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Relating soil properties to biomass consumption and land management in semiarid Sudan

- A Minor Field Study in North Kordofan

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Degree-thesis in Physical Geography and Ecosystem Analysis

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Abstract

In rural Sudan, as in many parts of Africa, biomass is the most important source of energy. Besides the use as fuelwood for cooking and heating of houses, biomass is also used for construction of houses and fences amongst other things. Among farmers in semiarid Sudan it's a known fact that the *Acacia* trees that grow and regenerate naturally on their lands help improve soil fertility and crop yield if left as fallow for some years before cultivating it again. During fallow the *A. senegal* and *A. seyal* trees can be tapped for gum Arabic, a resin used in food, beverages as well as for industrial purposes, as an extra source of income. This so called bush fallow system is commonly used in Sahel, but droughts during recent decades has caused many farmers to shorten the period of fallow as the need for more arable land increased. The removal of vegetation, in turn, makes the land susceptible to erosion and degradation and the need for even more land rises as nutrients are lost. At the same time, the drylands in Africa are seen as an underexplored potential sink of atmospheric carbon dioxide.

In this study two neighbouring villages with different land use focus are compared; one with emphasis on gum production and the preservation of the trees and the other with a greater focus on producing cash crops. The objectives are to see if there is a difference in the soil properties between the two and if this in turn can be linked to the biomass consumption and the land management in general. As a final step it evaluates the stability of these strategies and tries to make some projections for the future. To achieve these goals soil samples were collected, standing biomass stock was measured and calculated and interviews regarding household biomass consumption and land use history were held in each village.

Contrary to what could be expected, the results do not show one village having overall better soil properties than the other, with the most likely reason for this being that the villages chosen quite simply are not as different as anticipated. In both villages, the present annual biomass consumption does not exceed the production and the biggest concern for the future is access to drinking water. The lack of water is presented as the main reason for seasonal migration from the villages and it is likely to increase if the temperature rises and rainfall decreases.

Keywords: Geography, physical geography, semiarid, Sudan, agroforestry, nutrients, biomass, *Acacia senegal*, gum Arabic

Sammanfattning

I Sudan och många andra delar av Afrika är biomassa den huvudsakliga energikällan. Ved används för att göra upp eld till matlagning och uppvärmning av hus och mycket biomassa går också åt till att bygga hus, staket, verktyg och annat. Bönderna på den sudanesiska landsbygden är väl medvetna om att *Acacia*-träden som växer och förökar sig naturligt på deras marker hjälper till att öka bördigheten och skörden om de får ligga i träda ett antal år innan de åter brukas. Under åren i träda kan arterna *A. senegal* och *A. seyal* tappas på gummi arabicum, ett naturligt stabiliseringsämne som bland annat används i mat, läskedrycker och inom industrin och som är en extra inkomst för bönderna. Det så kallade ’bush fallow’-systemet är vanligt förekommande i Sahel men långa perioder av torka under de senaste decennierna har bidragit till att många bönder kortat ner trädaperioden, då behovet av odlingsbar mark ökat. Avsaknaden av vegetation gör marken mer sårbar för erosion och behovet av åkermark blir än större då mängden näringsämnen i jorden minskar. Torrområdena i Afrika ses som en hittills outnyttjad sänka av atmosfärisk koldioxid och det är just i marken den största andelen tros kunna lagras.

I den här studien görs en jämförelse av två byar med olika fokus gällande markanvändning; den ena har fokus på produktion av gummi arabicum och bevarandet av träd medan den andra i större utsträckning producerar grödor till försäljning. Syftet med studien är att se huruvida det finns skillnader i jordegenskaper mellan de båda och om detta kan tillskrivas konsumptionen av biomassa och valet av markanvändning. Som ett sista steg utvärderas stabiliteten och framtidsutsikterna för de båda strategierna. Metoderna som använts innefattar jordprovtagning, mätning och beräkning av trädbiomassa samt intervjuer gällande hushållens förbrukning av biomassa samt tidigare markanvändning i respektive by.

I motsats till vad som förväntades, visade resultaten inte någon tydlig trend åt något håll gällande jordegenskaperna. Den största anledningen till detta tros vara att byarna inte var så olika trots allt. Den årliga förbrukningen av biomassa överskred inte produktionen i någon av byarna och den största oron för framtiden är sannolikt tillgången på dricksvatten. Intervjuerna avslöjade att bristen på vatten är den huvudsakliga anledningen till att många människor tillfälligt flyttar från byn under torrperioden och allt fler förväntas göra det om temperaturen stiger och mängden regn minskar.

Nyckelord: Geografi, naturgeografi, semiarid, Sudan, agroforestry, näringsämnen, biomassa, *Acacia senegal*, gummi arabicum

1. Introduction

This degree project in physical geography is part of a larger study of the environmental impact of biomass substitution in rural parts of semiarid Sudan, a cooperation between researchers at the Department of Physical Geography and Ecosystem Analysis at Lund University and the Agricultural Research Cooperation (ARC) in El Obeid, Sudan. The field work was partly financed by the Swedish International Development Cooperation Agency (SIDA).

1.1. Objectives

In his study the soil and carbon properties of two adjacent villages (El Humeira and El Homara) in North Kordofan State, Sudan, which are practicing different land use strategies are compared. One village strongly focuses on gum production and use long fallows with trees. The land use in the other village is mainly continuous cultivation and/or fallows without trees. Grazing occurs in both villages. The aim of this study is to:

1. Compare the soil properties in the two villages with focus on soil carbon, soil texture, soil water availability and soil nutrients (N, P and K).
2. Quantify the biomass production and consumption in the two villages.
3. Investigate linkages between soil properties and biomass management in terms of nutrient status and carbon storage/sequestration.

By the end of the study the aim is to answer the following questions:

- Are the soil properties different in the village practicing agroforestry, compared to the village with more continuous cultivation? If so, what could be the causes for not all villages practicing agroforestry?
- Do the soil properties differ between two villages practicing different land management? Are there more nutrients in the soil close to trees than in pure cultivation?
- Does the bush fallow system provide the village households with enough income and biomass to make it independent of other inputs?
- With a gradually changing, warming climate, are the two strategies studied here good options for the Sahel region in the future?

1.2. Agroforestry and the bush fallow system

Agroforestry, the combined use of trees and agricultural crops in one and the same area, is based on the idea that the trees help improve soil fertility (Sanchez and Palm, 1996). By keeping the soil covered with vegetation the effect of erosion and land degradation[1] decreases (Reeves, 1997). In Sudan, overgrazing, removal of trees and an insufficient input of additional nutrients are among the most common reasons for soil degradation (Ayoub, 1998). Transformation of degraded crop and grasslands to areas practicing agroforestry is seen as one of the best ways to sequester atmospheric carbon and it becomes a win-win situation as it meanwhile provides different items that can be used by humans and animals (McMichael *et al*, 2005). Study results have shown higher crop yields close to trees or in areas recently covered by trees, such as

[1] Process, often brought on by human activities, that over time decreases the biophysical resources of the land in question, in turn affecting both productivity and yields (El Tahir *et al.*, 2009).

in the bush fallow system. The intercropping of trees and crops can be either sequential, meaning occurring within the same area at different times, or simultaneous, with both present at the same time (Palm, 1995; Sanchez and Palm, 1996). The positive environmental and economic effects of agroforestry are well known at this point, but it is a system that can't manage on its own. Jamal and Huntsinger (1993) states that even though *"agroforestry systems offer opportunities for the stabilizing of rural communities, stable rural communities are also necessary for the survival of agroforestry systems"*.

The *Acacia senegal* bush fallow rotation is traditionally split into three parts, starting with the clearing of old trees. The land is cultivated for 4-6 years, until the yield starts to decline, while the trees regenerate. After this point, the land is left as fallow for at least twice as long, and the trees are tapped for gum during the dry seasons. Tapping starts when the trees are 5-6 years (Rahim, 2008). At an age of approximately 20 years, gum production usually starts to decline so the trees are cut and left to regenerate and the cycle starts over with cultivation (Raddad *et al.*, 2006). Besides gum Arabic, the *A. senegal* trees provide fodder, fuelwood, timber, fibre and medicine (Web3).

During the wet season, farmers in Kordofan generally grow cereal crops such as sorghum (*Sorghum vulgare*) and millet (*Pennisetum purpureum*), along with cash crops like 'karkade' (*Hibiscus* supp.), sesame (*Sesamum* spp.) (Jamal and Huntsinger, 1993), groundnuts (*Arachis hypogaea*) and watermelons (*Citrullus vulgaris*) (Elmqvist, 2006). The type of crop chosen for intercropping with trees, as well as the density of trees, has been seen to affect the yield produced (Raddad *et al.*, 2006).

Severe droughts in the Sahel area during the end of the 1970's up until the middle of the 1980's has changed the traditional farming system, and particularly the length of the fallow periods. Smaller crop yields during this time gave rise to greater land areas being cultivated, on the expense of trees. The small-scale farmers had to put the need for food before the soil fertility improving trees. McMichael et al (2005) talks about 'destructive poverty syndrome', meaning that poor people that do not have the funding needed for sustainable management of the land and its resources will become even poorer as the land use results in diminishing resources.

1.2.1. Acacia trees and gum Arabic

Figure 1. Gum Arabic

There are 36 types of gum producing *Acacia* species in Sudan, with *A. senegal* (L.) Willdenow ('hashab') and *A. seyal* Delile ('talh') as the most common (Jamal and Huntsinger, 1993). Acacias are very drought resistant, but there are in spite of this some differences in where these two species are generally found. While *A. seyal* is most commonly found on clay soils in areas with a mean annual rainfall of 250-1000 mm (Web4), *A. senegal* grows on the vast areas of dry, sandy soils (Elmqvist *et al.*, 2005) that constitutes about 60% of the Kordofan States land area suitable for cultivation (El Tahir, 2006) and annual rainfall of 300-1200 mm. *A. senegal* can withstand greater temperatures but is sensitive to waterlogging (Web3).

