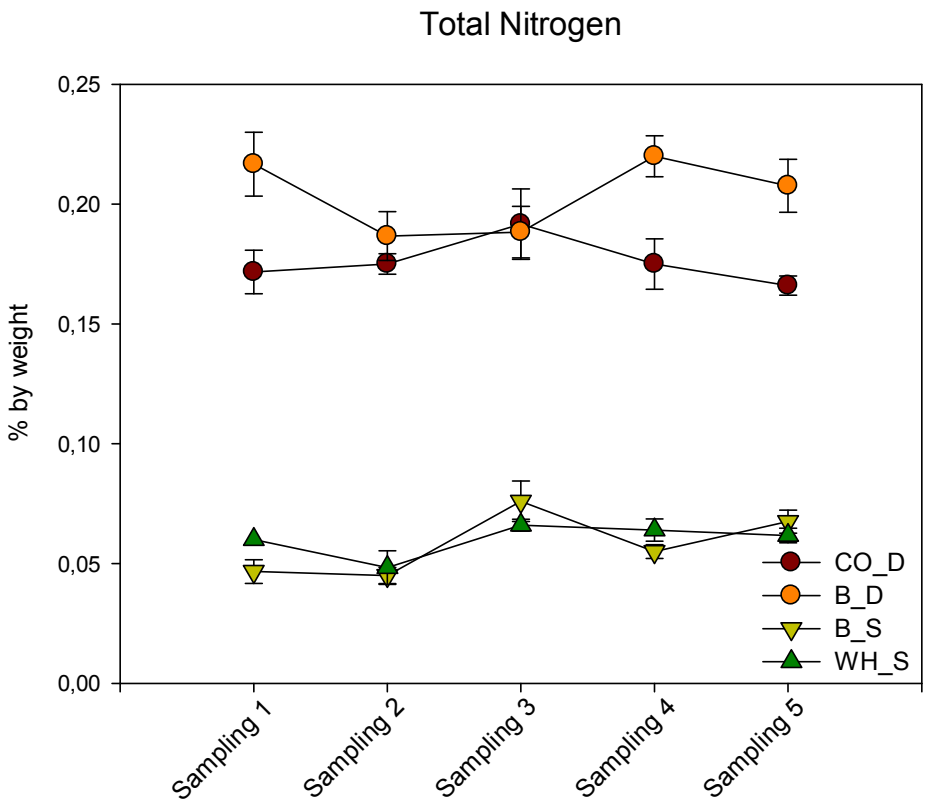

Figure 3.13: Total Nitrogen. All values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

C:N ratio (see figure 3.14) again differs between the two experimental sites. The strongest increase in C:N can be found in the field planted with cotton, where there is a higher value at the 5th sampling. Looking at the results of the Nile Delta, it is interesting to note that C:N ratio remains constant at the first two samplings, then increases slightly. At the fourth sampling, C:N ratio is lower in the cotton field, at the 5th sampling, C:N is higher in the field planted with cotton compared to the adjacent Berseem field.

In Sohag, C:N ratio is higher in the Berseem field at the second and the fifth sampling, the C:N ratio is lower in the Berseem field at the third sampling compared to all other samplings.

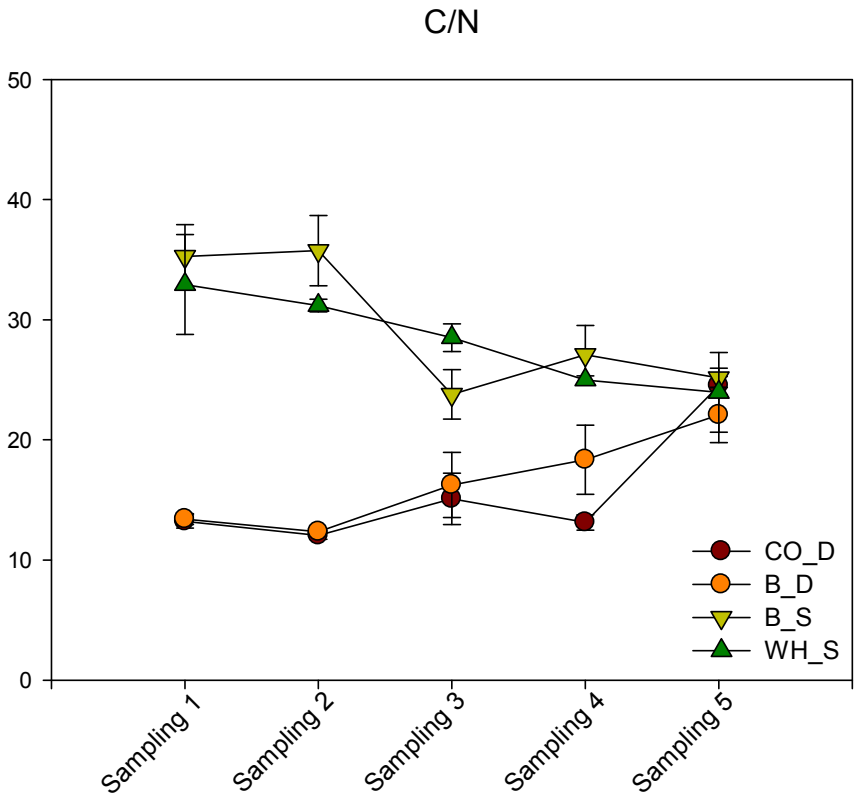

Figure 3.14: C:N ratio. All values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.26.: Values for Total C_{org}, total N and C/N. All values are means, S.E.=standard error.

TOC	**Cotton Delta**		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	% by weight	S.E.	% by weight	S.E.	% by weight	S.E.	% by weight	S.E.
Sampling 1	2,24	0,12	2,85	0,17	1,61	0,17	1,80	0,13
Sampling 2	2,08	0,03	2,54	0,15	1,54	0,08	1,66	0,13
Sampling 3	2,85	0,35	2,94	0,38	0,99	0,26	1,70	0,12
Sampling 4	2,27	0,08	3,97	0,63	1,55	0,14	1,37	0,19
Sampling 5	4,10	0,05	4,44	0,31	0,78	0,35	1,42	0,17
Total N	**Cotton Delta**		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	% by weight	S.E.	% by weight	S.E.	% by weight	S.E.	% by weight	S.E.
Sampling 1	0,17	0,01	0,22	0,01	0,05	0,00	0,06	0,00
Sampling 2	0,18	0,00	0,19	0,01	0,05	0,00	0,05	0,01
Sampling 3	0,19	0,01	0,19	0,01	0,08	0,01	0,07	0,00
Sampling 4	0,18	0,01	0,22	0,01	0,06	0,00	0,06	0,00
Sampling 5	0,17	0,00	0,21	0,01	0,07	0,00	0,06	0,00
C/N	**Cotton Delta**		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	C/N	S.E.	C/N	S.E.	C/N	S.E.	C/N	S.E.
Sampling 1	13,21	0,55	13,40	0,46	35,26	2,66	32,93	4,15
Sampling 2	12,04	0,32	12,36	0,11	35,75	2,94	31,17	0,52
Sampling 3	15,09	2,14	16,25	2,71	23,78	2,06	28,51	1,15
Sampling 4	13,13	0,63	18,34	2,88	27,08	2,44	24,99	0,33
Sampling 5	24,52	0,75	22,07	2,30	25,15	0,80	23,95	3,31

3.3. Soil Biological Parameters

3.3.1. Basal Respiration

Basal Respiration (figure 3.15) is generally higher in the Nile Delta compared to the fields in Sohag.
In Sohag, there is a general increase in respiration over time, but no differences between the two fields could be recorded at any sampling. In the Nile Delta, Basal Respiration in the clover field decreases between the first and second sampling with a higher value at the first sampling compared to the cotton field, other than that, no changes over time in neither field could be observed. Like in Sohag, no differences between the two fields could be found.

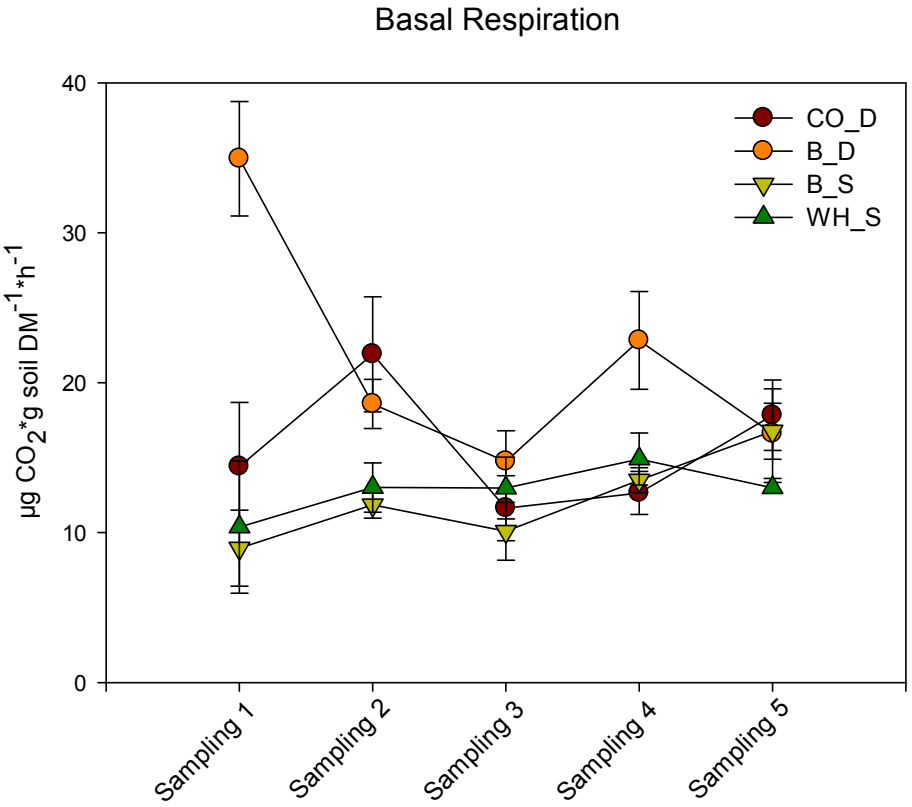

Figure 3.15: Basal Respiration in the Nile Delta and Sohag. Values are medians, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.27.: Values for Basal Respiration. All values are medians, µgCO$_2$ refers to µgCO$_2$ g DM^{-1}h^{-1}, S.E.=standard error.

	Cotton Delta		Berseem Delta		Berseem Sohag		Wheat Sohag	
	µg CO$_2$	*S.E.*	*µg CO$_2$*	*S.E.*	*µg CO$_2$*	*S.E.*	*µg CO$_2$ g*	*S.E.*
Sampling 1	14.4	4.3	34.9	3.8	9.0	2.5	10.4	4.4
Sampling 2	21.9	3.8	18.6	1.6	11.9	0.9	13.0	1.6
Sampling 3	11.6	2.2	14.7	2.0	10.1	1.9	13.0	2.1
Sampling 4	12.6	1.4	22.8	3.3	13.5	0.8	14.9	1.7
Sampling 5	17.8	2.4	16.6	3.0	16.8	1.9	11.3	0.8

3.3.2. Substrate Induced Respiration (SIR)

SIR (see figure 3.16) again is higher in general in the Nile Delta compared to Sohag. In the Nile Delta, SIR differs between the two fields at the second and third sampling, with higher values in the cotton field at the second sampling, and a lower value at the third sampling. SIR in the Berseem field increase from the first to the fourth sampling, then decrease to a value lower than at the first sampling.
In Sohag, both fields show very similar trends, however, there is a significant increase in SIR in the wheat field between samplings 1 and 2. Otherwise, there are no significant differences between the two fields in Sohag.

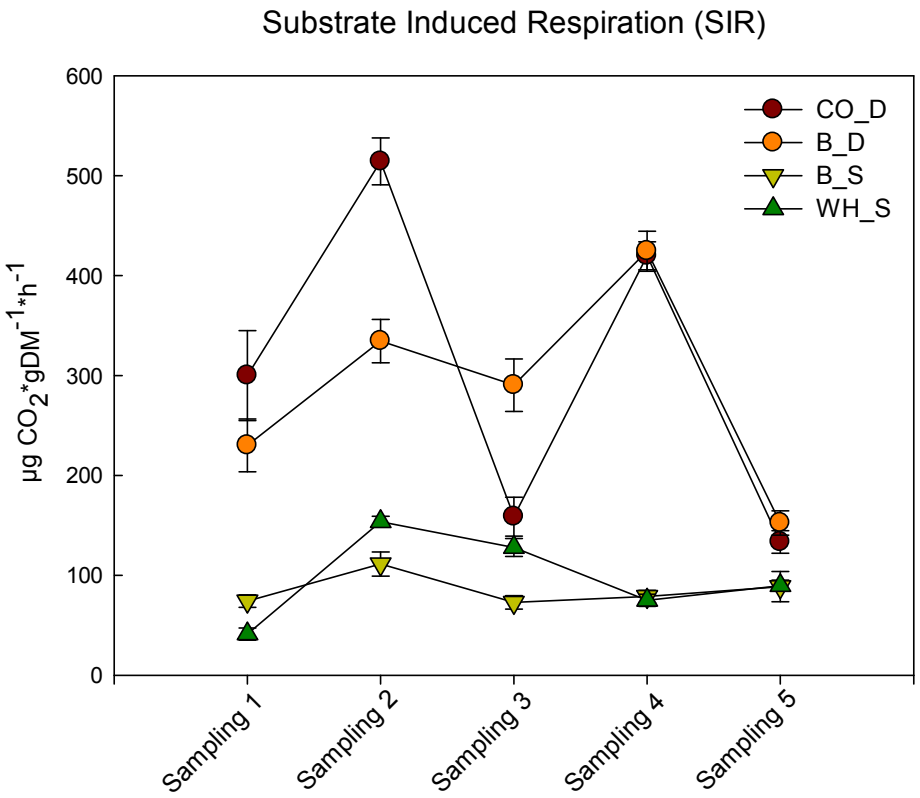

Figure 3.16: Substrate Induced Respiration (SIR) in the Nile Delta and Sohag. All values are medians, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.28.: Values for Substrate Induced Respiration. All values are medians, μgCO_2 g $DM^{-1}h^{-1}$ S.E.=standard error.

SIR	Cotton Delta		Berseem Delta		Berseem Sohag		Wheat Sohag	
	µg CO_2	*S.E.*	*µg CO_2*	*S.E.*	*µg CO_2*	*S.E.*	*µg CO_2*	*S.E.*
Sampling 1	299.9	45.0	230.0	26.4	74.2	6.3	41.4	6.0
Sampling 2	514.2	23.5	334.4	21.6	111.4	12.1	153.6	5.5
Sampling 3	158.8	19.5	290.4	26.3	73.0	6.7	127.9	8.8
Sampling 4	419.9	13.9	424.5	20.0	79.0	6.1	75.1	6.1
Sampling 5	133.5	11.4	152.5	12.3	88.8	15.2	89.6	5.5

3.3.3. Dehydrogenase activity

Dehydrogenase activity (see figure 3.17) is higher in the fields of the Nile Delta compared to those in Sohag, apart from the cotton field at the fifth sampling, when dehydrogenase activity in the cotton field is lower than that of the fields in Sohag.

In the Nile Delta, both fields show similar trends, with an increase of dehydrogenase activity at the fourth sampling with a subsequent decrease. Dehydrogenase activity is higher in the clover field than in the cotton field. In Sohag, both fields show similar activity and trends, with an increase at the fourth sampling and a subsequent decrease. However, at the time of the fifth sampling, dehydrogenase activity is still higher than at the first sampling.