Even though the first gum producing trees were identified by Carl von Linné in the 1700's, gum from Acacia trees is known to have been traded for more than 2000 years (Jamal and Huntsinger, 1993). Through historic times, gum Arabic (fig. 1) has been used for various purposes, from the time when Egyptians (around 2000 BC) added it to food and paint to the present day local use as a component in laundry starch and for plastering. The largest areas of gum Arabic use are the production of soft drinks (emulsifiers), confectionaries, pharmaceuticals (Elmqvist *et al.*, 2005) and photography (Barbier, 2000), with a smaller share being used in textiles, ink, paper, glue, makeup and rubber (Jamal and Huntsinger, 1995).

1.2.2. Keeping or forsaking gum production?

The main sources of income for farmers in rural areas of Kordofan are crops, gum Arabic, livestock and off-farm work. In recent decades there has been a decreasing trend in gum production, with a decrease from an average of 46,000 metric tonnes during the 1960's to 28,000 metric tonnes in the 1990's (Rahim *et al.*, 2005). In 1980-1995 attempts were made to once again increase the production of gum in the regions of Kordofan and Darfur, as a total of more than 15million *A. senegal* seedlings were provided for free to local farmers (Rahim *et al.*, 2005; 2008). Several projects during the 1980's and 1990's, assisted by international contributors, have tried to 'restock the gum belt' (El Tahir, 2006), but still the trend is going downwards. Estimations for the time period 1993-1998 shows more than 40% of the producers giving up the formerly so successful gum producing system (Rahim *et al.*, 2005; 2008). The possible reasons behind this abandonment or 'disadoption'[2] are environmental as well as socio-economic. They can be direct or indirect and by choice or brought on by outer forces such as droughts that kill trees. Some of the key drivers determining whether or not gum is produced can be identified. Drought, pest attacks, overgrazing, fires[3] (Jamal and Huntsinger, 1993) and overtapping are among the factors influencing the amount and variety of standing biomass stock (El Tahir, 2006). The most common reason given by farmers not producing gum is the low price they receive for their product (Mahmoud, 2004). The long-lasting drought in 1979-1986 has been blamed for much of the decrease in gum production that followed, but has been seen to be only partly responsible. The lack of water did, in fact, kill of weaker individual trees, but for the main part the drought-resistant characteristics of the *Acacias* kept them alive, and the effects of the drought were indirect. Low crop yields, resulting from the low rainfalls, caused farmers to cut down the trees in order to make money to buy food (Jamal and Huntsinger, 1993). While the gum producing farmers in the northern parts of Kordofan suffered during this time, the ones south of the Gum Belt were able to maintain, and some even extend, their production by smuggling gum into Chad (Jamal and Huntsinger, 1993). The decreased returns from crop production also lead to more land being turned into cultivated land, on the expense of trees (El Tahir, 2006).

Attacks by pests can be seen to be both direct and indirect forces on gum production. Locusts, for example, can cause a delay in the actual gum production inside the trees by eating the leaves (El Tahir, 2006) and pests generally tend to cause more severe problems as a consequence of harsh environmental conditions, such as droughts. The severity of pest attacks is also greater when trees are over-tapped, as a result of the

[2] The term 'discontinued adoption' or 'disadoption' is described by Rahim et al (2008) as "the decision to reject an innovation after having previously adopted it".
[3] Both of natural origin and from slash-and-burn included.

trees being temporarily weaker and more prone to infestation by pests that thrive on diseased wood (Jamal and Huntsinger, 1993). Also animals in the form of grazing livestock can cause damage to the gum producing trees and as the size of the herds grow, so does the need for fodder, hence more trees and bushes are consumed. With the growth of villages and cultivated areas and an increasing number of gum producers putting up fences to keep animals away, groups of nomads and transhumans have been seen to be restricted to smaller grazing areas along their routes, making the grazing pressure higher (IFPRI, 2007). A greater focus on livestock rearing on village level can also have indirect effects on gum production, both positive and negative. While the gum agroforestry system contribute to the supply of fodder to the animals, the income provided by the sales of animals may be more appealing to the land owner than that of the more labour consuming gum production (Rahim, 2008).

Rahim et al. (2008) reports a negative influence of small land holdings on the production of gum Arabic. The reason for this is mainly the lack of options for the farmer to leave some land as fallow when he has a family in need of food.

1.2.3. Soil nutrients

The amount of nutrients provided to the soil by litter fall from trees and shrubs depends on the nutrient content of the plant in question and this, in turn, is influenced by several factors. Soil fertility, climate and the age of the plant are just some of these, and the importance of each of these factors varies between species (Palm, 1995). For there to be a sequestration of carbon in the plant tissue there needs to be a sufficient amount of nutrients, water and light to keep a high rate of photosynthesis. In an ideal system, the nutrients that are taken up by the roots of a plant are later returned to the soil through litter fall and the process can start over. For many African countries intense cultivation and insufficient nutrient input has caused depletion and an imbalance in demand and supply (Sanchez and Palm, 1996). Most soils in dry land areas are low in both plant-available water and soil nutrients and artificial fertilizers are rarely used by small-scale farmers in semi-arid Sudan (Farage *et al.*, 2006). In many African countries the price for artificial fertilizers are several times higher than in Europe, North America or Asia (Sanchez, 2002).

Soil organic carbon (SOC)

Soil organic carbon (SOC) was described by Reeves (1997) as the “most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological indicators of soil quality”, with nutrient amount, soil texture, bulk density and pH value as some of the other indicators. The amount of SOC has been seen to affect respiration, nutrient load, infiltration capacity and stability, among other things (Reeves, 1997). On the other hand, records from the worlds longest running agricultural experiments (from the UK) show an increase in SOC as a consequence of C, N, P and K inputs, with greater changes from manure input than none or inorganic fertilizers (Reeves, 1997). Long-term studies have shown decreases in SOC as a result of continuous cropping, with varying extent depending on climate and soil type (Reeves, 1997). Cultivation causes a quick loss of C, as erosion and decomposition breaks down the structure of the soil (Agbenin and Goladi, 1997). According to Chapin et al (2002), the rate of decomposition is better estimated through measurements of soil carbon than nitrogen or the C:N ratio, due to the fact that while carbon is lost to the atmosphere nitrogen is bound into more complex compounds, unavailable to plants.

Nitrogen (N)

Despite the fact that the main part of the atmosphere consists of nitrogen (in the form of N_2), only a small amount of it is in a form that is directly available for the vegetation to use. While the carbon cycle has a direct exchange with the atmosphere through the incorporation of CO_2 in the process of photosynthesis, for access to nutrients such as nitrogen and phosphorous plants are more dependent on their roots, even though certain species has the ability to fix nitrogen directly from the atmosphere. In an agroforestry system the trees, that generally has deeper roots than crops, can increase the amount of nutrients by accessing greater depths (Sanchez and Palm, 1996). Other ways for plants to acquire N is through manure or fertilizers and mineralization of SOM. Recycling of nutrients from litter constitutes more than 90% of the N and P available for plants (Chapin *et al.*, 2002).

In a study by Jewitt and Manton (1954) a piece of land that had been cultivated for 30 consecutive years was compared to a part that had been turned into a gum garden with *Acacia senegal*. They found that the top 15cm of the soil layer in the gum garden had N content that was twice as high as in the cultivated plot (Raddad *et al.*, 2006). Deans *et al.* (1999) investigated the soil properties beneath *A. senegal* trees from the age of 3 to 18 years and found an addition of 24 kg N ha^{-1} yr^{-1}. Even though there are many studies showing higher levels of nitrogen in close connection to *A. senegal* trees compared to other species or fields without trees, the nitrogen-fixing potential of the species is yet to be proved (Elmqvist *et al.*, 2005). Results from a study on a continuously cultivated land in Nigeria showed equal, and in some plots increased, levels of organic N when it was fertilized with both artificial substances and manure, compared to the control site (Agbenin and Goladi, 1997). The organic N in the soil made up about 80% of the total N content.

C:N ratio

The concentration of carbon to nitrogen concentration ratio is often used for estimation of the rate of decomposition in the soil (Chapin *et al.*, 2002). A C:N ratio of 10 or above indicates that there is N mineralization occurring in the soil (Agbenin and Goladi, 1997).

Potassium (K)

Besides recycling of nutrients from litter, part of the plant-available potassium in many soils comes from weathering (Chapin *et al.*, 2002). Deposition of wind transported material or the addition of artificial fertilizers are also known sources of K (Web5) Potassium is present in the soil as cations and is lost through wind erosion, leaching or the removal of vegetation (Chapin *et al.*, 2002).

Phosphorous (P)

Unlike nitrate, phosphorous is a rather immobile nutrient, and the amount available for tree roots at greater depths is generally low (Sanchez and Palm, 1996; Raddad *et al.*, 2006). Instead, most of the plan-available P comes from recycling of the nutrients in decomposing litter or through the input of manure (Sanchez and Palm, 1996). While studies (Deans *et al.*, 1999) have shown increases in N and K for soils with *Acacia senegal*, changes in P are not as commonly presented (Raddad *et al.*, 2006). In general, African savannas are suffering from P and N deficiency, which affects the quality of plant biomass (Manlay *et al.*, 2002) and the amount of nutrients belowground, around the roots of trees, is an area that up until recently hasn't been much explored. Palm (1995), points out that the turnover processes taking place has the potential to add 2-4 times the amount of N and 6-10 times the P received from litterfall. In many of the P deficient soils the situation could be improved with a greater input of organic matter and higher rate of decomposition, as this produces acids that can help dissolve rock phosphates to the soil (Sanchez and Palm, 1996).

1.2.4. Clean Development Mechanism (CDM)

The UN Conference on Environment and Development (UNCED) that was held in Rio de Janeiro in 1992 resulted in two, for this study, very important treaties; the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD). As part of the UNFCCC's Kyoto Protocol[4] from 1997, the Clean Development Mechanism (CDM, Article 12) was formed. The CDM makes it possible for developed countries with greater releases of greenhouse gases (GHGs) than allowed by the Kyoto Protocol to invest in GHG reducing actions taken in developing countries (Perez *et al.*, 2007). The investing country can use this as a mean to reach the set goals of GHG emissions reduction. From 2005 until June 2008 25 projects in seven African countries were registered for the CDM (Web7). In the present so called commitment period (2008-2012), the CDM can be used for projects that include afforestation or reforestation, while actions like forest conservation and soil carbon sequestration may be included in the future (Olsson and Ardö, 2002; Ringius, 2002). Other markets for the sequestration of soil C, alternative to the CDM, are also taking form (Perez *et al.*, 2007). In late May 2009, in anticipation for the UN climate change convention meeting in Copenhagen in December, UNEP presented an agreement reached by more than 30 African ministers, pushing for changes in the CDM to include 'sustainable land use, agriculture and forest management' (Web8). Sequestration of C in the soil instead of standing biomass helps reduce logging and other activities that may be a tempting way for the landowner to make money (Olsson and Ardö, 2002). Most farmers very well know the more long-term positive effects on crop yields that come from trees or fallow periods and do not want to jeopardize this. Investments in soil C sequestration in agricultural land by other countries could be of great importance in sub-Saharan African countries, where the populations continue to grow while many people live in poverty (Ringius, 2002).

1.3. Study area

1.3.1. Sudan and the Northern Kordofan Region

With a surface area of more than 2.5 million square kilometres, Sudan (fig. 2) is the largest country in Africa, bordering the Red Sea in the northeastern part of the continent and neighbouring Central African Republic, Chad, Libya, Egypt, Eritrea, Ethiopia, Kenya, Uganda and the Democratic Republic of the Congo (Web1). The northern part of the country is classified as arid desert and towards the south the landscape gradually changes into savannah (bush and later tree) and among the mountains in the very south there is even some rainforest. Most of the Sudanese landscape is flat, with the exception of some inselbergs here and there, the Nuba Mountains in Kordofan, the Darfur plateau and Marrah mountains in the west and the

[4] The developed countries that signed on to the Kyoto protocol is aiming to cut their 1990 levels of greenhouse gas emissions by at least 5% during the years 2008-2012 (Olsson and Ardö, 2002).

Figure 2. Map of Sudan and the state of Kordofan. Source: Web6

mountain ranges bordering Uganda and the coast (Web2). A recent population count reached 39.4 million, with approximately 8.9 million living in, or in the suburbs of, the capital, Khartoum (Web2). With a growth rate of more than 2% the population is estimated to reach above 41 million in 2009 (Web1). Until the 2008 population count, the number of people was rather uncertain, to some extent as a result of the fragile situation in both Sudan and neighbouring countries[5], causing people to move across the borders (Web2). The majority of the population lives in the central parts of the country and the good, fertile soils is a great contributor to this fact. The Sahara desert makes most of the northern parts of Sudan unsuitable for living.

In Sudan, about 90% of the land that is under cultivation, sustaining 1.7 million households, is rain-fed (FAO, 2008) and therefore highly dependant on the sporadic rainfall. In the region of Kordofan, the rainfall averages from 750 mm/year in the south to 200mm/year in the north (IFPRI, 2007), placing it in the ranges of the semi-desert and sandy low-rainfall savannah agro-ecological zones (FAO, 2006). The rainfall across the Sahel is highly variable and can differ greatly over time as well as area. In Sudan, the rainy season occur in April to November, depending on region (Web1). This helps create a rather steep gradient of climate and vegetation in a north-south direction. For North Kordofan the time span of rainfall is rather small, normally July to October (El Tahir *et al.*, 2004). Results of the erratic behaviour of the rainfall in Sahel can partly be seen through decadal droughts or the mobile lifestyles practiced by groups of people in this part of Africa. Increasing severity of the dryspells in recent decades has put an additional strain on already vulnerable systems (Hulme, 2001). The soils in the area south of the Sahara desert are sandy soils known as gardude and Goz or 'Qoz', classified as Arenosols and covers about 28million ha (Ayoub, 1998). About 60-75% of North Kordofan contains Goz soil (El Tahir, 2004). In these semiarid regions of the country (Kordofan and Darfur) the 12million ha of Arenosols are more weathered (Ayoub, 1998) and is characterized by low nutrient and organic matter content (Gafaar *et al.*, 2006). The high draining capacity of the sand increases the nutrient leaching at times of heavy rains (Ayoub, 1998).

[5] During the civil war in southern Sudan in 1983-2004 about 1 million people fled the country. The war between Eritrea and Ethiopia in 1998-2000 caused people to move into eastern Sudan. (Web2). Thousands of refugees from Chad, Uganda and the Central African Republic are also present in Sudan (Web1).

Even though the general projections for the future climate in Africa indicates great changes, with increasing temperatures and longer dryspells, the expectancies for the Sahel are more uncertain (FAO, 2008), to some extent due to a lack of reliable data. Different models give diverging results regarding future amounts of rainfall, even for the same areas, and one of the most difficult things to project is the potential effect of increasing atmospheric CO_2 level on vegetation growth and crop production (FAO, 2008). The IPCC presents land use changes, increasing differences in land-ocean temperatures and changes in sea surface temperature in the northern hemisphere as factors that can have an impact on the future rainfall amount in Sahel and on the models constructed in an attempt to predict it (Christensen, 2007). Some changes in rainfall pattern have already been observed, with a 50-150mm/season decrease in rainfall during 1996-2003 in Eastern Africa (FAO, 2008).

1.3.2. Land in Sudan: ownership, tenure and use

Landownership in Sudan is a rather complicated matter. The Unregistered Land Act (URLA) from 1970 states that all land that is unregistered (which includes as good as all of Northern Kordofan), except for urban areas, belongs to the state. Despite this fact most people consider the land they live on to belong to either them or a more local authority. According to Egeimi et al (2003) there are three parallel systems governing what happens to the land, but the different responsibilities of these are unclear. The governmental technical departments and the government backed administration works on a basis of governmental policies, with the intent of having the best of the local communities in mind. In Northern Kordofan, however, it is the third authority, the Native Administration (NA), which has the greatest influence on the land use (Egeimi *et al.*, 2003). In order to maintain their position as an authority in greater parts of rural Sudan, including areas where they could not be present more directly, the British formed the NA in the 1920s-1930s (IFPRI, 2007). With some minor variations between different areas, the core of the NA consists of a number of local and regional level authorities from different tribes, sedentary as well as nomadic and semi-nomadic who are given the right to handle natural resources and solve conflicts (IFPRI, 2007). As the leader of a single village or a smaller group of nomads, a sheikh is at the bottom of the NA hierarchy which has the tribe leaders ‘nazirs’ at the top. Since the proclamation of Sudan’s independence in 1956 there has been a number of twists and turns regarding the Native Administration, with it being abolished for about a decade to later be reinstated with support from the federal government (IFPRI, 2007).

Crop production and livestock are the two main sources of income for farmers in Kordofan and there are three different lifestyles; nomadic, transhumant[6] and sedentary. The nomads base their livelihood on livestock, mainly camels or sheep, and move around based on the access to water and food. The great magnitude of the animal herds makes the pastoralists (mainly nomads and transhumants) the largest producer of meat in the area (Egeimi *et al.*, 2003). People practicing the transhumant lifestyle migrate along established routes during certain parts of the year, keeping livestock and cultivating the land. About 63% of the Sudanese population lives in a sedentary manner in the rural parts of the country. The bush-fallow way of cultivating the land is combined with the keeping of livestock, mainly sheep, and the population

[6] also known as semi-nomadic (IFPRI, 2007).

is resident (El Tahir, 2006). These kinds of traditional farming are practiced by a large percentage of the Sudanese population and the livestock is kept as a sort of insurance for crop failure (FAO, 2008). As the population of humans as well as animals keep increasing so does the pressure on the land and problems arise (Gafaar *et al.*, 2006). The natural resources have to be shared and the land suitable for cultivation is often used by the sedentary farmers as well as transhumant so called agro-pastoralists. Intraannual variations in the amount of basic resources (such as water) between different geographical areas, however, causes problems when trying to form rules regarding the access to it. (IFPRI, 2007) Having the majority of the population living in the arid and semiarid regions put strains on the soil. Activities such as overgrazing, deforestation, overexploitation of vegetation and unsuitable agricultural practices has caused degradation to vast land areas in Sudan (Ayoub, 1998).