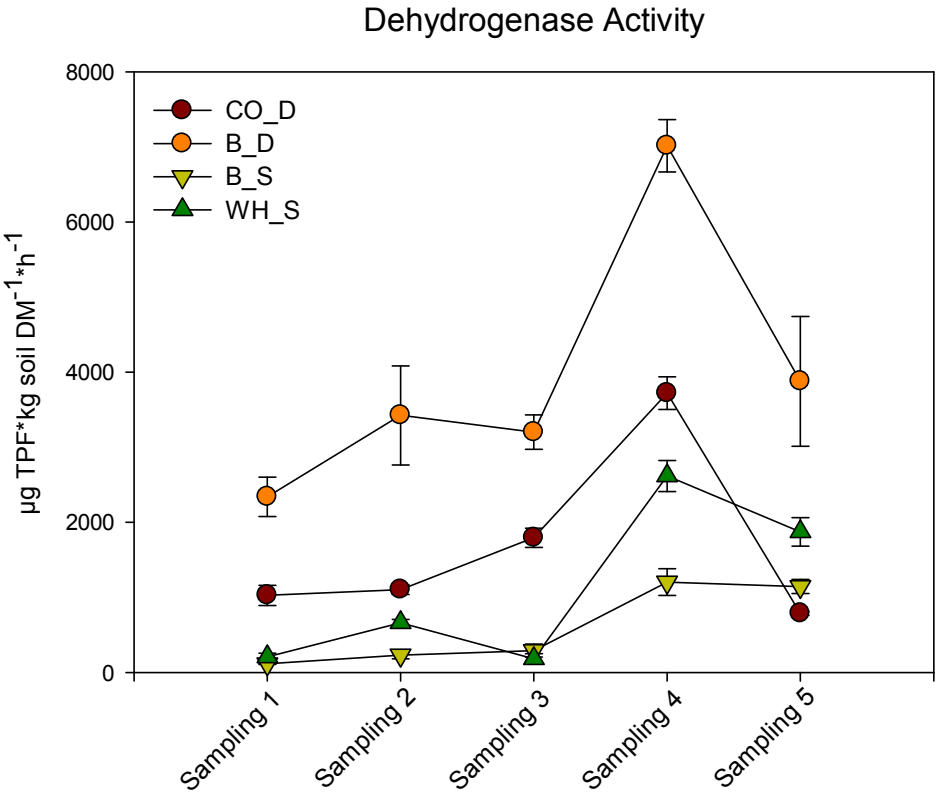

Figure 3.17: Dehydrogenase Activity in the Nile Delta and Sohag. Values are means, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.29: Dehydrogenase Activity. Values are means,µgTPF refers to µg TPF $kgDM^{-1}h^{-1}$, S.E.=standard error

	Cotton Delta		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	µg TPF	*S.E.*	*µg TPF*	*S.E.*	*µg TPF*	*S.E.*	*µg TPF*	*S.E*
Sampling 1	1026.9	133.6	2339.3	261.6	112.5	15.3	207.0	48.5
Sampling 2	1103.0	194.9	3424.6	602.6	231.4	48.5	663.6	117.6
Sampling 3	1918.1	690.8	3201.5	229.4	291.5	86.3	183.7	60.8
Sampling 4	3720.6	217.0	7015.1	349.4	1203.8	178.1	2617.8	207.7
Sampling 5	787.2	125.6	3878.4	863.2	1219.3	173.6	1873.4	188.6

3.3.4. Urease Activity

Urease Activity (see figure 3.18.) is higher in the Nile Delta than in Sohag.
Urease activity is very similar in both fields in the Nile Delta from sampling 1-3, then there is a significant increase in activity at the 4th and 5th sampling, where activity is significantly higher in the clover field. Urease Activity does not change significantly in the cotton field over time. In Sohag, there is no significant change over time, and the two fields show very similar values.

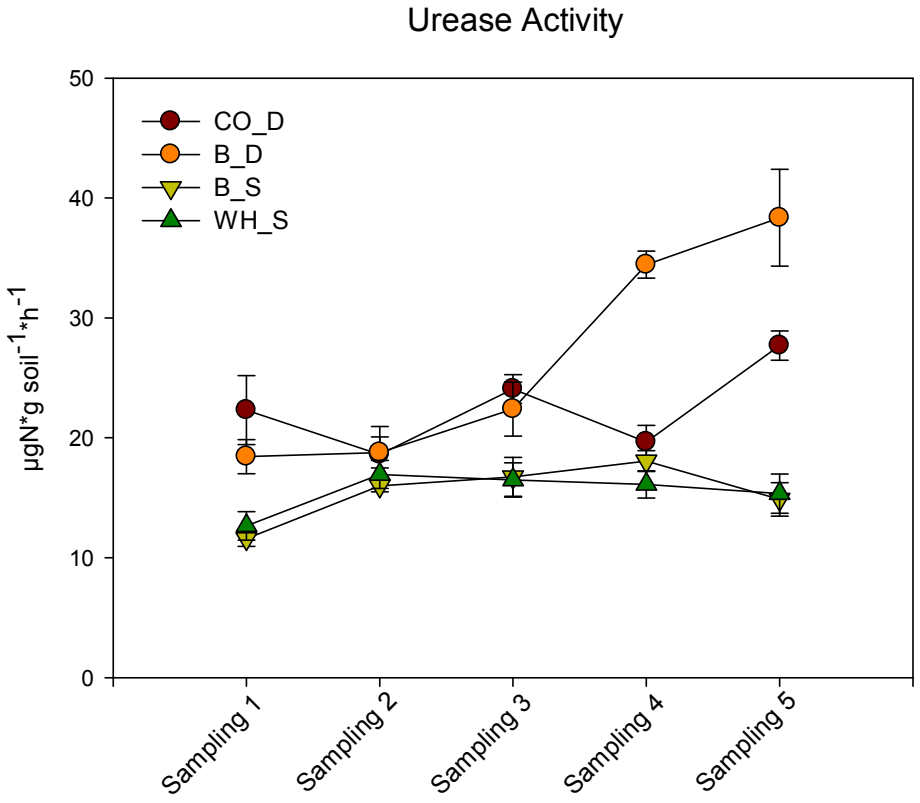

Figure 3.18: Urease Activity in the Nile Delta and Sohag. All values are medians, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.30.: Urease Activity. All values are medians, µgN refers to µgN g $DM^{-1}h^{-1}$, S.E.=standard error

	Cotton Delta		**Berseem Delta**		**Berseem Sohag**		**Wheat Sohag**	
	µgN	*S.E.*	*µgN* [1]	*S.E.*	*µgN*	*S.E.*	*µgN*	*S.E.*
Sampling 1	22,3	2,9	18,4	1,4	11,6	0,7	12,7	1,2
Sampling 2	18,6	2,3	18,8	1,3	16,0	0,5	16,9	1,2
Sampling 3	24,1	1,2	22,4	2,2	16,7	1,6	16,5	1,4
Sampling 4	19,7	1,4	34,4	1,1	18,1	0,9	16,1	1,1
Sampling 5	27,7	1,2	38,3	4,0	14,9	1,4	15,3	1,6

3.3.5. Phosphatase Activity

Phosphatase Activity (see figure 3.19.) is again higher in the Nile Delta than in Sohag. In the Nile Delta, there is a significant decrease (however, not highly significant) in the Berseem field between sampling 1 and 2, then values increase again, whereas they remain more or less constant in the cotton field. At the time of the 4th sampling, values are significantly higher in the Berseem field than in the cotton field. In Sohag, phosphatase activity is similar in both fields, there are no increases or decreases over time, nor is there a significant difference between the two fields.

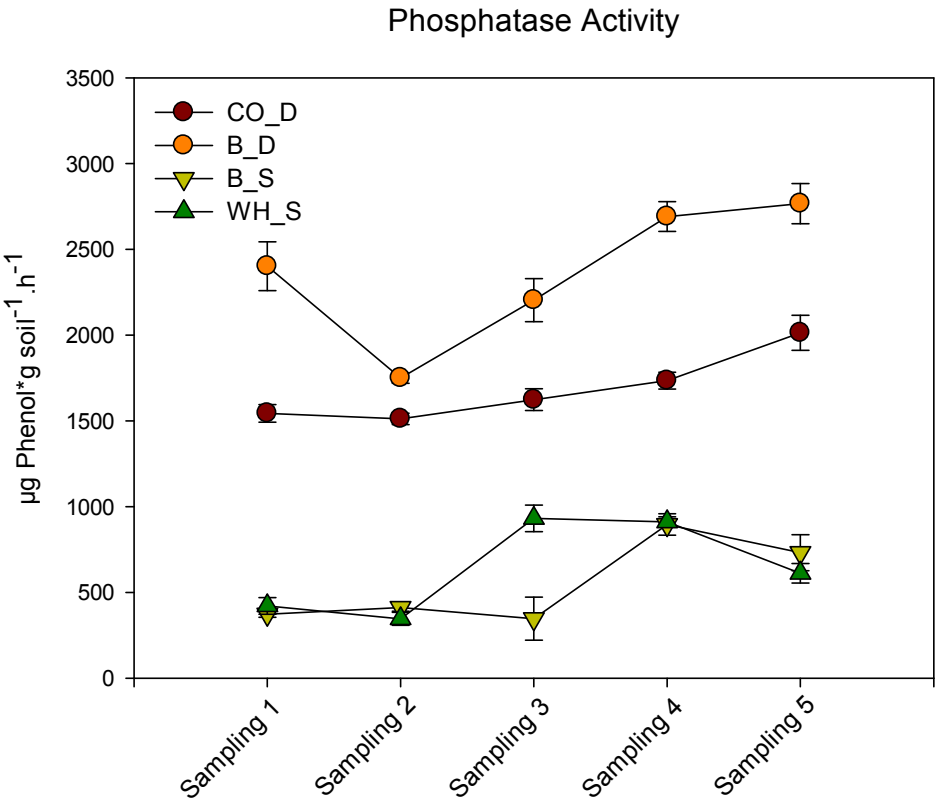

Figure 3.19.: Phosphatase Activity in the Nile Delta and Sohag. Values are medians, error=standard error. Only differences at a confidence level above 95% are discussed in the text.

Table 3.31: Phosphatase Activity. Values are medians, µg Phenol refers to µgPhenol $gDM^{-1}h^{-1}$, S.E.=standard error

	Cotton Delta		Berseem Delta		Berseem Sohag		Wheat Sohag	
	µgPhenol	*S.E.*	*µgPhenol*	*S.E.*	*µgPhenol*	*S.E.*	*µgPhenol*	*S.E.*
Sampling 1	1543,7	50,9	2402,2	142,3	372,8	17,3	421,1	48,7
Sampling 2	1511,8	32,7	1750,1	30,5	412,3	22,0	345,8	37,9
Sampling 3	1623,7	63,8	2203,6	125,6	346,4	125,4	931,2	77,8
Sampling 4	1734,8	48,2	2691,4	87,2	895,8	62,3	910,5	30,0
Sampling 5	2013,3	102,3	2767,0	117,1	731,3	104,8	611,0	57,4

3.4. Principal Component Analysis

For the Principal Component Analysis (PCA), soils from the Nile Delta and Sohag were analysed separately, in order to be able to assess correlations between parameters that might differ from site to site.

As principal component graphs are three dimensional, simple regressions (linear regressions) were used to analyse relations between components, these correlations are

explained in the text. Only significant relationships at the 95% confidence level or above, with a p value <0.01, are discussed in the text. The R-Squared value shows the percentage of variability in the y values explained by the x variable. For assessing the strength of a relationship (weak, moderate, strong) the default setting of Statgraphics Plus 5.0 were used and are referred to in the text.

3.4.1. Nile Delta

Looking at the PCA of soil physical parameters (WHC; pH, %SAS, DW%FW) depicted in figure 3.20., those elements assessed by mass spectroscopy (δ ^{13}C, δ ^{15}N, C_{org}, N, C:N) and salinity (Electrical Conductivity, EC) in figure 3.26 , it seems as if there is a correlation between EC, δ ^{13}C and δ ^{15}N, N, and %SAS.

The relationship between EC and N is significant, however, looking at the correlation coefficient (r^2), it indicates a relatively weak relationship between the variables (r^2=9.52). The same accounts for the relationship between EC and δ ^{13}C (r^2=18.92), %SAS (r^2=23.32), and δ ^{15}N (r^2=0.2). There is a moderately strong relationship between EC and pH (r^2=37.91), and δ ^{13}C and %SAS (r^2=29.24). Relationships between DW%FW and pH, as well as DW%FW and %SAS are significant, but weak. The same accounts for the relationship between δ ^{13}C and δ ^{15}N, pH, and WHC.

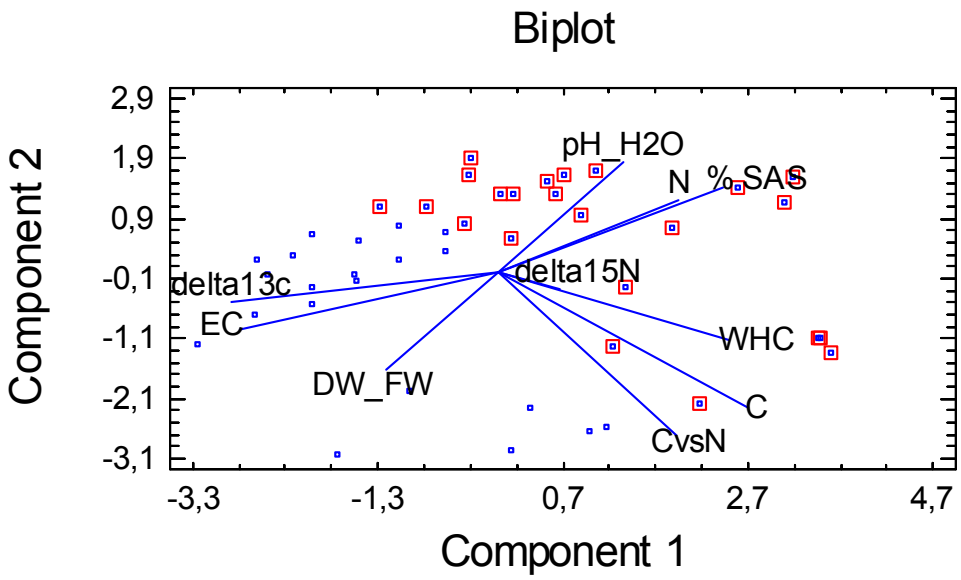

Figure 3.20: PCA of soil physical parameters, organic matter and salinity (EC). Squares indicate values of the Berseem field.

PCA of enzyme activity, soil physical parameters, cation exchange capacity (CEC) and electrical conductivity (EC) (see figure 3.21) indicates a possible relationship between EC, CEC and %SAS, urease and phosphatase activities.

The only moderately strong relationship found between parameters is between EC and phosphatase activity (r^2=39.83). Urease activity and Substrate Induced Respiration (SIR) are influenced by EC, but only weakly (r^2=10.8 and 1.5). The relationship between SIR and WHC is also significant, but weak (r^2=21.1).

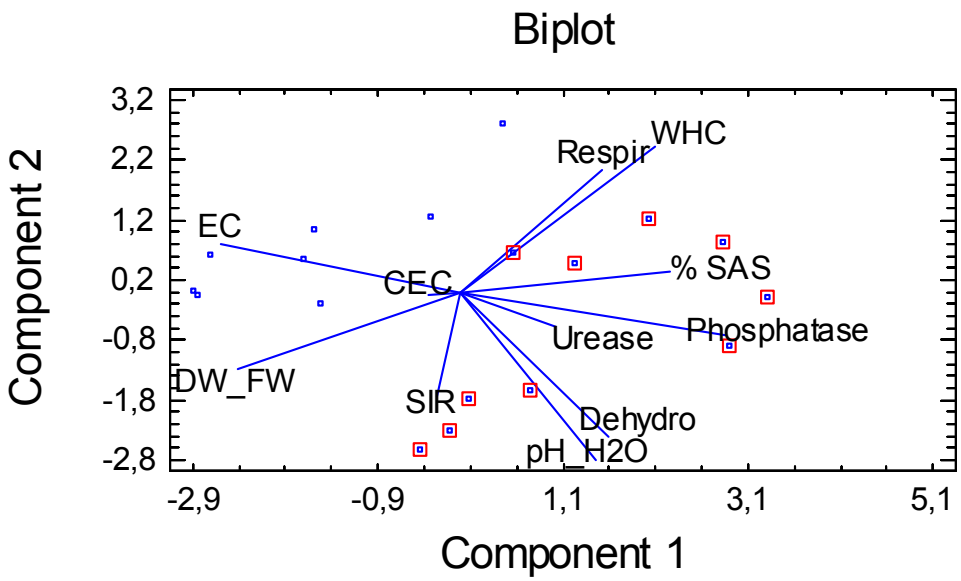

Figure 3.21: PCA of enzyme activities, soil physical parameters, Cation Exchange Capacity (CEC), and Electrical Conductivity. Squares indicate values of the Berseem field

Looking at the PCA of enzyme activities and parameters derived from mass spectroscopy (see figure 3.22), it seems as if δ ^{13}C influences phosphatase activity as well as other parameters.
The strongest influence can be found between δ ^{13}C and phosphatase activity, however, r^2=53.74, indicating only a moderately strong relationship between parameters. δ ^{13}C also influences dehydrogenase activity (r^2=26.7, indicating a moderately strong relationship), urease activity (r^2=18.3, weak relationship), and respiration (r^2=15.1, weak relationship).