1.3.3. El Humeira[7]

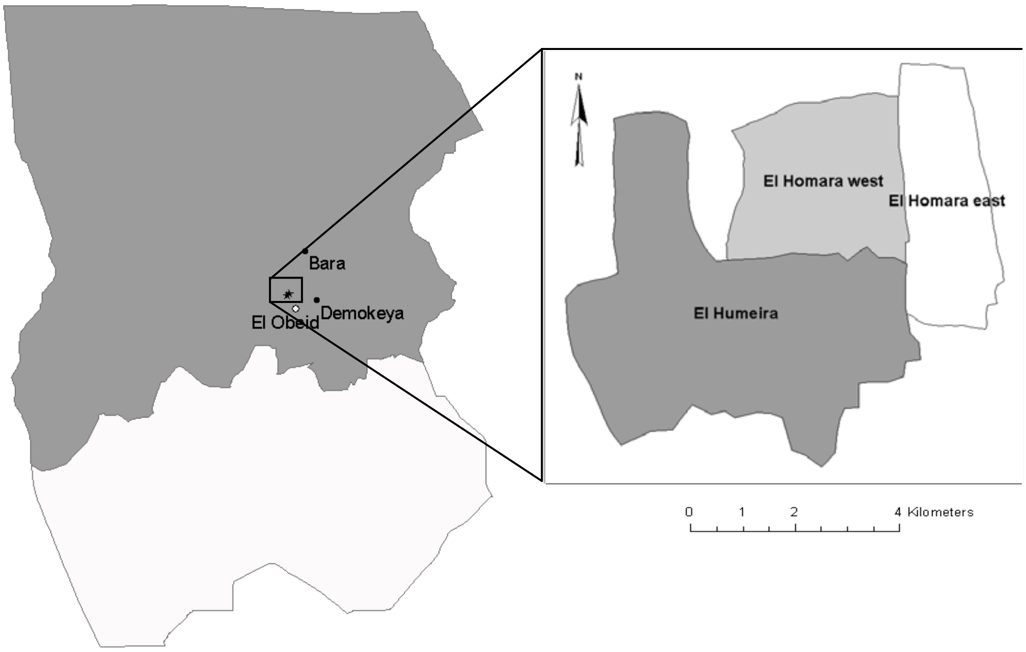

Figure 3. Map of Kordofan and the study site. Source (state map): Web6

People

The population of El Humeira (fig. 3) village belongs to the Shewihat tribe[8]. The village has 144 households with an average of five people in each. Approximately 75% are children and 66% are men. During dry season only 24 of the households live in the village, while the rest are located in El Obeid and return for the rainy season. An interview with the sheikh (head of the village) reveals that the households seasonally migrating to El Obeid used to live in the village permanently up until the 1984 drought. It is the lack of water that puts constrains on the livelihood during the main part of the year. The sheikh believes that more people would stay in the village if there was a better supply of drinking water. Another constrain, especially this year, is the problem of pests causing damages to crop or gum trees.

[7] The information describing the two villages could not be found in previous literature and was acquired through interviews with the leader of each village (see 2.1.3. and Appendix III).
[8] A group of semi-sedentary agro-pastoralists that have their tribal homelands or ‘dar’ in an area other than North Kordofan (IFPRI, 2007).

Land use

Despite the presently low price on gum Arabic the population of El Humeira has a great focus on *Acacia senegal* ‘hashab’, with many age classes of trees in the gum gardens and an unwritten rule saying “never cut hashab”. Only dead wood is gathered and used for various purposes. All households have *Acacia senegal* on their land (eight of them has ~35-75Ha[9], 15 has ~15-20Ha. and the rest ~3.5Ha) and gum is tapped every year, but not by all households. This year the gum collection occurs later than normal due to a pest eating the leaves of the trees, delaying the production of gum.

The time period for fallow and cropping is 8-10 years and includes 3-4 and up to 7 fields. According to the sheikh this hasn’t changed in the last 30years, contrary to the situation reported for other areas (Khogali, 1991). The village was provided tree seedlings from the forest department about seven years ago but is at present using its own seeds and the seedlings that propagate naturally. Cultivation takes place in combination with old (~20 years old), scattered (~10 m apart) trees. Intercropping is practiced as hibiscus (*Hibiscus sabdariffa*) and a local type of watermelon are mixed in with the fields of other crop, such as millet (*Penisetum typhoides*), sesame (*Sesamum indicum*), sorghum (*Sorghum bicolour*) and groundnuts (*Arachis hypogaea*). The land is by tradition inherited by family members. In the case of there not being anyone to take over, the land goes to the sheikh and it’s up to him to decide what to do with it.

Sources of income

According to the sheikh, the households in the village gets 80% of their income from agriculture (cash crops like groundnuts, sesame and hibiscus along with sales of any surplus of the millet yield) and the remaining 20% from gum Arabic, but this changes with the price of gum. A couple of years ago, when the price for gum Arabic was higher, the gum production was a much more important source of income than the crop production. At present, though, the price is low and the trend over the past 30 years has been downwards, with peaks lasting for only one or two seasons (Elmqvist *et al.*, 2005).

1.3.4. El Homara

People

The population of El Homara belongs to the same tribe as the people in El Humeira, the Shewihat tribe. According to the sheikh (Hamid Mahmoud Midawi, personal communication), there are 6 households in the village at present time, each with an average of 7 people. About 75% of the people are children and the men:women ratio is 1:1. During rain season there are about 15 households in the village, and it is mainly the older people that remain there all year round while the younger ones live in the city. According to the sheikh there used to be close to 100 households in the village but drought and desertification during the last 30 years has caused this number to decrease to 70. Many households living in the city pay someone else to cultivate and take care of their land. The sheikh believes that if there were more available drinking water, more people would live in the village.

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[9]Areas converted from the Arabic area unit mukhamos, where 1 mukh.= 7400m^2 or 0.74Ha and the groups were divided into holdings of ~50-100mukh., ~20-30mukh. and ~5mukh.

Land use

The village of El Homara is divided into two parts, the western and the eastern and there is one sheikh for each of them. According to sheikh Midawi there are 2 large (>75Ha) households in the village, 15 of medium size (35-75Ha) and the rest are small (<35Ha). All of them have *Acacia senegal* on their land (10 of them ~35-75Ha, 20 ~15-20Ha and the rest ~3.5Ha) but the tradition of gum Arabic tapping differs from the one in El Humeira. This year 5 of the households have tapped gum and the sheikh claims it's the low gum price that is the reason for not more households tapping. He believes that it would change if the price went up again. Just like in El Humeira the land is inherited and belongs to the sheikh if there is no one to claim it. The land of those who live in the city but don't have someone taking care of it is left as fallow.

The time for fallow and cropping in El Homara is 10 years and the fallow sometimes include trees, other times not. 2-4 fields are included in the rotation and at times the farms with only two pieces of land keep them both cultivated. At present there is one field that has been cultivated for 13 consecutive years. There is some monocropping in the village, but mainly intercropping, including sesame, hibiscus, watermelon and sometimes sorghum. Agroforestry is practiced in combination with young (~2-3years old) trees but not the older (>6-7years) ones. According to the sheikh, the only help provided by any institution to keep the bush fallow system was seedlings from the forest department about seven years ago. Today, the households use their own seeds and seedlings.

Sources of income

Contrary to the situation in El Humeira, the households in El Homara get 50% of their incomes from agriculture and the other 50% from selling wood and grass, according to sheikh Midawi. During the dry season the villagers may need to sell a goat or a sheep if the income from other sources isn't enough. The people living in the city get ~20% of their income from agriculture and the remaining ~80% from other jobs (including simple trading, smaller jobs within the government or labour job).

Households of El Homara produce cash crops such as sesame, groundnuts, hibiscus and watermelons. In years when there is a good supply of millet some of it can be sold after the basic needs are fulfilled. At present, <10% of the household income comes from the selling of gum Arabic (says the sheikh) and the importance of the gum production depends greatly on the price.

2. Methods

2.1. The field work

The field work was conducted in villages in the area surrounding El Obeid in Northern Kordofan, Sudan, mid January until mid March 2009.

2.1.1. Soil sampling

Samples of the top 30 cm of the soil were taken with a soil auger. To make an average over a slightly larger area, and hence decrease the number of samples required, four subsamples were taken within a 2x2 m square. These were thoroughly mixed in a bowl and about 500 g was collected, put in a paper bag[10] and sealed in preparation for analysis.

In one of the fields of El Homara, that had been cultivated without any trees for 13 consecutive years, a 1 m deep soil profile was created. By inserting a metal tube into the soil, samples were taken horizontally at the depths of 50, 70 and 90 cm. These were weighed and put into paper bags, in preparation for analysis. Together with the soil samples from the top 30 cm of the same field, these measurements would give an indication of how the soil properties changes with depth. In an attempt to compare water holding capacity between fields under different kinds of land use, moisture measurements were also made in a soil profile in the area of old fallow in El Humeira. The soil moisture was measured at the different depths with the help of a ThetaProbe Soil Moisture Sensor ML2x and HH2 moisture meter (±1% accuracy) by Delta-T Devices in Cambridge, England.

During the soil sampling a person from the village in question was present to describe the land use history, age of trees, etc. The plots where the soil samples were taken were categorized based on their type of land use; cultivated with *Acacia senegal*, cultivated without *Acacia senegal* and fallow/grazing with *Acacia senegal*. Due to the comparative nature of this study, both villages are represented in the different categories, El Humeira with an *E* and El Homara with an *A* (table 1). The strong focus on gum production and gum gardening found in El Humeira gave rise to the idea of having three age groups for the fallow areas; 5-10years (*Young*), 10-15years (*Middle*) and 15-20+years (*Old*). This would make it possible to investigate how the soil properties are improved with time. In the case of the fallow area soil samples half were taken with the four subsamples located around the stem (*stem*), underneath the crown, and the other half as far away from trees as possible (*open*). Figure 4 shows sub samples of the latter kind and the distance to the trees are approximately 4 meters.

Figure 4. Soil sampling in between trees.

[10] marked in advance based on a specific six digit code, constructed to also be used in the GPS.

Table 1. Distribution of soil sampling categories in the two villages.

El Humeira	El Homara
OldEst	MidAst
OldEop	Cult5A
MidEst	Cult13A
MidEop	Cult1350
YouEst	Cult1370
YouEop	Cult1390
Cult2E1	
Cult2E2	
Cult2E3	

In El Humeira, the samples for cultivated fields were represented by i) pure sesame field, cultivated for 2 years (*Cult2E1*); ii) mixed crops (beans, cowpea, sorghum and watermelon), cultivated for 2 years (*Cult2E2*) and iii) pure groundnut field, cultivated for 2 years, no *A. senegal* (*Cult2E3*). In El Homara the samples were gathered from fields of a) mixed crops (sesame, sorghum and millet), cultivated without trees for the past 13 years (*Cult13A*) and b) sesame and millet, cultivated for the past 13 years and present trees ~4-5 years old (*Cult5A*).

Examples of what the different classes of land use looked like in the two villages, providing an indication of tree density and presence of other types of vegetation can be seen in figure 5-7.

Figure 5. Field cultivated for 13 consecutive years without Acacia senegal trees, El Homara.

Figure 6. Fallow with young (5-10 years) Acacia senegal trees, El Humeira.

Figure 7. Fallow with old (15-20+ years) Acacia senegal trees, El Humeira.

2.1.2. Village location

On two separate occasions, GPS coordinates for the outer boundaries of the villages were registered, with the assistance of two people from the village in question. For El Humeira these were the sheikh and an older villager, while in El Homara the sheikhs of the two different halves provided assistance. The GPS used was a Magellan 320 and the UTM coordinate system.

2.1.3. Interviews

Semi-structured interviews for two different purposes were conducted on a household and village level (*see Appendix II and III*), with the help of an ARC worker for the translations, on 16-29 Jan 2009. The biomass consumption for the households, along with the size of it and its landholdings, is of interest when looking at the present and future demand and supply of biomass.

Household level biomass consumption

To get a wider overview of the household biomass consumption, interviews were made with five household owners in each of the villages of El Humeira and El Homara. For additional data on the general biomass use in the area, households in two villages (Um Nabag (close to Bara in fig. 3) and Demokeya) northeast and east of El Obeid were also included in this part of the study. Since there were only six households present in El Homara at the point of the interviews, all the households were included, making the total number of interviews 21. The questions were regarding the size of the household and its land, the amount of biomass used for cooking, heating of houses, construction of houses and fences and if there were any other purposes. The heads of the households were also asked if they would be willing to try an alternative energy source. As a final part they were asked if the biomass produced on their own land was sufficient to cover the need, how far they would have to go to gather it and whether or not any biomass was bought or sold.

Village description and land use history

Interviews with the sheikhs of the two villages provided the general information about the villages[11] and the questionnaire was split into three parts. The first one included general things like the tribes represented, the size of the population (number of households and average number of people in each) and land area, whether the households own livestock, potential constrains on the living situation in the village and whether any of these things has changed during the last 30 years.

The second part of the questionnaire focuses on land use history and gum tapping practices and includes questions on the amount of land that is covered by *Acacia senegal*, time of last tapping, reasons for tapping/not tapping, the length and extent of the bush fallow system and whether there has been a change in the last 30 years. The final questions are regarding the village's sources of income; which are the (financially) most important crops, the importance of gum production in comparison to this and if there are any other sources of income.

[11] The results of the interviews are included in the village descriptions (1.3.3. and 1.3.4.) and mainly used as a basis for explaining differences in land use strategies for the two villages. This part is therefore not included in the section 'Results'.

2.1.4. Tree biomass inventory

On the basis of the GPS coordinates recorded for the village boundaries, 30 plots of 10x10m were randomly selected for each of the two villages (fig. 8). The plots were spread to represent all categories of land use, not just gum gardens, in an attempt to estimate the total amount of available tree biomass. Within these plots, all trees taller than 0.5m were located with GPS for identification in satellite images later on and various measurements were made. The protocol for this biomass inventory (*Appendix IV*) was based on an existing document used by the ARC in El Obeid and included species name, location (coordinates from GPS), stem diameter, number of stems, tree height and stem and crown diameter. Since *Acacia senegal* trees generally have a less than circular crown, two crown diameter measurements were made for each tree and a mean value was later calculated. The height for the stem diameter measurement depended on the height and branch setting of the tree and was taken at 30cm for low growing trees with branches close to the ground, and at breast height (DBH,130cm) for taller ones. For trees with several stems, all diameters were measured and summed up (Jakubaschk, 2002).

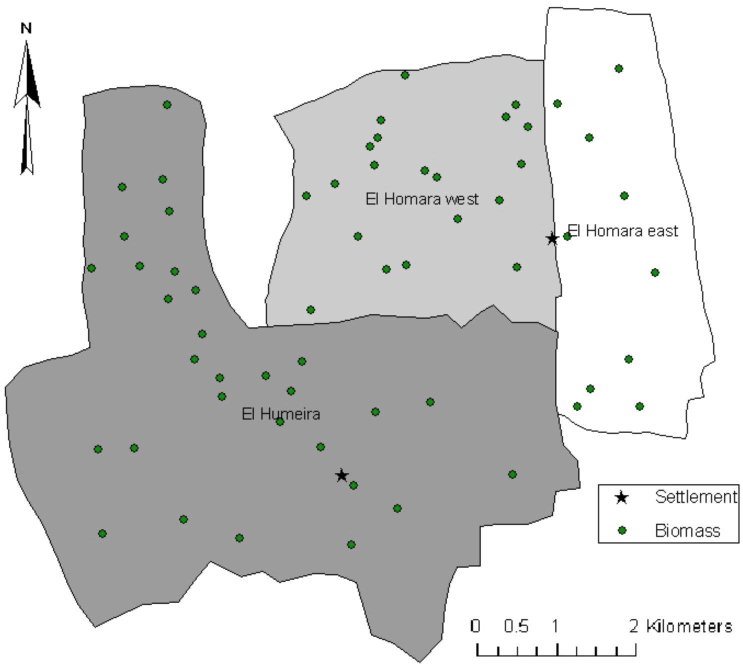

Figure 8. Locations of villages and plots for biomass inventory.

Different equations for calculation of the total aboveground biomass were used, depending on the tree species present. For *Acacia senegal* trees the following formula, developed by Deans et al (1999), was used and gives the amount of dry biomass (g):

$$y = -3.71 + 4.12 * CSA \qquad \text{with } r^2 = 0.97 \qquad (1)$$

where CSA is the cross-sectional area derived through the use of stem diameter at 30cm for smaller trees and DBH for tall trees. Deans et al (1999) studied trees in the ages of 3 to 18 years and found a linear relationship between CSA at 30cm and the increase in biomass. Their idea built on the findings by Snell and Brown (1978, in Deans *et al*, 1999) of the diameter at breast height being a good indicator of the amount of biomass.

For trees species other than *A. senegal* a combined formula for aboveground biomass was used. This is originally based on an equation by Olsson (1985):

$$Y= 0.19+1.28*X \qquad \text{with } r^2 = 0.94 \qquad (2)$$

where Y is $\log_{10}$ wet weight in kg and X is $\log_{10}$ squared crown diameter and with an estimated water content of 75% (Jakubaschk, 2002) the final equation used for calculating dry weight aboveground tree biomass is as follows

$$Y= 0.19+1.28*X*0.25 \qquad (3)$$

In order to make projections for the near future on whether or not the amount of biomass produced in the two villages will be sufficient to cover the need, values on annual increment were applied. These were gathered from tables provided by FAO (1993). With a growing period of two to four months (Fadul and Salih, 2006) and an input level that is low to intermediate for the area in question the mean annual fuelwood increments are 0.30-1.25t/Ha dry weight for low input and 0.45-1.85t/Ha for intermediate input, for both *A. senegal* and *A. tortilis* (FAO, 1993).

2.2. Soil sample analysis

Analysis of soil samples was performed by personnel at the ARC laboratories in Wad Medani, using standard techniques. Nuha Abdalla Mohamed, head of the soil laboratory unit, provided the following information regarding the analysis. The amount of total nitrogen was calculated using the Kjeldahl method, organic carbon was determined by the Walkley and Black procedure, available phosphorous through the use of O'lsen method and the amount of potassium (exchangeable cation) by the use of direct flame photometry in the soil extract. Bulk density was measured by using Core method. Soil texture was determined for 15 out of the 63 samples, using a mechanical analysis method and texture classes defined by the USDA textural triangle.

The results of the chemical and mechanical soil sample analysis were further analysed in the SPSS Statistics 17.0 programme through independent sample t-test. This test compares the means of data from two different groups, with the null hypothesis that there is no difference between them (SPSS Inc., 2008).

2.3 Method limitations

Sources of error:

Soil sampling – Animals such as camels, goats and sheep were seen grazing freely in both villages and their manure could influence the amount of nutrients found in the soil samples. To minimize the risk of overestimating the impact of the animals, samples were taken in areas that were seen to best represent the field in general, based on visual impressions.

Location of village boundaries – the absences of roads and clear markers made it problematic to make an exact location of the boundaries. Instead the word of the people in the villages needed to be taken as truths. The instruction manual for the GPS claims that it has a general accuracy of 25 meters or better but it is also affected by the positioning of satellites (Magellan Corporation, 2000).

Household level biomass consumption – this is mainly based on interviews and the approximations made by the interviewees are subjective and may be influenced by what they think the interviewer wants to hear. A belief that a certain answer will affect the living situation might skew the answer. In the end it may not represent the true reality and is therefore combined with information from various previous studies. There is also a certain possibility of lack of information and misunderstandings happening when using a translator.