There is a strong relationship between C:N and C_{org} (r^2=81.5%), but not between C:N and N (r^2=3.4, weak relationship)

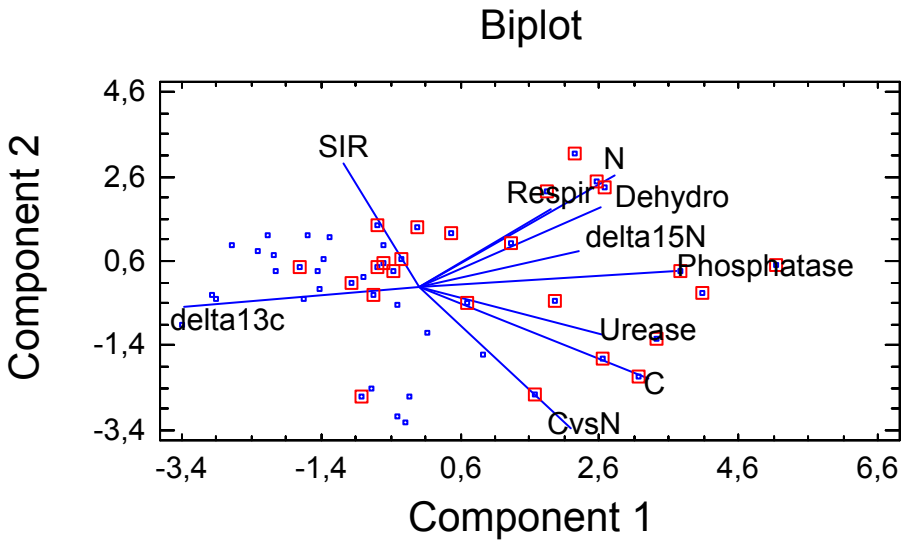

Figure 3.22: PCA of Enzyme Activities and Organic Matter. Squares indicate values of the Berseem field.

The PCA of EC, CEC, cations and anions (see figure 3.23) indicates moderately strong relationships between EC and: Na (r^2=80.3), Cl (r^2=71.2), Ca (r^2=76.4), Mg (r^2=75.1), K

(r^2=74.4), Mn (r^2=63.4), Al (r^2=36.3), Ni (r^2=36.3), Fe (r^2=36.9), Cu (r^2=37.1), NO_3 (r^2=73.14), and SO_4 (r^2=64.5). EC is not influenced by Zn (r^2=9.2), and PO_4 (r^2=14.26).

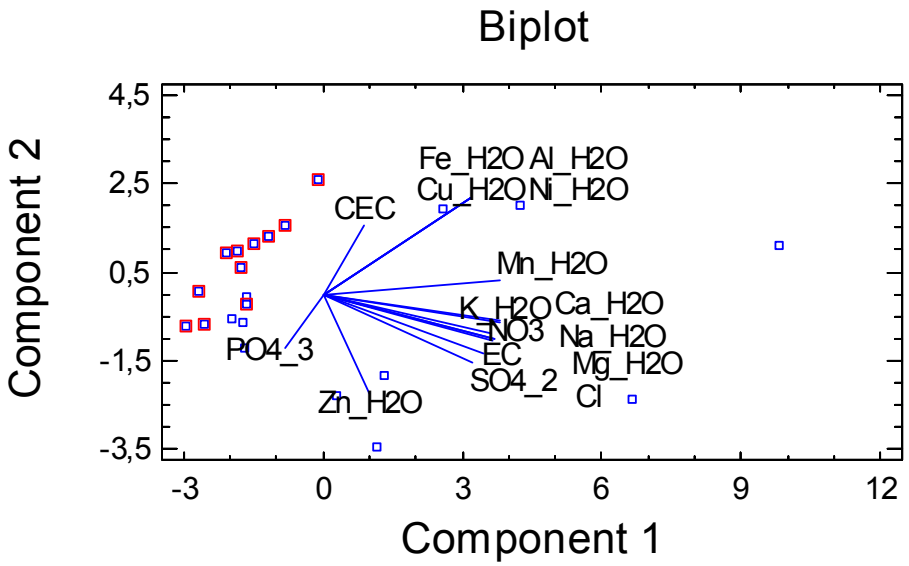

Figure 3.23: PCA of cations, anions, CEC and EC. Squares indicate values of the Berseem field.

PCA of enzyme activities, anions, and cations indicates some correlations between enzyme activities and anion and cation concentrations (see figure 3.24).

Urease activity is influenced by PO_4 (r^2=17.65), Ni (r^2=15.1), and Cu (r^2=15.5), but looking at r^2 values indicates a relatively weak relationship between the variables.

Phosphatase activity is influenced by SO_4 (r^2=37.5), Cl (r^2=36.89), K (r^2=33.3), NO_3 (r^2=30.52), Ca (r^2=36.55), and Na (r^2=51.6). Looking at r^2 values indicates a moderately strong relationship between those variables.

Dehydrogenase activity is influenced by SO_4 (r^2=13.43), Cl (r^2=12.14), K (r^2=12.66), NO_3 (r^2=7.28), Ca (r^2=6.48), and Na (r^2=18.7). R^2 values here indicate only relatively weak relationships between variables.Respiration is influenced by SO_4 (r^2=9.82), Cl (r^2=5.94), K (r^2=14.5), NO_3 (r^2=8.54), Ca (r^2=10.74), and Na (r^2=16.6), but r^2 values indicate only relatively weak relationships between variables.

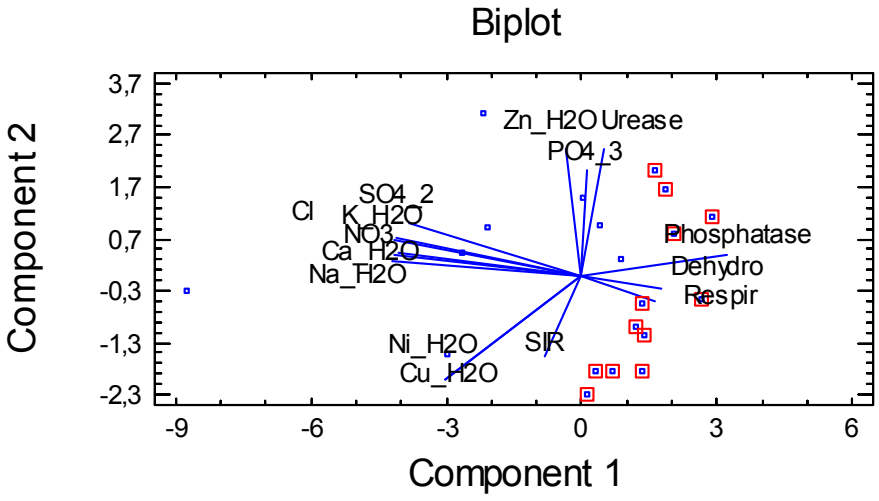

Figure 3.24: PCA of enzyme activities, cations and anions. Squares indicate values of the Berseem field.

3.4.2. Sohag

PCA of soil physical parameters, CEC, EC and parameters from mass spectroscopy (figure 3.25) indicates a relationship between pH (H_2O)/N and DW%FW, C:N, and δ ^{15}N.

Relationships between pH and DW%FW is relatively weak (r^2=19.5), the same accounts for pH and δ ^{15}N (r^2=5.7), pH and EC (r^2=0.85), and pH and C:N (r^2=13.46).

Total N influences C:N, this relationship is moderately strong (r^2=30.24), the same accounts for N and DW%FW (r^2=24.38).

It is worth noting that Total C_{org} weakly influences WHC (r^2=1.85) and δ ^{13}C (r^2=5.7), but not %SAS.

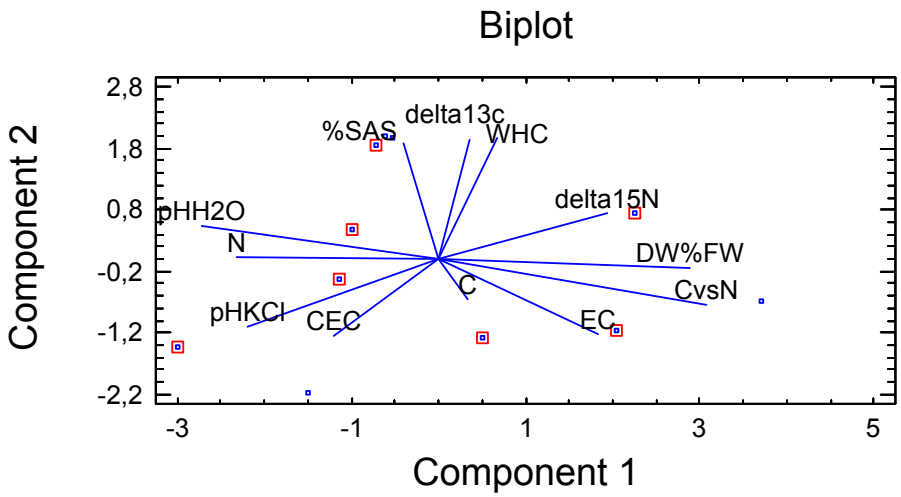

Figure 3.25: PCA of soil physical parameters, EC, CEC and Organic Matter. Squares indicate values from the Berseem field.

PCA of EC, CEC, cations and anions (see figure 3.26) indicates that parameters do not strongly influence each other. Simple regression between EC and other parameters shows, that the only relationship between parameters is that between EC and Ca, the r^2 of 28.8 indicates a moderately strong relationship between parameters.

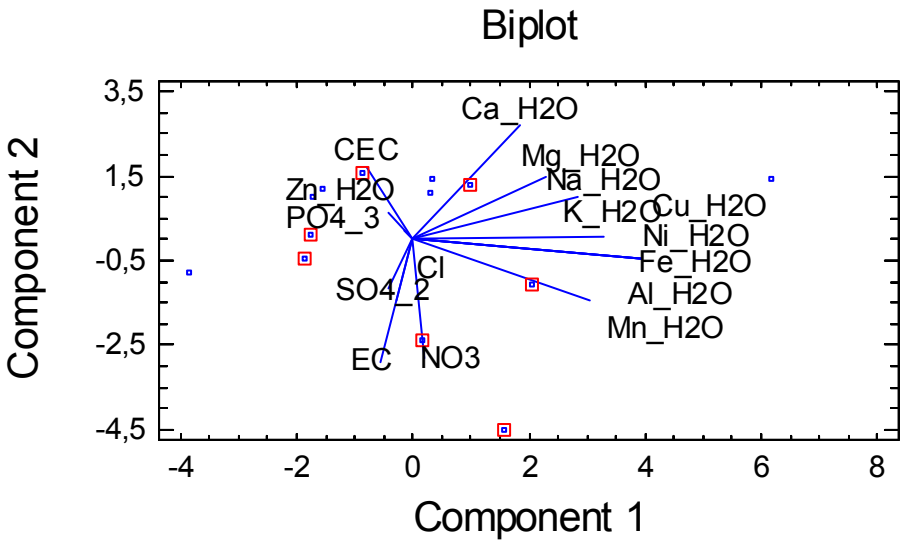

Figure 3.26: PCA of cations, anions, EC and CEC. Squares indicate values from the Berseem field.

PCA of enzyme activities, soil physical parameters and EC (see figure 3.27) indicates a possible relationship between EC/WHC and urease, dehydrogenase, and phoshpatase activities as well as pH.

Simple regressions showed that EC weakly influences WHC (r^2=7.23) but neither enzyme activity. It is important to note, that there is a correlation between SIR and %SAS, relationship between the parameters is weak (r^2=7.25).

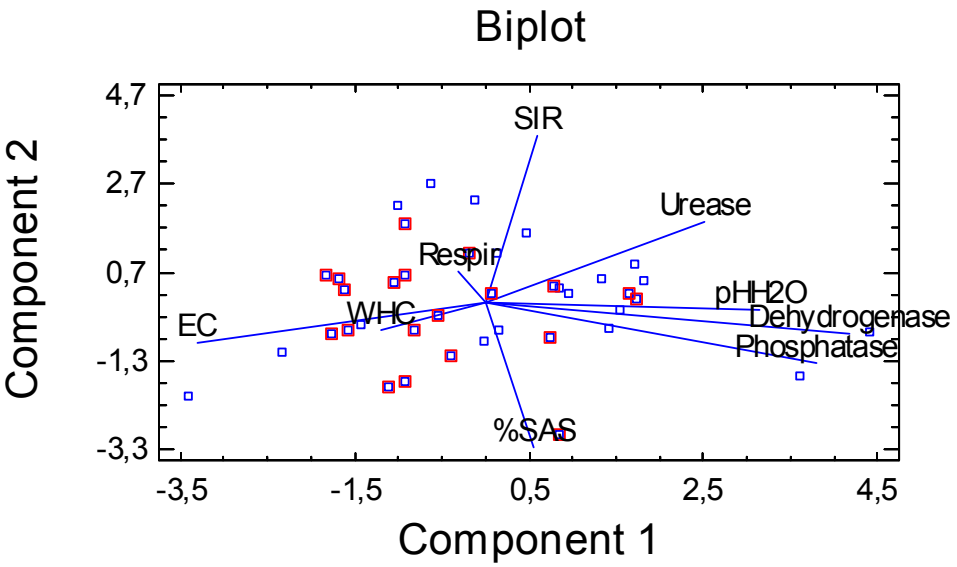

Figure 3.27: PCA of soil physical parameters, enzyme activities and EC. Squares indicate values from the Berseem field.

PCA of enzyme activities and parameters from mass spectroscopy (see figure 3.28.) indicates a possible correlation between C:N and urease, phosphatase, and dehydrogenase activity, as well as total N and respiration.

Simple regressions showed that this is only true for C:N and urease activity (r^2=7.35), indicating a relatively weak relationship only, and for C:N and total N with an r^2 of 30.24 indicating a moderately strong relationship between variables.

δ ^{15}N influences δ ^{13}C, the r^2 of 22.16 indicates a moderately strong relationship between variables. Total C_{org} also influences C:N (r^2=17.98), but only weakly.

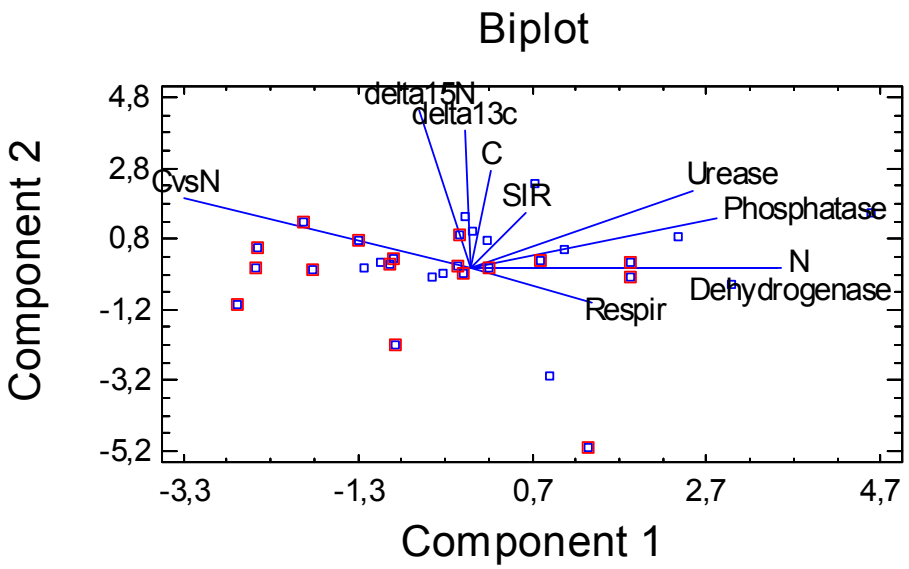

Figure 3.28: PCA of enzyme activities and parameters Organic Matter. Squares indicate values from the Berseem field.

PCA of enzyme activities and cations, anions and salinity (see figure 3.29) indicate a relationship between phosphatase and PO_4, and a possible correlation between salinity and several enzyme activities. However, no correlation between enzymes and any cations, anions or salinity could be measured.

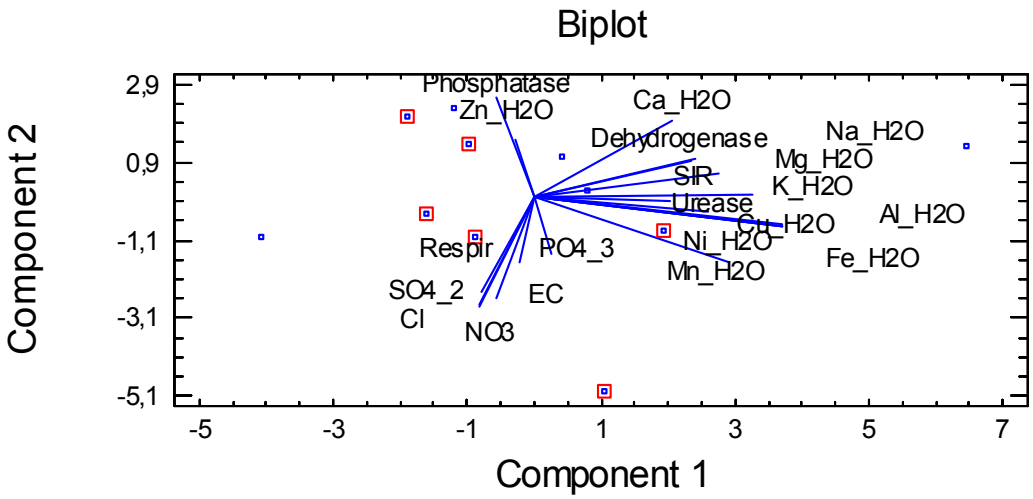

Figure 3.29: PCA of enzyme activities and cations, anions and salinity. Squares indicate values from the Berseem field.

3.4.3. Metavariables

In order to see how principal components of PCAs performed above influence each other, a PCA of metavariables of principal components (component 1 only) was performed. All results of PCAs without a proper correlation were left out.

In figure 3.30, metavariables from the Nile Delta are depicted. There is a clear, moderately strong correlation between metavariables D Structure SOM and D Enzymes SOM (r^2=66.7%), D Structure Enzymes (r^2=63.5%) , and D Enzymes Salinity (r^2=52.55%). D Salinity Ions does not correlate with D Structure SOM, but shows a moderately strong correlation with D Structure Enzymes (r^2=32.60%), and D Enzymes Salinity (r^2=33.52%), and a relatively weak relationship with D Enzymes SOM.

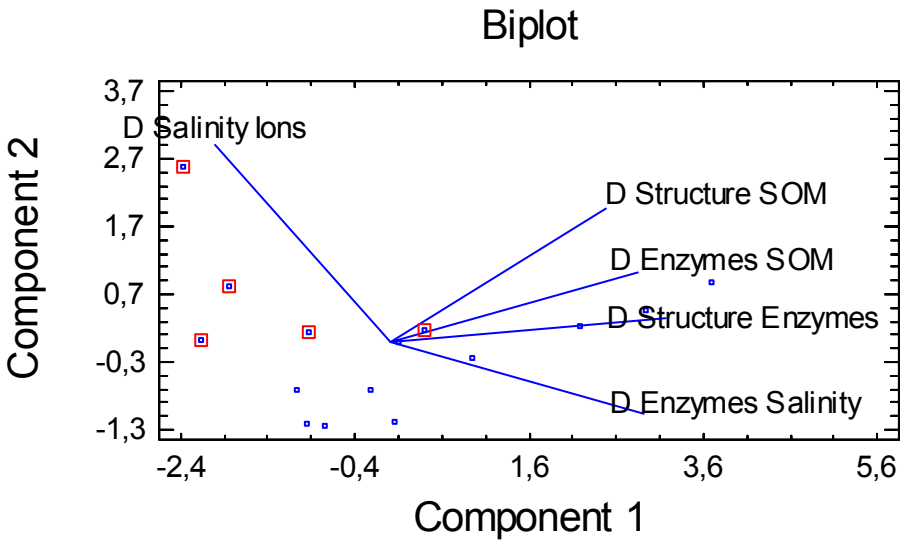

Figure 3.30: PCA of metavariables of the Nile Delta.. Component 1 accounts for 64.91% of variance, component 2 for 19.8%, and component 3 for 7.7% of variance. Squares indicate values from the cotton field.

PCA of metavariables from Sohag (see figure 3.31) shows a clear correlation between S Enzymes SOM and S Enzymes pH, this correlation is moderately strong (r^2=77.33%).

There is a relatively weak relationship between S Structure SOM and S Enzymes pH (r^2=12.5%), but none between S Enzymes SOM and S Structure SOM.

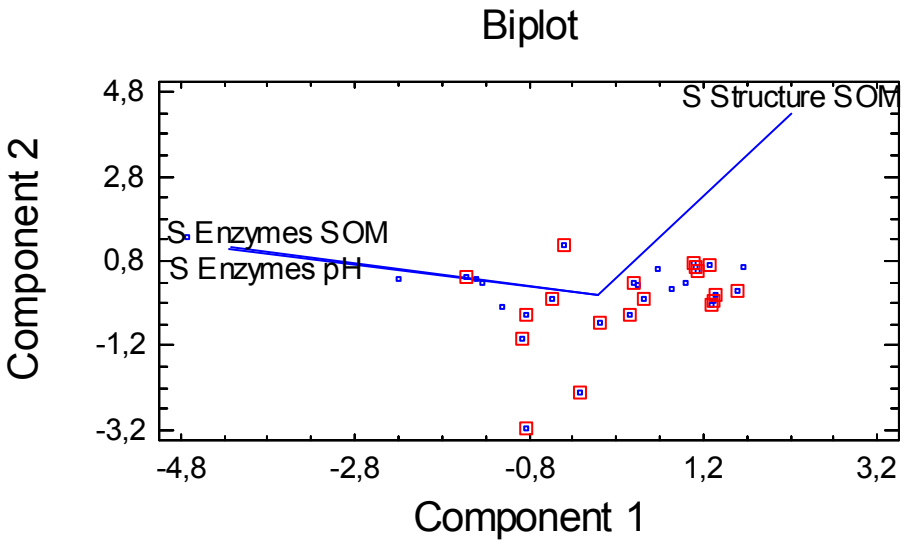

Figure 3.31: PCA of metavariables of Sohag. Component 1 accounts for 66.98% of variance, component 2 for 28.7%, and component 3 for 4.3% of variance. Squares indicate values from the Berseem field.

4. Discussion

A thorough analysis of soil physical, chemical, and biological parameters was performed in order to assess soil quality of the two experimental sites in Egypt. The aim was to investigate the hypothesis, whether due to the missing flooding and increased productivity of the soils in the Nile Delta results in soil degradation, and whether the soil in Sohag, which was created from Nile sediments, in comparison shows stronger buffering capacities towards soil degrading processes. The soil in Sohag, in a way, resembles sediments deposited by the flooding of the fields. The general objective of the research project was to assess the influence of land use on soil quality, and how parameters are affected by aridity and salinity, and how they can be used to identify mechanisms leading to soil degradation, as well as to assess the land reclamation project in Sohag. This chapter provides an interpretation of results depicted in chapter 3, for the conclusion and outlook please turn to chapter 5. It should be noted that, even though headings are given, parameters strongly influence each other, and are often discussed at the appropriate passages.

Soil physical parameters:

The grain size analysis (see table 3.1.) of all samples shows very little difference between the fields and between the two experimental sites. Soils of all fields can be classified as clayey silty soils, except for the wheat field in Sohag, which can be classified as medium-sandy silt (see tables 3.2.-3.3). It should be taken into account that the values used for the analysis are means of several samples of each field. Thus, the difference between the wheat field and all other fields could be due to the slightly higher standard deviation rather than an actual difference, or could result from the difference in crops and thus cultivation techniques. On the other hand, it is possible that this difference is due to the fact that the wheat field, due to the topology of the area, was closer to the actual desert than the Berseem field, and is thus more exposed to fine sand deposits.

Permeability coefficients show that water flows very slowly through the soils and the values obtained are within the range expected for clays (Brassington 1988). Results obtained using the Method of Moments do not differ greatly between the fields. The Mean (first moment) equals the mean of the distribution of grains, and is very similar for both Berseem fields and slightly lower in the cotton and wheat field. Standard deviation (second moment) provides information on the extent to which particle sizes are clustered around the mean and thus defines sorting. Values for all four fields indicate that the grains are very poorly sorted (Tucker 1996). Skewness (third moment) defines the symmetry of the curve and can be described as the tendency of a distribution to depart from the symmetrical form, and is thus sensitive to the presence or absence of fine and coarse fractions of particles. Values for all four fields can be interpreted as strongly positively skewed. Kurtosis is a measure of the rate of distributions of extreme values and the centre of distribution (i.e. “peakedness” of the probability distribution), and can be described as leptokurtic for all four fields, indicating a rather good sorting. All values derived through the method of moments are typical for river sediments, as could be expected for recent Nile alluvium (Tucker 1996, UNCCD 2005).

Minerals present in a soil can be taken as criteria to infer the origin of soil parent materials and can also be used as a tool to evaluate the uniformity and development of the soil profile, as well as soil genesis in terms of the degree of mineral weathering. Mineral content and distribution in soils are good means to estimate the stability of minerals against the weathering processes that occur under different soil conditions and to successfully evaluate the soil nutrient supplying power. Clay fraction is the most active constituent in soils. It plays an important role in determining the physical and chemical properties as well as the types of reactions that occur in soils. Knowledge of clay minerals is important in evaluating the

magnitude of soil fertility and providing a clear indication of the role played by weathering processes (Abd El-Aziz et al. 2005).

The results of the analysis of bulk mineralogy (table 3.4.) show that the main minerals in both experimental sites are quartz and clay minerals. Whilst in the Nile Delta, clay minerals were predominant (53-58%); there was almost as much quartz (32-37%) as clay minerals (32-34%) in the soils from Sohag.

The results of the semi-quantitative analysis correspond with those found in Nile sediments, the only exception being NaCl, which was not detected in Nile sediments.
Osman (1996), who studied recent to quaternary Nile sediments in Upper Egypt, described the bulk mineralogy of Nile sediments as consisting of quartz, plagioclase, alkali feldspar, calcite, magnetite, pyrite, and clay minerals (smectite, kaolinite, chlorite and mica).
Aboughalma (1999), who studied sediments around Kafr Elzayaat, 25km north of Tanta, in the Nile Delta, revealed in his semi-quantitative analysis of the bulk mineralogy that the following minerals were present: the feldspar group(represented by plagioclase and alkali feldspar), the carbonate group(represented by calcite and ankerite/dolomite), the clay mineral group(represented by smectite, kaolinite, chlorite and a sometimes very weak reflection in some samples for mica) and a fourth group of iron- (hydr)oxide minerals such as hematite, goethite, and lepidocrocite. Aboughalma also found quartz, with an average content of 27%, and some gypsum and anhydrite in a single sample.

Those findings correspond well with the results of this thesis, even though no magnetite or pyrite, hematite and lepidocrocite were found. On the other hand, gypsum and NaCl in considerable amounts were present. Mica (illite) could be found in all samples of both experimental sites, in the similar amounts (approximately 6% in the Nile Delta, and around 3% in Sohag).

The quartz content of the soils in the Nile Delta corresponded with the findings of Aboughalma (1999), the quartz content of the soils in Sohag with that of Osman (1996), who recorded an average quartz content of 20.3% in samples taken from the river's banks, and 59.1% in the samples taken from islands in the Nile. Chlorite could not be found in all samples from the Nile Delta (Aboughalma 1999), but in all samples from Upper Egypt in an average concentration of 6.5% was present (Osman 1996). In both studies, contents of kaolinite were slightly higher than the one described here, ranging from an average of 15% in the Nile Delta to 6.6% in Upper Egypt, as opposed to approximately 10% in the Nile Delta and 3% in Upper Egypt, described here.

Goethite is the only iron (hydro) oxide found in the soils discussed here and accounts for their yellowish brown colour. Soils from the Nile Delta were of a darker brown colour than the soils in Sohag, which again correlates with their mineralogy. Even though arid conditions a higher pH and lack of water usually favour hematite (Velde 1995), no hematite could be detected in the soil samples here.

Core samples from the Nile Delta (table 3.6.) showed no real difference compared to the analysis of the soil samples taken six months before. The low quartz content in Delta I is due to the inaccuracy of the semi-quantitative analysis according to Schultz (1964), and the fact that the results discussed above are means rather than absolute values. The core samples from the Nile Delta thus show no difference to the results of the samples taken previously.

Core samples taken from the fields in Sohag (Sohag II-IV) show the same minerals in a comparable amount as in the samples discussed above (tables 3.7.-3.8.) Samples Sohag I (20-60) and Sohag IV (40-60) show that below the layer of top soil, clay minerals and NaCl were below the detection limit. The analysis of the <2µm fraction (tables 3.10.-3.11.) shows that there are clay minerals present in an amount that is comparable to the other samples. However, the total amount of clay minerals is lower. Calcite and NaCl could also be detected

in higher amounts than in any other samples, which means that both percolate to below the top soil. The high amount of NaCl in the <2µm fraction indicates a suboptimal environment for microorganisms that are necessary for soil forming processes. Core samples from the adjacent, ruderal area (Sohag I and Sohag VI) show that in places where no fields are cultivated the amount of clay minerals is again very low. Clay minerals could not be detected in the bulk sample as the overall concentration was below the detection limit, but it was possible to separate a sufficient amount of the clay fraction for further analysis. In both samples, calcite and NaCl could be detected, which equalled the samples from below the humic layer, meaning that the subsurface of the fields is sandy, calcareous and also affected by salinity.

Mineralogy of the <2µm fraction of the samples taken at sampling 1-5 (table3.5. and 3.9.-3.11.) does not show any differences between the two sampling sites. All minerals, other than clay minerals (which are, as expected, the most predominant group) range around 2-5% and no trends can be seen.

Mineralogy correlates well with the main component analysis of x-ray fluorescence spectroscopy (table 3.18.) The high amount of SiO_2 correlates well with the amount of quartz found in the samples, with higher concentrations in the samples from Sohag. The same applies to Al_2O_3 which compares well with the overall content of clay minerals. Fe_2O_3 correlates well with the amount of goethite, CaO with calcite and gypsum, NaO and K_2O with feldspars. MnO could only be found in traces, as well as P_2O_5 – which is more likely derived from earlier uses of phosphate containing fertilizers rather than phosphates. As superphosphate fertilizers also contain $CaSO_4$, some of the gypsum could also be related to previous use of superphosphate, or the use of gypsum for amelioration purposes and for the alkalinization of soils.

Heavy metal contamination of soil is widespread due to metal processing industries, tanneries, combustion of wood, coal and mineral oil, traffic, and plant protection. The toxic effects of heavy metals result mainly from the interaction of metals with proteins (enzymes) and inhibition of metabolic processes. In contrast to organic pollutants, metals are not mineralized by microorganisms but can be oxidized,reduced or transformed to different redox stages or complexed by organic metabolites (Schinner & Klauser 2005).