3. Results

3.1. Soil properties

Table 2a shows the mean values for the different soil properties of the 13 land use categories and table 2b includes descriptions of the categories. The tables in Appendix V (table A and B) summarize the results found in the soil sample analysis and that are presented in this section. Table A shows the ranking of categories that can be made based on the means in table 2a and table B is a summary of the significant (0.05 level) differences in the amount of soil nutrients that were found when the 13 land use groups were put through an independent samples t-test two by two.

Table 2a. Mean values* for soil organic carbon (SOC), nitrogen (N), C:N ratio, Potassium (K), available phosphorous (Av. P) and bulk density.

	No. samples	SOC (%)	N (%)	C:N	K (mg/100g soil)	Av. P (mg/kg)	Bulk density
Cult13A	5	0.150	0.033	4.619	0.106	2.840	1.436
OldEst	5	0.206	0.022	9.305	0.186	3.920	1.524
OldEop	5	0.140	0.026	6.128	0.146	3.040	1.526
Old	10	0.173	0.024	7.716	0.166	3.480	
MidEst	5	0.140	0.024	6.109	0.084	2.200	1.558
MidEop	5	0.140	0.030	5.602	0.052	1.800	1.540
Mid	10	0.140	0.027	5.855	0.068	2.000	
YouEst	5	0.115	0.023	5.327	0.056	1.160	1.510
YouEop	5	0.115	0.022	5.308	0.084	1.520	1.566
You	10	0.115	0.023	5.317	0.070	1.340	
Cult2E1	5	0.097	0.015	6.430	0.094	1.640	1.508
Cult2E2	5	0.132	0.021	6.287	0.080	1.240	1.612
Cult2E3	5	0.127	0.022	6.079	0.076	1.080	1.508
Cult5A	5	0.168	0.021	7.647	0.044	1.080	1.538
MidAst	5	0.187	0.025	7.430	0.054	1.640	1.522
Cult13A50	1	0.031	0.020	1.550	0.110	1.000	1.510
Cult13A70	1	0.062	0.012	5.167	0.050	1.400	1.410
Cult13A90	1	0.078	0.027	2.889	0.050	1.200	1.420
Cult13Adep	3	0.057	0.020	3.202	0.070	1.200	1.447

*The one-sample values for Cult13Adep, presented as Cult13A50, Cult13A70 and Cult13A90, are also included but shown in italics to point out that these are not mean values.

Table 2b. Descriptions of the 13 land use categories sampled and presented in table 2a.

Category	Description	
Cult13A	cult. 13yrs, no *A. senegal*	sesame and sorghum
OldEst	gum g, trees 15-20 yrs	around stem
OldEop	gum g., trees 15-20 yrs	open area
MidEst	gum g., trees 10-15 yrs	around stem
MidEop	gum g., trees 10-15 yrs	open area
YouEst	gum g., trees 5-10 yrs	around stem
YouEop	gum g., trees 5-10 yrs	open area
Cult2E1	cult. 2yrs, *A. senegal*	sesame
Cult2E2	cult. 2yrs, *A. senegal*	mixed crops (beans, cowpea, sorghum, watermelon)
Cult2E3	cult. 2yrs, no *A. senegal*	groundnuts
Cult5A	cult. 13yrs, *A. senegal*	trees 4-5yrs old, sesame and millet
MidAst	gum g., 13-15yrs	around stem
Cult13Adep	samples from Cult13A	soil profile measurements at 50, 70 and 90cm depth

E represent samples taken in El Humeira and A represent samples from El Homara.

3.1.1. Soil organic carbon (SOC)

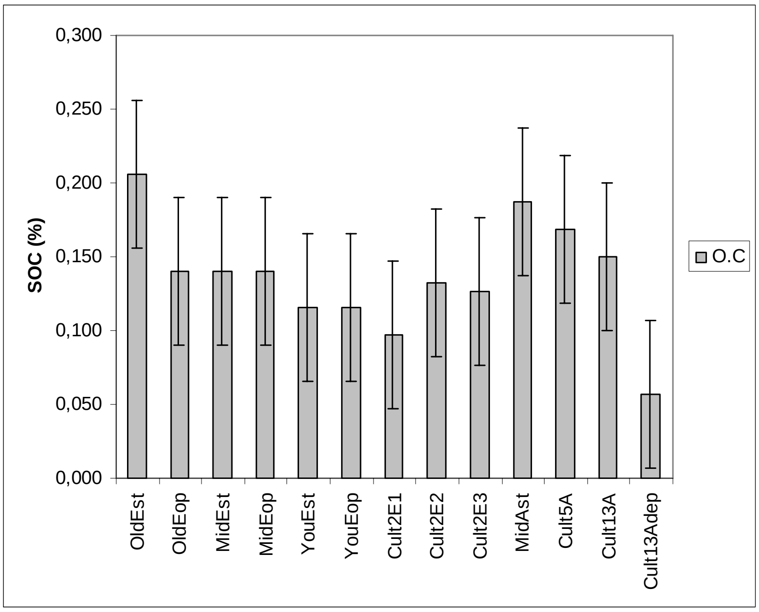

Figure 9. Mean values and standard deviations (0.05) for SOC content of the 13 land use categories.

In the results, soil samples taken close to the stem of old trees (OldEst) have values for soil organic carbon that are significantly higher than those of all other groups except for Cult13A, MidEop, Cult5A and MidAst (fig. 9). Samples that were gathered in open areas within the same category of trees (OldEop) are, in turn, equally different from the values found for Cult2E1, MidAst and Cult13Adep. The mean SOC value for the samples taken at deeper depths are increasing in the order of 50-70-90cm but neither one has a value greater than the lowest for the other groups (table 2a). Besides the previously mentioned results, the amount of OC in the MidAst samples were significantly higher compared to the ones for MidEst, YouEst, YouEop, Cult2E1, Cult2E3 and Cult13Adep. The depth measurements that were recorded in Cult13Adep also showed deviating values compared to both categories (stem and open) of young and middle aged trees as well as for Cult2E2. When combining the two mean values for each tree category, the level of organic carbon in the soil shows a trend towards increasing with length of fallow time, with the differences being significant only in the comparison of young and old gum gardens. There is also a deviation in mean values between the middle aged trees in the two villages, at the level of 0.05, with a higher value found for the samples from El Homara.

3.1.2. Nitrogen (N)

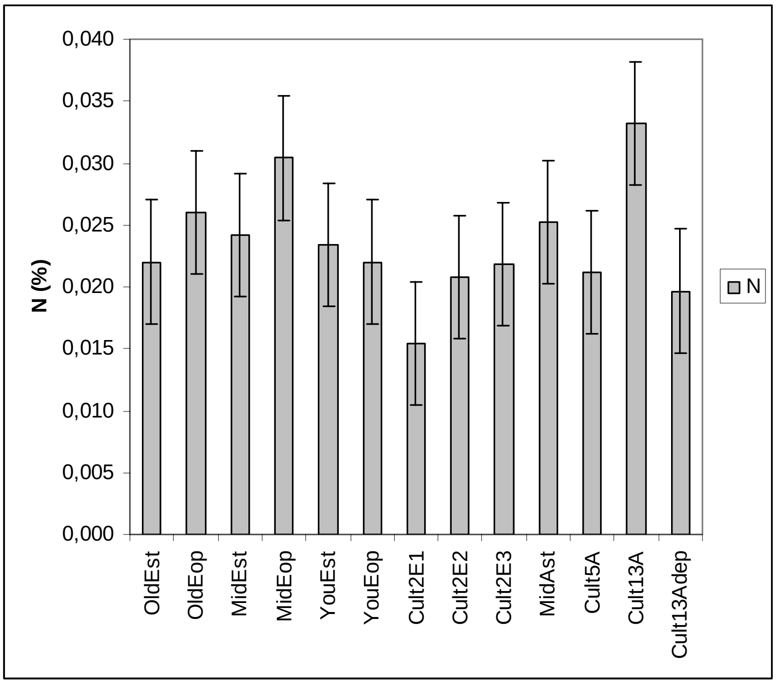

Figure 10. Mean values and standard deviations (0.05) for N content of the 13 land use categories.

There is a significant ($P<0.05$) difference in N content when comparing the value for Cult13A with the ones for OldEst, Cult5A, MidAst and Cult13Adep and highly significant ($P<0.01$) for YouEop, Cult2E1, Cult2E2, Cult2E3. A look at the mean values for the different categories shows that Cult13A is the one with the highest value, almost twice that of Cult2E1. The mean value for the samples taken at depth in the same category places it as the second smallest while the three recorded vales would end up being the lowest and third largest. Besides Cult13A, Cult2E1 is also significantly different from OldEst, MidEst, MidEop, YouEop, Cult2E3 and MidAst. When combining the samples taken at the stem and in open areas, the mean amount of nitrogen found in the samples from the three tree fallow classes is greatest for the middle aged group, followed by the old and the young. The differences are, however, not significant at the level of 0.05. A comparison between the middle aged group in El Humeira and the one in El Homara shows a higher mean value for the former one, but once again not at a significant level.

3.1.2.1. C:N ratio

The differences in C:N ratio between the various land use types show significant values for a comparison between OldEst and all of the other groups. Both MidAst and Cult5A differs significantly from YouEop and Cult13A. Finally, YouEst is significantly different from Cult2E3 and MidAst. When ranging the mean values of C:N ratio, the field cultivated non stop for 13 years ends up having the lowest values, for the top 30cm as well as the deeper layers. When including the actual results for the deeper layers the highest value of the four is found at 70 cm. For the different age groups of trees, the mean C:N ratio is greatest in the samples from the fields of old trees, followed by the middle and young, but is only significant for the comparison between the categories of old and young. The samples taken around the stem of middle aged trees in El Homara has a higher C:N ratio than the ones in El Humeira, but not at the 0.05 level.