Trace elements/heavy metal concentrations of the soils of Sohag and the Nile Delta (table 3.19.) determined by x-ray fluorescence spectroscopy show that the concentration of As (of less than 5 ppm) does not differ between the two experimental sites and is within the range of uncontaminated soils. The concentration of Cr is higher in the Nile Delta (130 ppm) than in Sohag (115 ppm), and in both cases this is above the critical concentration in soils. The content of Cu is again slightly higher in the Nile Delta (63 ppm) than in Sohag (43 ppm) and thus only just reaches a critical content in the Nile Delta, as the critical concentration in soils is described as ranging from 60-125 ppm (Alloway 1995). However, the values found here are similar to that found in sediments of beach soils of the river Nile close to the respective experimental site, and might be more associated with the organic muds rather than inorganic clays (Awadalla 1996, Gorham & Swayne 1965). The content of Ni is within the range of non-contaminated soils, however, the concentration of Ni found in the solid phase of the soils is approximately three times as high as Ni found in the acidic solution, and thus results from the high content of clay minerals in the soils. Contents of Pb in the soils are slightly higher in Sohag (15 ppm) than in the Nile Delta (12 ppm), and are thus far from critical and are below the values found for Nile sediments and beach soils. Zn does not differ greatly between the two experimental sites, reaching 110 ppm in the Nile Delta, and 106 ppm in Sohag, which is above the lower threshold of critical concentrations in soils, which starts at 70 ppm. It is possible that Zn contamination is due to the use of fertilizers or pesticides, which often contain considerable amounts of Zn. Or perhaps it is derived again from the Nile Sediments, as the concentration of Zn in the sediment of the River Nile at Sohag is 123 ppm,203 ppm in the beach soil of the River Nile at Sohag,193 ppm in the sediment and 232 ppm in the beach

soil of the Nile at Giza (Awadallah 1996). Contents of Co is higher in the Nile Delta (33 ppm) than in Sohag (23 ppm), and thus only reaches a critical content in the Nile Delta, as the lower threshold for a critical concentration in soils starts at 25 ppm. The high concentration of Co could be due to anthropogenic influences rather than due to the mineralogy of the soils. Phosphate fertilizers usually contain Co, which is then enriched in layers containing a high amount of clay minerals which is aided by a slightly alkaline environment (Alloway 1999). The content of Co in Sohag is very similar to the content of Co measured in the beach soil of the Nile at Sohag, where the concentration reached 32 ppm. In the Nile Delta, this concentration amounts to 30 ppm in the sediment and 31ppm in the beach soils of the river at Giza (Awadallah et al. 1996). Thus, it appears that the concentrations of heavy metals equal that of the sediments of the river Nile, of which the soils of this study are formed.

As expected, the soils examined in this thesis are very similar to the Nile sediments described by Osman (1996), Aboughalma (1999), and Stanley&Wingerath (1996), the only difference being a very small content of kaolinite, which was found in higher amounts by the cited authors. The predominant clay minerals described were also smectites (montmorillonite) and mica (illite). Kaolinite was found in higher concentrations (up to 50%) close to Qena or traces only in shale-derived soils in the New Valley (Stanley&Wingerath 1996, Abd El-Aziz et al. 2005). Weathering of feldspars under slightly alkaline conditions and higher concentrations of Si and Mg favours the formation of smectites and at higher K concentrations the formation of illite. The formation of kaolinite is favoured under acidic conditions and a moderate concentration of Si. Thus it seems that pH and the concentration of elements does not favour the formation of kaolinite in the soils of the Nile Delta and Sohag, and rather supports the degradation of kaolinite (Scheffer-Schachtschabel 2002, Righi &Meunier 1995, Tucker 1996). The soils described here were ultimately formed before the creation of the dam in Aswan, and thus equal assemblages from the river Nile before 1964, which were described as smectite enhanced by Stanley & Wingerath (1996). Smectite is generally found in alkaline soils as well as the Vertisols of arid regions (Tucker 1996).

The high content of smectite and content of mica is fortunate in terms of soil quality, as is the low content of kaolinite. Kaolinite shows a rather low Cation Exchange Capacity (CEC), and thus, soils containing high contents of kaolinite are generally less fertile. Micas weather to vermiculites and smectites, and K^+ released during weathering is an important source of K^+ for plants (Delvaux et al. 1990, Prasad &Power 1997). Classically, there are two main K pools in soils: the exchangeable pool and the non-exchangeable pool. It is assumed that exchangeable K^+ ions are adsorbed on soil organic matter, exchange sites on smectite clay minerals and edge sites of clay minerals. The non-exchangeable pool is much larger, 90-99% of total K in many soils. It is composed of K from feldspar minerals and fixed K in interlayer sites of micaceous clay minerals, such as illite. Non-exchangeable K can contribute from 80 to100% of the K in soils (Hinsinger 2002, Barré et al. 2007).

Smectites, because of their enormous expanding nature, have a very large specific surface area and a high CEC. The shrink-swell behaviour of smectites, however, can sometimes lead to problems in the management of these soils (Prasad & Power 1997, Delvaux et al. 1990). Soil bacteria, on the other hand, reduce Fe(III) in smectites to Fe(II).,This means that the specific surface area decreases, but CEC increases, swelling in water decreases, reactivity with organic chemicals and pesticides increase and the potential for mineral dissolution and transformation increases. These changes, however, are small (Stucki et al. 2006, Favre et al. 2006).

In general, the soils in Sohag are dryer than in the Delta (table 3.14.), which was to be expected due to the more arid climate in Upper Egypt compared to the Nile Delta. In general, the soil of the cotton field was slightly dryer than the Berseem field in the Nile Delta, which is also to be expected given the sparser vegetation cover which leads to more evaporation and faster drying of the soil. The same accounts for the differences between the wheat and the

Berseem field in Sohag, where the soil of the wheat field is moister, as plants are higher and very dense, and thus the prevailing microclimate lessens evaporation.

The amount of stable aggregates (table 3.15.) is higher in the Nile Delta than in Sohag. In the Nile Delta there is a difference between the Berseem and the cotton field, where the amount of stable aggregates is smaller. In both fields, there is an increase in stable aggregates over time. In Sohag, there is no difference between the two fields, but a significant increase in stable aggregates over time. In both undisturbed and agricultural soils, water stable macro-aggregates in soils with adequate carbon concentrations are held together by a fine, three-dimensional network of small roots and a hyphae of mycorrhizal ,saprophytic fungi and other organisms. Roots affect aggregate formation, and this influence can be attributed to associations with mycorrhizal fungi. The strength and nature of this association also depend on the morphology of the root system (Miller & Jastrow 1990). Because of their small sizes and elevated surface areas, interactions between clays and organic matter assume great significance in structural stability, important interactions also occur with larger particles. The most important organic materials in terms of soil aggregation are the polysaccharides and humic materials, although they act as different temporal and spatial scales (Lavelle & Spain 2001). The increase of stable aggregates over time in all fields can be attributed to the growth of plants on the fields and the increase in root biomass. Thus, more stable aggregates are formed, and the combination of both plays an important role in the amount of mesopores formed in soils. Results from the principal component analysis show that in the Nile Delta the amount of stable aggregates is weakly influenced by soil moisture, and that there is a moderately strong relationship between $\delta^{13}C$ and stable aggregates. In Sohag, the only correlation found was a weak one between SIR and the amount of stable aggregates. Thus, it seems that in the Nile Delta, the formation of stable aggregates is linked to the overall turnover of soil organic matter, whereas in Sohag it is mostly linked to general microbial activities (Glaser 2005, van Gestel et al. 1996).

Water Holding Capacity (WHC) is generally higher in the Nile Delta than in Sohag (table 3.16.). The field planted with Berseem in the Nile Delta shows slightly higher values than the field planted with cotton, even though those differences are not significant. In both fields, there is an increase in WHC over time, with the highest values at the last sampling, and a slight decrease at samplings 2 and 3 (and 4 for the cotton field). In Sohag, the field planted with Berseem, values remain constant throughout all five samplings, in the wheat field there is a slight increase at sampling 5. WHC is on the one hand linked to clay minerals and their ability to hold water, and on the other hand to soil organic matter, as it has to do with the amount and kind of pores as well as soil stable aggregates, as well as with the fact that soil humic materials can hold up to 20 times their weight in water (Tate 1992). Results from the principal component analysis show a weak correlation between $\delta^{13}C$ and WHC in the Nile Delta, as well as between SIR and WHC. In Sohag, WHC is weakly influenced by salinity. This indicates that the increase of WHC in the Nile Delta has to do with microbial activity and the general turnover of soil organic matter and thus the formation of humic substances, whereas in Sohag it is influenced by salinity. As there is no decrease of WHC in Sohag, it seems that this influence mostly concerns an inhibition of processes leading to a higher WHC. The higher WHC in general in the Nile Delta is most probably attributable to the higher content in clay minerals.

Cation Exchange Capacity (CEC) differs between the two experimental sites, with soils from the Nile Delta showing a higher CEC than those in Sohag (figures 3.4.a.-b.). However, there is no difference between the fields from the respective experimental sites, or any changes over time. CEC depends on soil colloids (principally phyllosilicates and organic matter), which have a mixture of positively and negatively charged sites on their surfaces to which a range of organic an inorganic ions are attached (Lavelle & Spain 2001, Glaser 2005). The CEC of the soils examined here are within the range of that of a cultivated soil with a high content of clay minerals (Vertisol) (Lavelle & Spain 2001). The differences between the two

experimental sites can be explained by the difference of clay mineral contents, which is higher in the Nile Delta.

Soil chemical parameters:

pH (determined in a soil:water solution) differs between the two experimental sites (table 3.20.). The pH of the soils in Sohag (total mean of 7.9) is slightly higher than in the Nile Delta (7.6). In both cases, the fact that soil pH in both cases is higher than 7, can be attributed to the content of calcite, which is present in concentrations high enough to raise pH. In Sohag, there is no difference between the two fields, but in the Nile Delta the pH of the cotton field is lower at samplings 2 and 3 (7.4-7.2 for the cotton field compared to 7.8-8.0 for the Berseem field). In order to bring more exchangeable H^+ ions in solution, and thus in order to overcome variations in pH values that might have to do with the solution process, pH can be measured in a soil:KCl solution. This usually lowers pH by 0.5 to 1 unit (Prasad & Power 1997). pH in a soil:0.01M KCl solution shows no differences in pH between the two experimental sites (table 3.21), the only difference found was between the cotton and Berseem field in the Nile Delta at the third sampling, with a higher value in the Berseem field. Unfortunately, due to technical problems, pH in a soil:KCl solution was not determined in the Nile Delta for samplings 1 and 2. In general, pH measured at both experimental sites shows that the soil ranges from neutral to slightly alkaline. The buffering capacity of a soil is related to its cation exchange capacity and is therefore related to the clay content and mineralogy and to the amount of soil organic matter present. The larger the amounts of either clay or organic matter the greater the buffering capacity of the soil (Prasad & Power 1997). Thus, it would have been expected that pH in the Nile Delta would change less than in Sohag, as the amount of clay minerals present is higher in the Nile Delta. Soil pH is affected by the kind of chemical fertilizer used, the amount of basic cations removed by the crop plants, the leaching of cations and organic residues and their decomposition and nitrogen transformation (the deposition of nitrate, sulphate and acid forming chemicals by rain can be neglected in this case, due to the almost non existent precipitation) (Prasad & Power 1997). It is possible that the decrease in pH in the cotton field in the Nile Delta was due to the use of fertilizers. Unfortunately this can only be assumed as the farmer was not very consistent with his information on fertilizer use, however, results discussed later indicate that fertilizers were used on the cotton field at this time (apparently these fertilizers did not contain any gypsum). There is a moderately strong correlation between salinity and pH in both experimental sites, this will be discussed below, as pH has a strong influence on nutrient availability, and thus on salinity.

Looking at the concentrations of macronutrients in general (figures 3.5.a-b), the amount is higher in the Nile Delta. NO_3, SO_4, PO_4, and Ca are the predominant macronutrients in the Nile Delta, in Sohag NO_3, SO_4, and Ca dominate. The changes of concentrations of macronutrients are quite high in the cotton field, where concentrations are quite high at the first sampling, then increase at the third sampling, and then decrease to a level very similar to that of the adjacent Berseem field at the fifth sampling. Values of macronutrients in the Berseem field do not change except for the level of SO_4, which decreases over time. Concentration of PO_4 shows a very similar trend between the two fields. In Sohag, the overall level of nutrients remains almost constant throughout time, except for K and Mg; concentrations of those two nutrients increase over time. The increase of nutrients in the cotton field and the almost constant levels in all other three fields is mirrored in results for salinity, which will be discussed below. The fact that of all nutrients NO_3, SO_4, PO_4, and Ca are the ones that show the highest variations in the Nile Delta leads to the presumption that they can be attributed to the use of inorganic fertilizers.

The findings for NO_3 compared to the total level of total N are contradictory, as total N does not increase over time, on the other hand, there are no apparent changes in macronutrient concentrations in Sohag, even though organic matter changes in the Berseem field. The main N fertilizer in Egypt is urea, which degrades to NH_3 and O_2 gases, leading to an increase of pH, which in turn can result in loss of N by ammonia volatilization (Prasad &

Power 1997). However, the farmer in the Nile Delta had also indicated the use of nitrate fertilizer, and as nitrate was measured only, this indicates the use of nitrate fertilizer. Upon observation of the values for total N, the trend of the values for the cotton field in the Nile Delta appear to mirror the trend of NO_3 availability. The relatively high values for Ca in both sites may have to do with $CaCO_3$ found in industrial fertilizers, and the use of $CaCO_3$ or gypsum for the alkalinization of soils, which was indicated by both farmers.

The concentrations of micronutrients and Ni (figures 3.6.a-b and 3.7.a-b) show that Na and Cl are the two predominant micronutrients. In the Nile Delta, the concentration of Na and Cl is 50 times than that of other micronutrients, in Sohag it is 10 times as high. In the Nile Delta, the amount of micronutrients shows the same trend as micronutrients, which could again be explained through the use of fertilizers. In Sohag, the concentration of micronutrients increases slightly over time, which could be explained by increased chemical weathering due to enhanced humification processes. In general, the amount of micronutrients does not differ between the two experimental sites, the only exception being a slightly higher overall concentration of Zn in Sohag and a higher concentration of Mn in the cotton field compared to all other fields.

However, pH of the soil determines the availability of nutrients to plants (figures 3.9.a-d). The pH of the soils, ranging from an average of 7.4 – 8.1 means that availability of Phosphorus, Mn, Bo, Cu and Zn is limited (Prasad & Power 1997, Lavelle & Spain 2001). Cationic mobility, i.e. the illustration of nutrients in a water solution (and thus available to plants in the soil-water solution) as percentage of nutrients in an acidic solution (a measure of the total existence of nutrients in the soil), also needs to be taken into account. This shows that Na is highly mobile in all four fields, as is K. The availability of K can be linked to the mineralogical aspects of the samples, as K is held between adjacent tetrahedral layers of micas, and weathering of micas (and feldspars) releases K into the soils. The mobility of Zn is increased in the wheat field in Sohag, which may be attributed to the generally higher concentration of Zn in Sohag. It also seems that Al, Fe, Ni and Cu are more mobile in Sohag, however, this could only be determined for the Berseem field.

In general, nutrient availability in all four fields is good, however, the high concentrations of Ca, SO_4, Na and Cl are a cause for concern. Looking at the results calculated in mEq/kg soil (figures 3.8.a-d) show that the amounts of Na and Cl are almost equal, which means that NaCl is present in all soils. This corresponds with the results of x-ray diffractometry, where a peak for NaCl could be found. Ca seems to be available as $CaCl_2$ as well as $CaSO_4$, the latter can be explained by the addition of gypsum for the amendment of soils. Both NaCl and $CaCl_2$ are salts causing salinity in soils. The trends of concentrations of Na, Ca, Cl and SO_4 in mEq/kg correlate strongly with salinity (figure 3.10.), measured by electrical conductivity of a soil-water solution). This is mirrored by the results from the PCA, where a moderately strong relationship between electrical conductivity and Na, Cl, Ca and SO_4, as well as Mg, K, Mn, Al, Ni, Fe, Cu, and NO_3 could be found in the Nile Delta, but only a moderately strong relationship between electrical conductivity and the concentration of Ca could be found in Sohag. It seems as if the application of fertilizers on the cotton field, irrigation and increased evapotranspiration of water (due to the lack of vegetation cover) are the predominant causes for the high salinity of the soil of the cotton field, and for the higher salinity in the Nile Delta in general. The decrease of electrical conductivity in the cotton field between sampling 4 and 5 can be explained by the fact that cotton was harvested before Berseem, the soil then ploughed and irrigated. Apparently the farmer was aware of the fact that the planting of cotton leads to an increase of salinity, and followed the advice of thoroughly irrigating the ploughed land, which leaches out salts from the soil surface (Kotb et al. 2000). Results from PCA indicate that in Sohag, the addition of gypsum in order to decrease exchangeable Na to the extent that it does not degrade soil physical properties or interferes with plant growth is more successful than in the Nile Delta (Prasad & Power 1997).