3.1.3. Potassium (K)

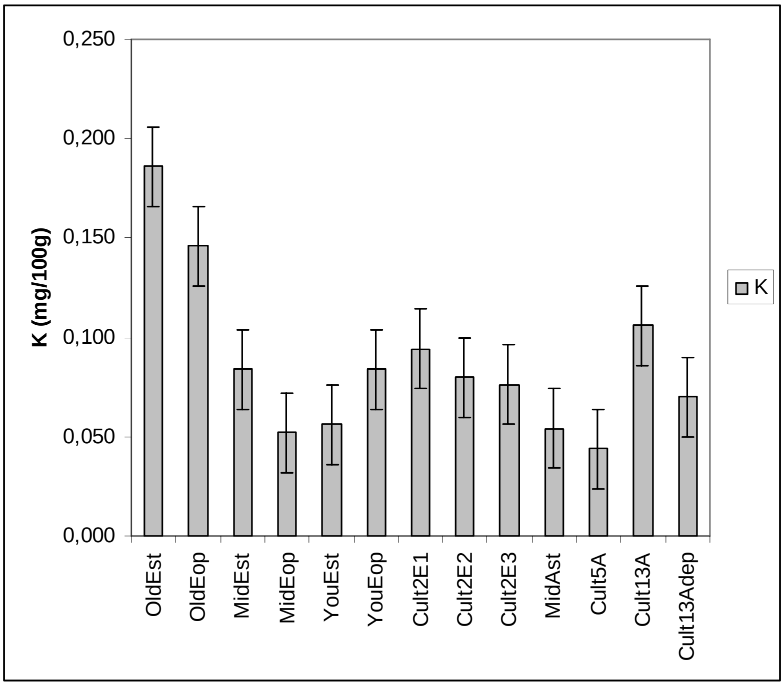

Figure 11. Mean values and standard deviations (0.05) for K content of the 13 land use categories.

As can be observed in figure 11 and table A (Appendix V), the mean value of the samples taken around the stem of old *Acacia senegal* trees in El Humeira (OldEst) is significantly higher than those of all other categories except for Cult13A and OldEop. The same is true for the samples gathered in the open areas (OldEop), with the exception of Cult2E1. Cult5A has the lowest mean value of all and is significantly lower than that of all but MidEop, YouEst, Cult2E2, MidAst and the two categories from fields cultivated for 13 years. The potassium level in the soil samples from open areas in the fields of middle aged trees (MidEop) deviates from the levels in open areas around young trees (YouEop) as well as Cult2E3. The values for YouEop also differ from those of MidAst. When combined, the soil samples from the plots with young trees have a slightly higher mean value for potassium content, however not significantly different, compared to the middle aged trees (table 2a). In comparison to the older trees the value for the young trees is less than half the size, making it significantly different. The same is true for middle-old. The levels of potassium content for middle aged trees in El Humeira and El Homara do not differ by much. While the mean value for Cult13Adep is low enough to range in the bottom half, two of the original values would be among the bottom three and the third in the top three. The recording for the 50cm layer has a value that is greater than that for the top 30cm (table A).

3.1.4. Phosphorous (P)

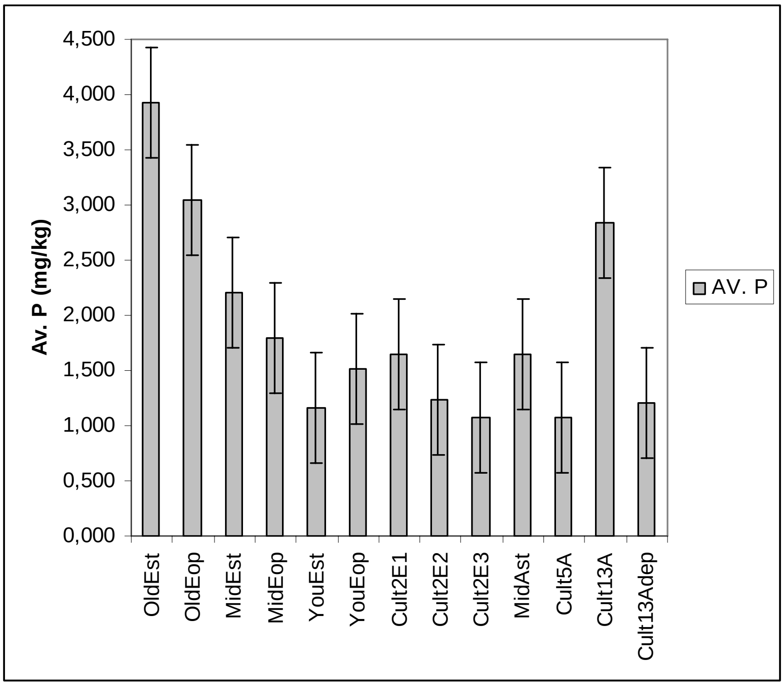

Figure 12. Mean values and standard deviations (0.05) for the amount of available phosphorous found for the 13 land use categories.

The level of available phosphorous in the soil varies significantly between Cult13A and all other groups except for OldEst, OldEop and MidEst, with highly significant (P=0.01) difference compared to Cult2E3 and Cult5A. Both groups of samples taken in the proximity of old trees differ from the ones from all other categories except for Cult13A, OldEop and YouEop. In a similar manner, MidEst deviates from all but Cult13A. The mean value for the deeper layers of the latter category is among the lowest and the original values show increasing amount of available phosphorous from 50-90-70cm. All but one of the significant phosphorous level differences found involving MidEop come from samples taken in cultivated fields, with the exception being YouEst. For the rest of the land use groups there are only scattered recordings of significantly different phosphorous levels. When adding up the values for the samples taken close to the stem and in open areas for the three tree classes it is clear that there is a significantly higher level of phosphorous for the middle aged group compared to the young one and even greater when comparing the young and the old. All comparisons between the three groups are significant at the level of 0.05. The samples taken around trees in El Humeira indicate having a higher amount of phosphorous than the ones from El Homara, at a significance level of 0.052.

3.1.5. Bulk density

Statistical testing show a significant difference in bulk density between Cult13A and OldEst, OldEop, MidEst, YouEop, Cult2E2 and Cult5A. Only a few of the other comparisons have values of significant difference. A ranking of the means of bulk density (table A) places the categories involving old and middle aged trees in the middle part and four groups from cultivated areas in the lower range. For the deeper layers of category Cult13A the values decrease in the order of 50-90-70cm.

3.1.6. Soil moisture

Figure 13 shows the results from the soil moisture measurements, with values ranging from 2.7%vol at the surface (top 5 cm, measured vertically) to 8.6%vol at 70 cm depth for the gum garden soil profile and 6.6%vol at 90 cm depth to 9.1%vol at 50 cm depth for the open, cultivated area.

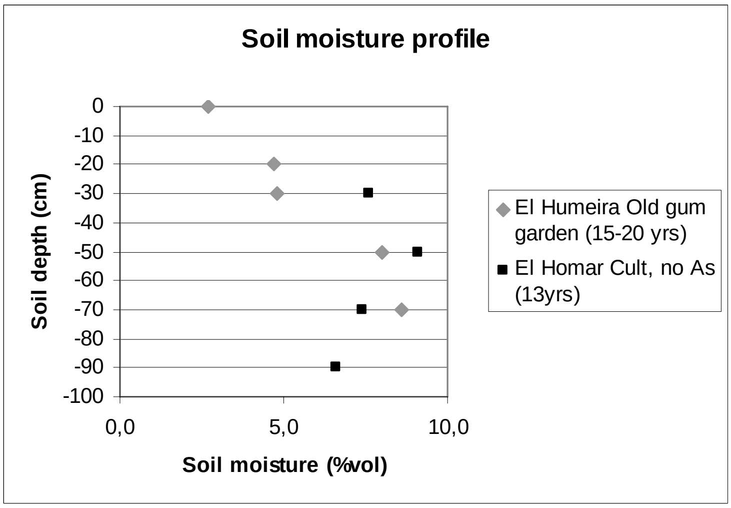

Figure 13. Soil moisture profile for samples taken at 20 cm intervals in two soil profiles; an old gum garden in El Humeira and a field in El Homara, cultivated for 13 consecutive years.

3.1.7. Texture

Table 3 shows the soil texture results acquired from the mechanical analysis, presented here by the mean values for each of the three groups that were tested. Surprisingly, the highest percentage of both silt and clay are found for the cultivated field (Cult13A), followed by the open area (OldEop) and the samples taken close to the stem of trees (OldEst). The differences observed when comparing the means are, however, not statistically significant (P>0.05). All three groups are categorized as having a sandy texture and the percentage of sand ranges from 88-93% for the open area, 86-94% for the stem samples and 84-93% for the crop field. The resulting percentage of silt / clay varies from 1-5% / 3-7% for OldEop to 2-7% / 4-7% for OldEst and 1-11% / 5-8% for Cult13A.

Table 3. Results from soil texture analysis. Mean values taken

Category	No. samples	Sand (%)	Silt (%)	Clay (%)
Cult13A[1]	5	89.4	4.2	6.4
OldEst[2]	5	90.8	3.6	5.6
OldEop[3]	5	90.8	4.0	5.2

[1]) in a field in El Homara that has been cultivated for 13 consecutive years (Cult 13A);
[2]) around the stem of 15-20+ years old *Acacia senegal* trees in El Humeira and
[3]) in open areas in between 15-20+ years old *Acacia senegal* trees in El Humeira.