The natural abundances of stable isotopes in ecosystem components are viewed as recorders that can be used to reconstruct ecological processes or to trace ecological activities (West et al. 2006).
Regular variations in stable N ratios can potentially provide useful information about sources of N used by plants and fluxes of N in ecosystems. Natural ^{15}N abundance is commonly expressed in δ units, which denote parts per thousand deviations, ‰, from the ratio ^{15}N:^{14}N in atmospheric N_2, which is 0.0036765 and corresponds to 0.3663 atom % ^{15}N (Högberg 1997, Junk & Svec 1958, Mariotti 1983). Within a specific system there can be a number of pools of compartments of N-containing molecules or ions with distinctly different ^{15}N abundances. The turnover of inorganic N pools in agricultural soils ranges from less than one to a few days. Free amino acids and proteins might possibly turn over at similar rates, whereas microbial N and other labile N pools turn over within weeks or months. Generally speaking, N isotope fractionation occurs during any number of physical, chemical, and biological N processes, including mineralization, immobilization, ammonia volatilization, nitrification and denitrification (Högberg 1997,Kielland 1995, Lynch et al. 2006). ^{15}N abundance can provide insights into the N balance of an ecosystem. The $\delta^{15}N$ values of soils and plants reflect several physical and enzymatic processes that discriminate against ^{15}N. Denitrification, for example, and volatilization of ammonia result in preferential losses of gaseous ^{14}N, enriching the residual nitrate in the soil in ^{15}N; biological N_2 fixation discriminates against ^{15}N, causing a decrease in the abundance of ^{15}N in the plants (Aranibar et al. 2007).

The measured $\delta^{15}N$ (figure 3.11.a) differs again between the two experimental sites, with higher values in general in the Nile Delta. The two fields in the Nile Delta only differ slightly between each other (with lower values in the cotton field) and values remain almost constant throughout time, with only one exception: values in the cotton field decrease at the fourth sampling. In Sohag there is a slight difference between the two fields, with slightly lower values for the wheat field, with the only exception being the third sampling where $\delta^{15}N$ in the Berseem field decreases dramatically by almost 50%, but goes back to even higher values compared to sampling 1 at the fourth sampling. PCA shows that there is a slight relation between salinity and $\delta^{15}N$ in the Nile Delta, as well as between $\delta^{13}C$ (figure 3.11.b.) and $\delta^{15}N$. In Sohag, $\delta^{15}N$ is weakly influenced by pH, and also by $\delta^{13}C$ (in this case the influence is moderately strong. This influence is most probably caused by the application of fertilizers and the following turnover. In agricultural soils, remineralization of added NH_4^+ takes place after 2 weeks, and that of NO_3^- after 4 weeks. Microbial N compounds are the precursors of stable organic N. This recalcitrant pool, which is formed by biological as well as chemical immobilization of N, forms the major portion of soil total N and might, like the C it is bound to, have turnover times of hundreds of years (Bjarnason 1988, Paul & Clark 1996). In agricultural soils, with annual additions of N, low rates of additions lower $\delta^{15}N$ in plants, whereas high addition rates increase the $\delta^{15}N$. The effects of soil total-N on δ15N are small due to the large amounts of N already present in the soil. Urea has stronger effect on $\delta^{15}N$ abundance in soils (> 5‰) than NH_4NO_3 (< 2‰) (Högberg 1997). The long term input of inorganic fertilizers decrease soil $\delta^{15}N$ values (Lobe et al. 2005). It is possible that the decrease of $\delta^{15}N$ in Sohag at the third sampling had to do with the input of inorganic fertilizer on the Berseem field The use of mineral N fertilizer increases the supply of readily available N, leading to soil processes which are connected to the loss of the ^{15}N depleated compounds. Depending on fertilizer type and quantity, as well as on soil moisture, processes of N mineralization, immobilization, nitrification, denitrification and plant N uptake can be enhanced shortly after fertilization. This is especially the case after addition of mineral fertilizer with the bulk of N being readily accessible for plants and microorganisms. Many N transformation processes discriminate against ^{15}N (Watzka et al. 2006) This would explain, why total N did not decrease at sampling 3 in the Berseem field in Sohag. It is also worth noting that increasing aridity leads to a ^{15}N enrichment in plants and soils, which is thought to reflect the degree of “openness” (N losses relative to internal N cycling) of the N cycle (Handley et al. 1999). Thus it is surprising that the values of the fields in Sohag are lower, as it is more arid there. It is possible that this has to do with the long term and more intensive use of inorganic fertilizers than in the Nile Delta. The slightly higher value of $\delta^{15}N$ of the two

Berseem fields can not be attributed to N_2 fixation of the rhizobia prevalent in Leguminosae, which discriminate against ^{15}N in soils but are rather a sign for increased composition (Lobe et al. 2005, Lynch et al. 2006). $\delta^{15}N$ values in very arid sites decrease with land use intensity (Arinabar et al. 2007). This might be an explanation for the overall lower values of $\delta^{15}N$ in Sohag, but not for the decrease at the third sampling in the Berseem field.

Analysis of carbon isotope ratios ($\delta\ ^{13}C$) on the other hand (figure 3.11.b), provides insights into dynamics of the carbon cycle and are useful as a constraint in carbon cycle models. With respect to natural abundance of C isotopes in the environment, 98.9% of C exists as ^{12}C, 1.1% as ^{13}C, and 10^{-8}% as the cosmogenic radioactive ^{14}C. The basis for the work with stable isotopes (^{12}C and ^{13}C) at natural abundance is the fact that during kinetic and thermodynamic processes, (such as biochemical reaction, phase changes, or diffusion) heavier isotopes are normally discriminated against by the lighter counterparts because of the higher kinetic energy of the latter. As a consequence, the lighter isotopes accumulate relative to the heavier ones in the reaction products. The photosynthetic fixation of CO_2 leads to a discrimination against the heavier isotope in the assimilated products. As a consequence, the range of $\delta\ ^{13}C$ value in plant material varies between -10‰ and-34‰. In general, determining $\delta^{13}C$ in soils serves as a principal objective to quantify sequestration and turnover of specific organic substances (Glaser 2005, Ehleringer et al. 2000). ^{13}C is a useful tracer for studying the decomposition and incorporation of organic material into more stable C_{org}. The ^{13}C content of C_{org} corresponds closely with the ^{13}C content of the plant material and/or of the organic manure from which it originates. Microbial and chemical transformation during humification enriches ^{13}C in silt and clay. Consequently, the introduction of organic manures whose ^{13}C enrichment differs from that of the soil potentially enables the C derived from amendments to be traced into the existing C_{org} pool (Gerzabek et al. 2001).

As expected, values for $\delta\ ^{13}C$ are very similar to those of $\delta\ ^{15}N$, with values generally lower (i.e. more negative) in the Nile Delta, with slightly more negative values in the Berseem field compared to the cotton field, especially at the first and last sampling. The more negative the value, the higher the ^{13}C content in the soil. In Sohag, there is the same trend as for $\delta\ ^{15}N$, with a decrease of $\delta^{13}C$ at the third sampling in the Berseem field (by 20%).
In the Nile Delta, PCA indicates a moderately strong relationship between $\delta\ ^{13}C$ and Phosphatase, Urease and Basal Respiration. During microbial degradation, there is a preferential loss of ^{12}C as well as the enrichment of organic compounds less available for microbial digestion, which means that during composting, $\delta\ ^{13}C$ decreases slightly. The decrease of $\delta\ ^{13}C$ at sampling 3 in the Berseem field in Sohag is thus in stark contrast with the decrease of $\delta^{15}N$, which should also increase during composting. The decrease of $\delta^{15}N$ as well as the decrease of $\delta\ ^{13}C$ could thus be attributed to N losses in gaseous form, which would be attributable to the addition of nitrate (through manure or fertilizers) (Glaser 2005, Lynch et al. 2006).

The primary element contained in soil organic matter (SOM) is C. It comprises slightly less than half the weight of plant residues but somewhat more than 50% of the weight of SOM (Paul & Collins 1998). Usually, significant changes in soil organic C can only be observed after a long period of time (Gerzabek et al. 2001).

Total organic carbon (TOC, figure 3.12) is higher in the Nile Delta compared to Sohag. In Sohag, values remain constant over time, with a slight (but not significant) decrease of TOC at the third sampling in the Berseem field. In the Nile Delta, TOC increases from the first to the fifth sampling, with a decrease of TOC in the cotton field at sampling 4. In general, values found in the cotton field were lower than in the Berseem field. Looking at the results from PCA, there are no correlations between TOC and any other parameter in the Nile Delta, whereas in Sohag, there is a weak correlation between TOC and WHC. In both experimental sites, there is a correlation between C:N and TOC, which shall be discussed later.

Organic Matter by definition consists of the partially decayed microorganisms and microfauna involved in decomposition and the by-products of microbial growth and decomposition. These by-products undergo humification to form the materials known as humus. Because the humification process is primarily a chemical one, it is not only enzymatically controlled but is primarily a free radical type of reaction (Paul & Collins 1998, Gerzabek et al. 2001). Change in land use can alter the soil organic carbon pool, which usually decreases as the climax vegetation is removed for conversion to an agricultural land. The rate of soil organic carbon depletion is vastly accentuated with onset of soil degradation by any of the major degradative processes, e.g., physical, chemical or biological. It is also lowered by accelerated soil erosion on-site (Lal 1998). The results of the determination of organic carbon shows that the increase in the Nile Delta is most probably due to enhanced chemical humification processes, and also show that the organic matter of the two experimental sites seem to be stable and not adversely affected by erosion or anthropogenic activities.

Like soil organic C, Total N (figure 3.13.) may also be altered by anthropogenic activities (Pouyat et al. 2002). N is found in soil mainly within the organic matter fraction where it occurs largely in humic compounds but also in plant roots, the microbial biomass and in decomposing organic materials. Despite the fixation of atmospheric nitrogen by prokaryote organisms, most of the nitrogen required for plant growth in terrestrial ecosystems must be supplied through faunally, microbially – and abiotically – mediated decomposition processes, or through fertiliser application (inorganic N) (Lavelle & Spain 2001, Amundson & Davidson 1990). Total Nitrogen remained almost constant in all four fields, with only a slight increase at the third sampling in Sohag. Results from the principal component analysis show a weak correlation between total N and salinity in the Nile Delta, and a weak correlation between total N and DW%FW and a moderately strong correlation between N and the C:N ratio (this correlation is only weak in the Nile Delta). The increase in total N in Sohag could be attributed to an addition of nitrogen fertilizer, which would explain the changes in parameters linked to soil organic matter discussed above. The correlation between total N and salinity in the Nile Delta could also be linked to the use of inorganic fertilizers, even though there is no apparent increase or decrease of total N.

Approximately 90% of soil nitrogen reserves are organic, thus the distributions of nitrogen and carbon are usually closely correlated (Sowden et al. 1977, Lavelle & Spain 2001). The ratio of carbon to nitrogen (C:N) has been widely used as an index of tissue decomposability and of the capacity of various materials to supply nitrogen to higher plants and to micro-organisms. Other tissue properties, including the lignin content, the ratio of structural tissues to cytoplasm and the presence of secondary plant compounds also strongly influence the pattern of breakdown. Heterotrophic micro-organisms decomposing plant tissues in terrestrial environments normally have to cope with materials with higher C:N ratios than those of their own tissues. In such environments, micro-organisms in order to increase their numbers will absorb the available inorganic nitrogen to incorporate into their own biomass. In soils, lower C:N ratios generally pertain in the heavy fraction of the soil organic matter and in both the light and the heavy fractions the C:N ratio generally declines with decreasing particle size (Baldock et al. 1992, Lavelle & Spain 2001). Nitrogen deficiencies may limit the productivities of both micro-organisms and plants, depending on the nature of the decomposing materials and their stage of decomposition. Net mineralization leading to an increase in inorganic nitrogen will occur below a C:N ratio of 20, an approximate equilibrium state will pertain between 20 and 30, and over 30 net immobilisation will take place constraining the supply of nitrogen to plants (Stevenson 1986, Lavelle & Spain 2001). C:N ratio (figure 3.14.) is higher in Sohag, with values over 30 for the first two samplings, then values reaching 30 and just below at the third and all subsequent samplings. The decrease of C:N is more significant in the Berseem field at the third sampling. In the Nile Delta, there is an increase of C:N from below 20 to around 20 at the fifth sampling. Values for all four fields are almost the same at the fifth sampling. This means that net immobilisation prevails in Sohag, leading to a decrease of N, whereas mineralization dominates in the Nile Delta. Those findings correspond with the findings for total N, discussed above. PCA shows a correlation between

C and N and C:N ratio, which was to be expected. In general, unfertilized soils show a higher C:N ratio of the particles (Kandeler et al. 1998), which corresponds with the results of nutrients, indicating the use of fertilizers in the Nile Delta, but not in Sohag.

The discussed parameters represent soil organic matter, which is linked to organic resources in soils that consist of dead organic material as well as living resources (roots and soil organisms) that are an important pool for nutrients. On the other hand, mineral nutrient elements are derived ultimately from soil parent materials through weathering processes, although constant inputs of particular elements may also be derived from atmospheric sources. Some of these nutrients accumulate in the living biomass and are recycled through decomposition processes. A further part is retained in the soil in mineral form, adsorbed more or less tightly to clay particles or organic materials by electrostatic forces, or mechanically trapped within them. Lastly, fertilizers constitute an anthropogenic influence on the nutrient level in soils (Lavelle & Spain 2001).

Soil biological parameters:

Microbial biomass represents the living component of the organic matter of soil, excluding animals and plant roots. Although microbial biomass usually makes up less than 5% of soil organic matter, it carries out many critical functions in the soil ecosystem, among which the following could be pointed out: it is both a source and sink for nutrients, it participates in the C, N, P and S transformations, it plays an active role in the degradation of xenobiotic organic compounds, and in the immobilisation of heavy metals, it participates in the formation of soil structure, etc. (Gil-Sotres et al. 2005, Dalal 1998, Nannipieri et al. 2002). A single enzymatic activity, which reflects the enzymes catalysing a specific reaction in soil, can not be taken as an index of more complex functions such as a total microbial activity, soil fertility or soil quality, which all depend on many reactions and properties (Gil-Sotres et al. 2005).

Temperature and moisture indirectly affect enzyme activities by influencing microbial growth and substrate availability. Enzyme assays on regional and microenvironmental scales can indicate quick responses of soils to environmental change, data which can in turn be used in the model of biogeochemical cycling of ecosystems (Sinsabaugh et al. 1991, Moorhead & Sinsabaugh 2000).

Basal respiration serves as an index for general microbial activity, whereas substrate-induced respiration (SIR) provides information for the content in microbial biomass in soils (Raiesi & Ghollarata 2006, Gil-Sotres et al. 2005). Active living cells need a constant supply of energy, which for heterotrophic microflora derives from the transformation of organic matter such as cellulose, proteins, nucleotides and humified compounds. Energy-supplying reactions in the cell are redox reactions based on the transfer of electrons from a donor to an acceptor. By respiration, that is the oxidation of organic matter by aerobic microorganisms, oxygen functions as the end acceptor of the electrons. The end products of the process are carbon dioxide and water. The basal respiration is defined as the respiration without the addition of organic substance to soil. SIR is the soil respiration measured in the presence of an added substrate such as glucose (Alef 1995). Some authors suggest that ecological information on specific aspects of microbial activity should be obtained by calculating the ratio of soil enzyme activity to microbial biomass, even though there is no confirmation whether this ratio can be used for evaluating biochemical soil quality (Gil-Sotres et al 2005). Due to the limited access to laboratory materials in Cairo, biomass C determined by fumigation extraction method could not be measured. SIR, on the other hand, serves as a good alternative as an indicator of total microbial biomass (Sparling & West 1987, Kandeler et al. 1999). According to Tscherko et al (2007), soil microbial biomass is the most sensitive index of soil quality.

Basal Respiration (figure 3.15) is slightly higher in the Nile Delta compared to Sohag. In Sohag, there is a general increase in respiration over time, but no differences between the

two fields. In the Nile Delta, basal respiration is higher in the Berseem field in the beginning, then declines, and stays more or less constant in both fields over time. SIR (figure 3.16.) again is higher in the Nile Delta compared to Sohag. Values for both fields increase slightly between the first and the second sampling (only the increase in the wheat field is significant) and then stay almost constant in both fields until the end of the experiment. In the Nile Delta, SIR differs between the two fields at the second and third sampling, with higher values in the cotton field at the second sampling, and a significantly lower value at the third sampling. Results from the PCA from the Nile Delta show that SIR is weakly influenced by salinity and water holding capacity, and basal respiration is weakly influenced by $\delta^{13}C$, as well as by SO_4, Cl, K, NO_3, Ca, and Na. In Sohag, a weak correlation between SIR and %SAS could be found, but no correlations between nutrients and enzyme activities could be detected. Climatic conditions affect nutrient cycling in terrestrial ecosystems, especially in arid and semiarid environments. Temperature and moisture affect the enzyme activity indirectly through increasing microbial growth and substrate availability, as well as particle size (Li & Sarah 2003, Kandeler et al. 1999). This could explain the generally lower content of microbial activity and microbial biomass in Sohag, due to the climatic difference, and the slightly lower values for the wheat field, due to slightly bigger particle sizes. The correlation between $\delta^{13}C$ and basal respiration is due to the increased decomposition of plant organic materials (Kandeler et al. 1999). Salinity in the Nile Delta, i.e. in the cotton field, is obvious: at the third sampling, when salinity and the concentration of several macronutrients and NaCl is highest, microbial biomass declines by almost 50% in the cotton field and 23% in the Berseem field (compared to the second sampling). Even though there was no correlation found in the PCA, there is a slight increase in C:N ratio at the third sampling also, which might explain the slight decrease of values for basal respiration in the Nile Valley at that time, during which the threshold of 20 was crossed, which indicates the onset of immobilization processes (Lavelle & Spain 2001). It seems that the increase in salinity, which was most probably due to the application of fertilizer and suboptimal irrigation, negatively affected soil microbial biomass in general, whereas microbial activity was not adversely affected. As microbial biomass is a measure for potential rather than activity (Caldwell 2005), this could be an indicator that microbial activity in general could be higher in the soils of the Nile Delta, but salinity of the soils serves as a limiting factor. This corresponds with the findings of Mohammad et al. (2008), who found no clear correlation between salinity and sodicity effects and microbial biomass, but stated, that a decrease in salinity and sodicity would improve the accessibility of soil organic matter to the soil microbial community.

Because microorganisms produce enzymes that catalyze the degradation of substrates in their immediate environment, decomposition rates should be related to the activities of enzymes associated with the degradation of key classes of compounds (Sinsabaugh et al., 1991). Measurements of particular enzyme activities provide a more precise insight to microbial activities than general determinations of biomass or bulk respiration (Moorhead & Sinsabaugh 2000), as biomass and activity give an overview on potential, whereas functional diversity is related to the actual activities resulting from that potential (Caldwell 2005). The analysis of dehydrogenase, urease and phosphatase activity together with microbial activity and biomass was recommended by Römbke et al. (2002).

Dehydrogenase activity can be seen as a general measure of viable microorganisms (Gil-Sotres et al. 2005). It is considered to be an indicator of the microbial redox system and of the oxidative activities of the soil (Trevors 1984). This property has been used mainly to assess the influence of management on soil quality and contradictory results have also been obtained. For example, ploughing can both increase and decrease dehydrogenase activity, whilst the addition of organic fertilizers, landfill effluents and industrial waste generally increases dehydrogenase activity. In general, this activity is not affected by the presence of heavy metals, unless in very high doses (Gil-Sotres et al. 2005). Dehydrogenase is thought mainly to be microbial in origin (Li & Sarah 2003).

Dehydrogenase activity (figure 3.17) is higher in the Nile Delta, with higher values for the Berseem field. The values in the cotton field increase over time, then drop to a level below that of the fields in Sohag at the fifth sampling. The strong increase of dehydrogenase activity between sampling 3 and 4 could be related to the use of fertilizers before sampling 3, which caused an increase in salinity and the subsequent increase of enzyme activities when salinity decreased again. The generally lower values of the cotton field could be attributed to the missing vegetation cover, which negatively influences soil microclimate and salinity in the cotton field. The decrease at the fifth sampling may be due to the fact that cotton had been harvested, but indicate that the methods of mixing and drying of the soils (as told by the farmer) do not ameliorate biological soil properties. As values in the Berseem field show the same trends, with a higher activity in general, and the lower and almost constant values for salinity, supports the idea of the negative influence of salinity on dehydrogenase activity in general, but does not explain the decrease at the 5th sampling in both fields. The PCA of enzymes and salinity shows no correlation between those values for the Nile Delta, the only moderately strong relationship could be found between $\delta^{13}C$ and dehydrogenase activity, and weak relationships between SO_4, Cl, K, NO_3, Ca, and Na. This indicates an indirect correlation between the major causes of salinity and dehydrogenase activity as those ions are directly linked to salinity. The influence of $\delta^{13}C$ shows another link between humification processes and microbial activity. It is thus likely that the decrease in activity at the end was due to the harvest of cotton plants, and possibly due to climatic influences.

Dehydrogenase activity of the fields in Sohag do not differ, but increase over time, with the highest values at the fourth sampling and a subsequent, slight decrease, which still poses a total increase compared to sampling 1. The general increase could not be linked to any other parameter by PCA.

Urease, the enzyme that catalyses the hydrolysis of urea, can be used for the evaluation of changes in soil quality due to soil management. Its activity increases due to organic fertilisation and after the addition of cattle slurry to the soil. It then decreases as a consequence of ploughing (Gil-Sotres et al. 2005, Chakrabarti et al. 2000, Kandeler & Eder 1993, Saviozzi et al. 2001).

Urease activity (figure 3.18.) again is higher in the Nile Delta compared to the fields in Sohag. In the Nile Delta, both fields show a similar trend from samplings 1-3, with almost constant values.Then there is a significant increase of urease activity in the Berseem field. Urease activity does not alter significantly in the cotton field over time. Urease activity in the Nile Delta is weakly influenced by salinity, as well as by $\delta^{13}C$, PO_4, Ni, and Cu, these influences, apart from salinity, are positive rather than negative. In Sohag, urease activity is weakly influenced only by C:N ratio, which seems to be linked to the availability of N. Those results indicate that in general, Berseem as a fallow crop, has a positive influence on soils in the Nile Delta, at least compared to cotton. In Sohag, the values in the Berseem field are not significantly higher.

Phosphatase activity serves as a measure for changes in soil quality due to either management or the presence of contaminants. It is a good index of the quality and quantity of organic matter in the soil (Bergstrom et al. 2000) and can be very high in arable soils as long as the levels of organic matter in the soil are maintained. For this reason, if the organic matter content of degraded soils increases during recovery, the level of this enzyme activity also rises. Studies have also shown that this enzymatic activity increases as a consequence of organic fertilisation and decreases when phosphate fertilizers are used, and can be decreased by the presence of lead and other heavy metals, whilst the presence of pesticides in the soils only decreases it temporarily (Gil-Sotres et al. 2005). The values for phosphatase activity (figure 3.19.) are again higher in the Nile Delta, with higher values for the Berseem field. Whilst the values in the cotton field remain almost constant throughout time, values decrease at the second sampling in the Berseem field, then increase to values higher than in the beginning at the time of sampling 4 and 5. Phosphatase activity is moderately strongly

influenced by salinity, as well as by $\delta^{13}C$, SO_4, Cl, K, NO_3, Ca, and Na. The nutrients show that this influence is strongly linked to salinity again, which explains the lower values in the cotton field. In Sohag, no correlation between phosphatase activity and any other parameter could be found.

The PCA of metavariables (figures 3.30. and 3.31.) derived from first components from all above mentioned PCAs (figures 3.20. – 3.29.) shows, that in the Nile Delta, there is a clear indication for the effects of salinity on enzyme activity and soil structure, but not so much on soil organic matter. In Sohag, There is a clear correlation between enzymes, soil organic matter and pH, and soil structure, pH and enzyme activities. In the Nile Delta, the ions forming the metavariable called “Salinity Ions” incorporated Na, Cl, K, Ca, Mg, SO_4, NO_3 and EC (electrical conductivity), clearly showing that those ions are mostly adversely affecting soil structure, as well as enzyme activity (in this case, mostly phosphatase and urease activity). In Sohag, enzyme activity (phosphatase and dehydrogenase activity) was mostly influenced by soil pH, whereas urease and phosphatase activity were mostly influenced by total N.

The results of the analysis of enzyme activities show that in general, Berseem as a fallow crop, has a positive effect on soil microorganisms, at least compared to cotton as an alternative field crop. It also has a positive effect on soil structure, resulting in better root penetration due to the denser vegetation cover. In Sohag, where values were generally lower and which could be attributed to the dryer climate and generally more arid condition, no difference between the crops could be found. Generally, the soils in Sohag are much less adversely affected by salinity, which might be due to the fact that both crops, wheat and Berseem, provide a dense vegetation cover which prevents salinisation due to the evaporation of water. As values of all parameters are much lower than in the Sohag, this could be an index of progressing soil degradation, due to the adverse conditions and the fact that these soils are intensively used, even though they are especially fragile.

In the Nile Delta, there are correlations between almost all parameters linked to soil microorganisms and salinity and $\delta^{13}C$. As values in the Berseem field increase, and are higher than the ones found in the cotton field, this indicates that salinity negatively influences soil organic matter turnover, as well as enzymatic activities, which is a clear indication for degradation processes due to anthropogenic influences. The cultivation of cotton is thus expensive, in terms of water used and regarding soil processes indicating an onset of degradation. Bearing in mind that soils in Egypt are very fragile due to the climatic conditions, it is clear that soil amelioration processes should be started. The fact that after harvest, most parameters returned back to normal is reassuring, however, this does not account for dehydrogenase activity, basal respiration and SIR, which indicates that the viability of soil microorganisms and the general potential of soil microorganisms decrease slowly due to the long term effects of salinity, which can be interpreted as an onset of biodegradational processes.

5. Conclusion and Outlook

The determination of soil quality is difficult, especially if one considers that many changes take place over the long term, and thus a change in soil quality can only be perceived when all the effects are combined over a period of time. Due to the lack of agreement on the definition of soil quality, there is currently no general consensus regarding the soils that should be considered of maximum quality. The different approaches to the latter point can be summarized in two options. The first considers that a maximum quality soil is the soil in equilibrium with all the components of the environment, i.e. a climax soil developed under climax vegetation. The second option considers that the maximum quality reference soils are soils capable of maintaining high productivity and of causing the minimum of environmental distortion (Gil-Sotres et al. 2005). Both demands are hard to meet in Egypt, as climax soils, if at all, are hard to find in the relatively small area of arable land that is very densely populated. If undisturbed climax soils existed at all, they would, most probably, not be accessible. The soils of the Nile Delta still maintain a high productivity, however, as results indicate, these soils are already adversely affected by land use. It is still possible, though, to compare the soils from the Nile Delta to the soils of the land reclamation project in Sohag and to draw conclusions from results in order to answer the research hypothesis and to meet research objectives.

In general, the physical and physico-chemical parameters of soils only alter when the soil undergoes a really drastic change (Filip 2002). The thorough analysis of physico-chemical as well as mineralogical parameters in this thesis shows that the soils of the two experimental sites are comparable in structure, parent material and origin. On the contrary, biological and biochemical parameters are sensitive to the slight modifications that the soil can undergo in the presence of any degrading agent (Gil-Sotres et al. 2005). The results of the biological and biochemical analysis show that the soils in the Nile Delta are prone to degradation processes due to intensive use and the cultivation of cotton as a cash crop, which leads to salinisation of the soils. Even though salinity declined after the harvest, microbiological processes were still lower than in the beginning of the experiment. It is unclear whether microbial activity would have recovered. The decrease of activity could be a sign of onset degradation.

On the other hand, results from Sohag indicate that these soils are already slightly degraded, as the parent material is very similar to the Nile Delta, but the soils show less soil organic matter and less microbiological activity. However, the biological parameters are much more stable in Sohag than in the Nile Delta, which might indicate a better buffering capability of the soils than in the Nile Delta. As both crops in Sohag provide a dense vegetation cover, this could also be attributed to the use of crops, but this is contradicted by the results derived from the Berseem field in the Nile Delta, which also show alterations in values over time.

The onward salinisation of soils in the Nile Delta has been subject to several studies, looking for amelioration techniques. One of the most popular suggestions, namely rice cultivation as an amelioration technique against salinisation in the Nile Delta, as suggested by Kotb et al (2000) is water intensive (Oad & Azim 2002). Kotb et al. (2000) perceived that enforcement of rice cultivation would be difficult due to the periodic shortfalls in supply of irrigation water and the salinity of supply waters. The subsequent burning of rice straw leads to a dark pollution plume that has been regularly observed over Cairo during the autumn season for almost a decade now. This “Black Cloud” accounts for a great part of the air pollution in Cairo (Favez et al. 2008).

A possible way out of the vicious circle would be the end of cotton cultivation. As Egyptian cotton is world famous, this will not happen. Von Boguslawski (2002) compared organic and conventional cultivation of cotton and the use of pesticides, and showed that organic

cultivation would be a way forward in order to combat pests, facilitating the situation of small farmers tremendously. Unfortunately, he did not examine soil quality or fertility. He suggests strip-cultivation for both organic and conventional cotton cultivation, as this would make it possible to grow additional plants next to cotton. The way cotton is planted traditionally makes this almost impossible due to the intensive flooding of gaps between cotton rows. He describes the planting of onions inbetween rows of cotton plant in some parts of Upper Egypt, but as those onions are only sparsely planted, this will not ameliorate soils. A dense vegetation cover prevents the fast evaporation of water and thus salinization, as well as other processes enhancing soil degradation, like wind or water erosion of organic matter. On the other hand it supports an optimal soil structure, which is necessary for soil (micro)organisms. In order to evaluate soil quality of strip-cultivated cotton, further studies dealing with cotton cultivation would be necessary.

Given the harsh climate and fragile soils, special emphasis should be put on research regarding crop rotation options. Kotb et al. (2000) suggest several crop rotation cycles, including the cultivation of rice, which cannot be the only way forward, given the problems described above. Berseem as a fallow crop is also affected by soil salinity, as the dry weight of root and shoot decreases with an increase in the concentrations of soil solutions (Ghollarata&Raiesi 2007), which again negatively influences soil quality as root penetration is a very important factor. The results of this thesis also indicate that Berseem as a fallow crop does not distinctly ameliorate soils. A recent review of changes in soil quality and profitiability of rotation crops after cotton in Australia, looking at study results from 1970 to 2006, indicate that wheat after cotton is better for the improvement of soil quality in Vertosols compared to growing legumes. This is because the intensity of wet/dry cycles is greater with wheat than with legumes, which in turn is related to wheat's higher subsoil root density in most Vertosols and, consequently, its ability to dry out the subsoil to a greater extent. Leguminous rotation crops can improve soil aggregate stability and N by fixing atmospheric nitrogen, by reducing exchangeable sodium content through a process of chemical exchange rather than leaching. However, these changes, particularly in sodic soils, are restricted to surface soils. They also suggest that crop rotations using 2 or more rotation crops sown after cotton could improve soil quality. They either suggest cotton-cereal-legume, cotton-cereal-legume-cereal, or cotton-oilseed-cereal-legume, or the incorporation of high value crops, such as melons and onion types. Another possibility would be further research into possible "energy" crops for biofuel production that positively affect soil quality (Hulugalle&Scott 2008). Currently, the Egyptian crop rotation cycle seems to follow their suggestions to a certain extent, however, Berseem/bean is mostly planted after cotton, as well as other vegetables (Kotb et al. 2000). Given the poverty of most Egyptian farmers, research on high value crops leading to the amelioration and desalinization of soils would be of ecological as well as sociological interest.

Results also show that negative influences of cultivation and increased salinity are strongly enhanced by the arid climate in Egypt. Soils in arid environments are especially fragile and prone to degradation processes, which can be emphasised by the results from this thesis. It is clear, however, that soil degradational processes are enhanced by the anthropogenic use of soils, and the increasing need of crops due to the increase in population.

In order to answer the research hypothesis, it can be said that the missing flooding of the soils in the Nile Delta negatively affects soil quality. The soils of the field in Sohag can be seen as 10 year old sediments from the river Nile, which makes some sort of comparison with the 1mm of sediments that used to be deposited in the Nile Delta before the construction of the High Dam possible. The more constant values of biological parameters in Sohag could be a sign for a better buffering capacity of the soil there, leading to the assumption that flood deposits of river sediments would have a positive effect on the soils in the Nile Delta in general. Two definite advantages of floods on soil quality in the Nile Delta are obvious: the fact that only one harvest would be possible means that soils would be less intensively used, as well as the fact that salts accumulated in the top layers would be leached out. As the

Aswan Dam exists and will remain, and as it is impossible to go back to the flooding of the Nile Delta, due to the extensive urbanisation, the increased population since the 1960 and the general demand for crops show that amelioration of the soils in the Nile Delta is more urgent than ever.

In order to evaluate the Land Reclamation Projects in Upper Egypt as well as to gather further information about how the missing deposition of Nile sediments in the Nile Delta influences soil processes, it would be necessary to perform at least another evaluation of processes, as the results of this thesis provide a snap-shot of soil quality only. All biological and biochemical processes analysed in Sohag showed lower values than in the Nile Delta. In general, it can be said that for future land reclamation projects, the results of this thesis indicate that, whether due to climatic or anthropogenic influences, those soils are prone to degrading processes from the onset. As land reclamation projects are very cost and labour intensive, it needs to be taken into account that intensive agriculture will lead to onward degradation in as little as a decade. Therefore, it is paramount that those soils are cultivated in the least exploitive way , i.e. organic agriculture rather than the intensive use of fertilizers, which increase salinisation; dense vegetation cover, long fallow periods; and optimised irrigation. In order to achieve this, it is important that only skilled and educated settlers are allowed to cultivate soils there.

Investing in human capital through education and supportive institutions and infrastructure is analogous to companies reinvesting capital into research, development, and equipment replacement. Educated people will understand and use the tools of sustainable natural resources management. Such tools have resulted in much land saved from human encroachment that can sustain other uses such as wildlife habitats and protect fragile or unique ecosystems. Attempting to curtail soil and land degradation without investing in the currencies of human capital and social benefits is to ignore the primary drivers of ecosystem deterioration (Miller 1998). This also accounts for Egypt.

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Zusammenfassung:

Landwirtschaftlich genutzte Flächen in ariden Gebieten sind aufgrund vieler Faktoren von Degradation bedroht: falsche Bewässerung, Überdüngung und nicht nachhaltige Methoden resultieren häufig in der Versalzung von Böden. Das bedeutet, dass die Bodenfruchtbarkeit abnimmt und verschiedene inhärente Prozesse, die für einen funktionierenden Boden notwendig sind, abnehmen. Wenn diese Prozesse nicht bereits zu Beginn ameliorisiert werden, kann diese Degradation in Desertifikation resultieren, also dem Verlust des Bodens und der Ausbreitung von Wüsten.

In Ägypten werden diese Probleme durch das hohe Bevölkerungswachstum, den geringen Anteil an landwirtschaftlich nutzbarer Fläche (weniger als 4% der gesamten Fläche des Landes) und der Wasserknappheit verstärkt. Die bestehende landwirtschaftlich nutzbare Fläche geht einerseits durch die sich rasant ausbreitenden Städte und Bodendegradation verloren, andererseits hat die ägyptische Regierung Programme zur landwirtschaftlichen Erschließung von Wüstengebieten gestartet, die die landwirtschaftlich nutzbare Fläche auf 25% der Gesamtfläche bis ins Jahr 2017 ausweiten soll.

Um die Bodenqualität von bereits existierenden landwirtschaftlich genutzten Flächen zu bestimmen, wurden zwei Beprobungsflächen ausgewählt: Böden zweier Felder des Nildeltas, die seit Jahrhunderten bebaut worden sind, wurden mit zwei Feldern in Oberägypten verglichen, die Teil eines Wüstenwiedergewinnungsprojektes in Sohag sind. Im Nildelta wurde ein Baumwollfeld mit einem Kleefeld (als Zwischenfrucht, *Trifolium alexandrinum*, genannt Berseem) verglichen, in Sohag ein Weizenfeld mit einem Kleefeld. Durch die Auswahl von Feldern mit denselben Feldfrüchten (Klee) war ein direkter Vergleich zwischen den beiden Standorten möglich, genauso wie eine Erhebung des Einflusses der Feldfrucht auf die Böden eines Standortes. Bei beiden Versuchsflächen wurden je fünf Beprobungen durchgeführt, indem sechs Proben pro Feld, die regelmäßig über die Felder verteilt waren, genommen wurden. Jede dieser Probe bestand aus 5 Einstichen von 0-25cm unter der Oberfläche. Durch die Kombination von geologischen und biologischen Parametern, die ausgewählt wurden um sowohl bodenphysikalische, -chemische und –biologische Einflüsse untersuchen zu können, konnte eine ausführliche Bodenqualitätsanalyse beider Standorte stattfinden.

Um die bodenphysikalischen Parameter bestimmen zu können, wurden Korngrößenanalysen und Röntgendiffraktometrische Analysen durchgeführt, das Verhältnis von Trockensubstanz und Bodenwasser, stabile Aggregate, die maximale Wasserhaltekapazität und die Kationenaustauschkapazität gemessen. Bodenchemische Parameter umfassten die Bestimmung der Chemie des mineralischen Anteils durch Röntgenfluoreszenzanalyse, die Bestimmung des pH Wertes, den Gehalt an Organischer Substanz ($\delta^{13}C$, $\delta^{15}N$, C:N, total C_{org}, total N), der Kationen und Anionen in Bodenwasserlösung, sowie deren Gesamtmenge (im Säureextrakt), und die elektrische Leitfähigkeit (als Indikator für Salinität) analysiert. Als bodenbiologische Parameter wurden die Basalatmung, Substratinduzierte Respiration, Dehydrogenaseaktivität, Ureaseaktivität und Phosphataseaktivität gewählt.

Die mineralogischen Analysen zeigten die Ähnlichkeit der Bodenprofile hinsichtlich der bodenmineralischen Zusammensetzung, obwohl die beiden Standorte rund 400km von einander entfernt liegen. Die hauptmineralogischen Anteile der Böden waren Quarz und Tonminerale, aber auch Feldspäte, Calcit, Goethit, Gips und NaCl in beachtlichen Mengen waren ebenfalls vorhanden. Die Tonminerale beinhalten Smektit (als Hauptvertreter), und geringere Anteile von Illit und Kaolinit. Der relativ hohe Anteil von Smektit ist für landwirtschaftliche Böden durch seine große spezifische Oberfläche und der daraus resultierenden Kationenaustauschkapazität positiv, andererseits wirkt sich die Quellfähigkeit und das Schrumpfen bei Austrocknung negativ auf die Bewirtschaftlichkeit aus.

Die Böden in Sohag waren generell trockener als die des Nildeltas, was durch das trockenere Klima in Oberägypten erklärt werden kann. Im Nildelta war das Baumwollfeld trockener als das Kleefeld, was durch die kleinere Vegetationsdecke und die daraus resultierende stärkere Verdampfung des Bewässerungswassers zu erklären ist.

Der Gehalt an stabilen Aggregaten war höher im Nildelta, und nahm bei beiden Versuchsstandorten im Zeitraum von der ersten bis zur fünften Beprobung zu. Das kann auf das Pflanzenwachstum und die daraus resultierende größere Wurzelbiomasse zurückgeführt werden. Die Wasserhaltekapazität war höher im Nildelta, was auf die größere Menge an Tonmineralien im Nildelta, genauso wie auf den höheren Gehalt an organischer Substanz zurückgeführt werden kann. Die Kationenaustauschkapazität war ebenfalls höher im Nildelta, was auf einen größeren Anteil von Smektit zurückgeführt werden kann. Der Boden pH war etwas höher in Sohag (mit einem Mittelwert von 7,9) im Vergleich zum Nildelta (Mittelwert von 7,6). Der etwas niedrigere pH im Nildelta kann als Konsequenz auf die Verwendung von mineralischen Düngern während der Versuche gesehen werden.

Die Analyse von Kationen und Anionen zeigte eine größere Nährstoffverfügbarkeit im Nildelta, allerdings sind die hohen Anteile von Ca, SO_4, Na und Cl bedenklich. Die Nährstoffmenge korrelierte stark mit der elektrischen Leitfähigkeit (als Maß für die Versalzung), die im Baumwollfeld des Nildeltas am höchsten war.

Die Aktivität der mikrobiellen Biomasse war höher im Nildelta als in Sohag, genauso wie der Gehalt an organischer Substanz. Allerdings zeigte die mikrobielle Biomasse eine verringerte Aktivität im Baumwollfeld des Nildeltas, was durch die erhöhte Versalzung erklärt werden kann.

Generell waren alle Parameter, die mit Bodenfruchtbarkeit in Zusammenhang gebracht werden können, niedriger in Sohag als im Nildelta. Das zeigt, dass die neuerschlossenen Böden anfälliger für Prozesse sein können, die zu einer Degradation führen, als die Böden im Nildelta. Andererseits resultierte der Anbau von Baumwolle im Nildelta in einer Zunahme der Versalzung (die allerdings nach der Ernte und der anschließenden Durchmischung und Spülung der Böden wieder abnahm), die zu einer Abnahme der mikrobiellen Aktivität führte. Dies kann ebenfalls als einsetzende Degradation gewertet werden.

Die Ergebnisse dieser Arbeit zeigen, dass die Auswahl der Feldfrucht, der Bewässerungs- und Düngungsmethoden, genauso wie das Klima und die „Geschichte“ der Böden deren Qualität stark beeinflussen.

Insbesondere durch die Planung weiterer Wüstenerschließungsprojekte und der Empfindlichkeit dieser Flächen, sind nachhaltige Bebauungsmethoden genauso wie die Ausbildung der Bauern von größter Wichtigkeit für den Erfolg dieser teueren und arbeitsintensiven Programme.

Summary:

Cultivated soils in arid environments are threatened by degradation due to many factors: false irrigation, overfertilisation and non-sustainable practices often result in salinisation of the soils. This means that soil fertility decreases, and many inherent processes of soils that are needed for a functioning soil environment decline. If those processes aren't ameliorated at their onset, this degradation can result in desertification, i.e. the complete loss of soils and the extension of deserts.

In Egypt, these problems are intensified due to the constant population growth and the relatively small amount of arable land (<4% of the total area), which is lost due to soil degradation and urbanisation, as well as the limited amount of water. On the other hand, very ambitious land reclamation programmes have been started by the Egyptian government to increase the amount of arable land up to 25% of the total area by the year 2017.

In order to assess soil quality of already existing agricultural soils, two experimental sites were chosen in Egypt: soil of two fields in the Nile Delta, which have been agriculturally used for centuries were compared to two fields in Upper Egypt that are part of a desert reclamation project in Sohag. In the Nile Delta, a cotton field was compared to a clover field (fallow crop, *Trifolium alexandrinum*, also called Berseem), in Sohag, a wheat field was compared to a clover field. By choosing fields with the same crops, a thorough comparison was made possible as well as the assessment of the influence of crop use on soil quality. In both sites, five samplings were performed, by taking 6 samples evenly spread across the fields, which consisted of 5 sub-samples taken from 0-25cm below surface. By combining geological as well as biological parameters, which were chosen to assess physical , chemical and biological soil conditions, a thorough analysis of soil quality in both experimental sites was conducted.

In order to evaluate soil physical parameters, grain size analysis, x-ray diffraction, dry matter and water content, the amount of stable aggregates, maximum water holding capacity, and cation exchange capacity were measured. For the assessment of soil chemical parameters, the chemistry of minerals was measured by x-ray fluorescence, additionally the parameters soil pH, soil organic matter content (determined by measuring $\delta^{13}C$, $\delta^{15}N$, C:N, total C_{org}, total N), cations and anions in soil water as well as their total content (measured in acid extract), and electrical conductivity (as an indicator for salinity) were analysed. Soil biological parameters consisted of the measurement of basal respiration, substrate induced respiration, dehydrogenase activity, urease activity, and phosphatase activity.

The thorough mineralogical analysis showed the similarity of the soil profiles, even though both experimental sites were approximately 400km apart. The main minerals in all soils were quartz, clay minerals; feldspars, calcite, goethite, gypsum, and NaCl in considerable amounts were also present. The predominant clay mineral found was smectite, and a small amount of mica and kaolinite. The high content of smectite is fortunate in terms of its large specific surface area and high cation exchange capacity. The shrink-swell behaviour of smecites can sometimes lead to problems of the management of arable soils.

Soils in Sohag were generally dryer than the soils in the Nile Delta, which can be explained by the more arid climate in Upper Egypt compared to the Nile Delta. In the Nile Delta, the soil of the cotton field was slightly dryer than the Berseem field, which can be explained by the sparser vegetation cover which leads to more evaporation of water and thus faster drying of the soil.

The amount of stable aggregates was higher in the Nile Delta than in Sohag, in both experimental areas and increased over time. This could be attributed to the growth of plants

on the fields and the increase in root biomass. Water Holding Capacity was higher in the Nile Delta compared to Sohag. This can be explained by the generally higher content of clay minerals in the Nile Delta, as well as a greater amount of organic material. Cation Exchange Capacity (CEC) also differed between the two experimental sites, with a higher CEC found in the Nile Delta, which can also be linked to the greater amount of clay minerals, smectite in particular. Soil pH was slightly higher in Sohag (mean of 7.9) compared to the Nile Delta (mean of 7.6). The slightly lower pH in the Nile Delta can be a consequence of the use of fertilisers during the experimental period.

The analysis of cations and anions showed a higher availability of nutrients in the soils of the Nile Delta, however, the high content of Ca, SO_4, Na, and Cl are a cause for concern. Results for these nutrients correlate strongly with salinity, which was highest in the cotton field in the Nile Delta.

Microbial biomass activity was higher in the Nile Delta than in Sohag, as well as the content of soil organic matter, however, microbial biomass showed a decline in activity in the cotton field of the Nile Delta, which can be linked to the high salinity of the soil.

In general, all parameters linked to soil fertility were lower in the fields of Sohag. This shows that reclaimed soils, due to their fragility, are much more prone to degradational processes than the soils in the Nile Delta. On the other hand, the cultivation of cotton in the Nile Delta resulted in an increase of salinity (which declined after harvest and a thorough flooding and mixing of the soil), which lead to a decrease of microbial biomass activity, which can be regarded as onset degradation.

Results from this thesis show, that the choice of crop, the agricultural methods used (regarding irrigation and fertilisation of soils), as well as climate and history of the soils strongly influence their quality.

Especially regarding further land reclamation projects and the sensitivity of those soils, sustainable cultivation methods as well as thoroughly trained farmers will be of paramount importance for the success of these cost and labour intensive programmes.

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PhD in Geology, Thesis title: "Land use and Soil Quality in an Arid Environment (Egypt)"

- assessing soil quality in the Nile Delta and a newly reclaimed area close to Sohag, Upper Egypt
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