3.2. Biomass consumption

3.2.1. Cooking

For the four villages, the average daily amount of biomass used for cooking within a single household ranges from 3.2 to 7.9 kg (Table 4) or 0.5-1.1kg/person, dry weight. The deviating value found for Demokeya is the result of one household representative estimating their daily amount of wood used for cooking to be 20 kg, compared to 2-8 kg reported in the interviews with the remaining households in all villages. When excluding this extreme value the mean value reaches 4.9 kg per household and year. The daily values add up to a yearly consumption ranging from 1155 to 2884 kg per household, with the greatest use found for Demokeya and the smallest for El Homara. When calculated as annual consumption per person the people in El Humeira uses the least amount of biomass (181 kg/pers/year) and the ones in Demokeya more than twice as much (408 kg/pers/year). An earlier evaluation of the consumption of biomass in the Kordofan States, performed in 1993, estimated that 78.26% of the total wood consumption in North Kordofan State was in the form of fuelwood[12] (El Tahir, 2006).

Table 4. Household (HH) level biomass consumption based on interviews in January 2009.

Village	El Humeira	Um Nabag	El Homara	Demokeya
No. of HH (settled/rain season/ total*)	24/144/144	120/190/190	6/15/70	-/-/<470
HH interviewed	5	5	6	5
Ave. No. people/HH	9	5	6	8
Ave. Land area (Ha)	81.1	8.7	71.7	54.3
Cooking (kg/day)	4.3	4.8	3.2	7.9
Heating of house (kg/day)	3.0	3.0	no extra	no extra
Constr. of house (kg/yr)	84.0	111.0	87.3	99.3
Constr. of fence (kg/yr)	40.6	160.0	55.0	102.7
Ave. HH consump. (kg/yr)	2351.1	3118.0	1632.8	3158.5
Ave. consump. (kg/pers./yr)	265.4	679.5	311.4	446.7

*settled refers to the number of households that are present in the village all year long; rainy season the number of households present during the rainy months and total the total number of households belonging to the village (including those living in the city that employ others to care for the land).

All households interviewed express a will to try gas as an alternative energy source to the use of biomass for cooking. Some have tried it, or is even using gas on rare occasions, but it is not the standard, by some said to be caused by a lack of money or too long distances to get the gas tube refilled.

3.2.2. Heating of houses

In El Homara and Demokeya more than half of the people interviewed answered that they didn't use any additional biomass for heating of houses, instead they used the heat that came from the cooking or made use of any rests from the 'cooking wood'. Three of the households in El Humeira and all in Um Nabag reported using, on average, 3 kg of biomass each day to keep warm indoors. One of the participants, however, pointed out that this is only true for the very cold days. Without a clear definition of a 'very cold' day, this value was excluded from the calculation. Seven people from the group stating not to use any biomass for heating of the house says that the heat from cooking or the rest of the 'cooking wood' is used to heat the house.

3.2.3. Construction of houses

The reported amount of biomass used for construction of houses (figure 14) varied by a lot between different households, regarding both the actual amount used for each house (15-250 kg) and the time elapsing between two building events (every 1 to 10

[12] The term 'fuelwood' includes both firewood and charcoal.

years). This of course widens the range of the amount of biomass used and has an effect on the reliability of the results. El Humeira and El Homara are being very similar in their consumption, with Um Nabag and Demokeya averaging somewhat higher, all in all ranging from 84 to 111 kg/year.

Figure14. Newly built house in El Humeira, January 2009.

Various types of species, both tree and grass biomass, are used for different parts of the houses. There is also a clear difference in the type of houses that are built in the villages. The huts in El Humeira, El Homara and Um Nabag are generally smaller and made solely of biomass while many houses in Demokeya are larger and some made of clay or bricks.

Alternative energy source

One part of the questionnaire was concerning the household's will to substitute some of the biomass presently used for cooking for liquid petroleum gas (LPG) or the use of solar panels. While discussing this question of the possibility of introducing an alternative energy source, several of the people interviewed in Um Nabag expressed an interest in substituting the biomass that is today used for construction of houses for a more permanent alternative, suggesting bricks or clay. A change like that would, of course, help to reduce the use of biomass.

3.2.4. Construction of fences

Figure 15. Typical type of fencing, El Homara, January 2009.

Figure 15 shows a fenced area in El Homara. Fences are built around the houses or as a way to keep the animals in place. Bushes, rather than wood from trees, are the basic materials for the construction of fences. Various species, such as *Leptadinia pyrotechnica*, are commonly used for this purpose (El Tahir, 2006). The thorny characteristics of *Acacia* tree branches makes them suitable for this purpose too.

Just like with the estimated use of biomass for construction of houses, the amount reported for fencing varied greatly between the households, ranging from 20 to 300 kg/year. The average use for the four villages show an almost fourfold use of biomass in Um Nabag compared to El Humeira (160 and 40.6 kg/year, respectively (table 4)).

3.2.5. Total biomass consumption

The last two rows of Table 4 illustrate the average total biomass consumption for the households in the four villages, as total and per person. The ranking in consumption changes from Demokeya > Um Nabag > El Humeira > El Homara to being in the order of Um Nabag > Demokeya > El Homara > El Humeira when presented as consumption per person. This can be explained by the larger number of people in each household in Demokeya and El Humeira, making the use more efficient.

To gather the biomass needed for cooking, heating and construction of houses and fences the people in El Humeira, Um Nabag, El Homara and Demokeya have to walk, on average, 2.5, 3.3, 1.6 and 3.2 km, respectively. For most of them this is done daily, while some gather enough each time to last for up to two weeks. All except for two said to have enough biomass on his own, a relative's or common land to cover the need. The two households claiming not to have enough own biomass either gathered it outside the village, up to 7 km away, or bought 5-6 kg every week.

3.3. Biomass inventory

The results from the inventory of tree biomass in 30 plots á 10x10m in each of the villages of El Humeira and El Homara show a total of 22 and 23 trees, respectively. In total this would render a density of 73.3 and 76.7 trees per hectare, respectively. For 16 out of the 30 plots in El Humeira there were no trees. For El Homara this value was 15. Contrary to the similarity in tree density, there is a clear difference in the proportion of *Acacia senegal*, with 73% (16 of 22) of the trees in El Humeira being *A. senegal* and 48% (11 of 23) *Acacia senegal* for El Homara. The species besides *A. senegal* occurring in the plots includes *A. tortilis, Leptadinia pyrotechnica, Ziziphus spinachristi* 'Nabag', *Calotropis procera* 'Usher' and *Faedherbia albida* 'Haraz'. All except for *C. procera* are among the species that dominate in the area of North Kordofan (El Tahir, 2006). The *C. procera*, on the other hand, is native to desert areas and when occurring in larger numbers in more semi-arid regions considered to be a sign of land degradation.

For El Humeira and El Homara, the total amount of aboveground tree biomass in the 30+30 plots reached 947 and 536 kg or 3158 and 1788 kg/Ha, respectively. The great differences arise mainly from the larger proportion of *A. senegal* trees in El Humeira. These range from 0.5 to 4.5m in height and 1.9 to 125.5 kg dry weight biomass per tree. In El Humeira, 90.5% (857.3 kg) of the measured biomass weight comes from *A. senegal* trees. For El Homara the value is 85.7% (459.8kg). In conclusion this give the two villages a total amount of aboveground *A. senegal* biomass of 2.86 and 1.53 tonnes per hectare, respectively.

Due to errors in measurements of trees, UTM coordinates for all registered trees were not recorded.

4. Discussion

As described in the introduction, the objective of this comparative study was to attempt to answer the following questions:

- Are the soil properties different in the village practicing agroforestry, compared to the village with more continuous cultivation? If so, what could be the causes for not all villages practicing agroforestry?
- Do the soil properties differ between two villages practicing different land management? Are there more nutrients in the soil close to trees than in pure cultivation?
- Does the bush fallow system provide the village households with enough income and biomass to make it independent of other inputs?
- With a gradually changing, warming climate, are the two strategies studied here good options for the Sahel region in the future?

4.1. Soil properties

When interpreting the results from the soil analysis it is important to keep in mind that the number of samples for each category is small and a single value can make a great difference. The samples are, however, composite and considered a representable mean of a larger number. Effects of animals should also be taken into account at this point. During dry season animals are allowed to graze the fallow areas and their manure is very likely to affect the amounts of nutrients in the top soil. Studies have even shown that manure is a better alternative than inorganic fertilizers (mainly N, P and K), in terms of reducing the loss of soil N, SOC and P when performing continuous cultivation (Agbenin and Goladi, 1997). Agbenin and Goladi (1997) found the level of P to decrease as a result of input of inorganic fertilizers in their study site in Nigeria, although when adding manure these numbers became positive instead. Areas of old fallow, where the trees are few and scattered (fig. 7) are more easily accessible for grazing animals than the denser young and middle aged (fig. 6).

The soil samples taken around the stem of old trees are showing the highest values of SOC, C:N, K and available P compared to the other groups. Regarding the nitrogen content the values for the same category is among the lowest, which is surprising considering the input from litter fall close to the stem and the grazing of animals. When grouped together into classes of old, middle aged and young trees, the SOC and amount of available P increases with the age of the trees. For the other soil properties there are no clear tendencies in any direction. The same is true in the comparison of samples around the stem of middle aged trees in the two villages, with the exception of the N content.

In this particular study, comparison between open areas and those with trees do not show any clear indications of so called ‘islands of fertility’, described by Schlesinger et al (1996). This is true for both areas between trees and those that are cultivated. A similar trend of annual increase in soil K and N content that Deans et al (1999) found for *A. senegal* trees in the ages of 3 to 18 years could not be found between the age classes of this study. Instead, the samples from the soil in proximity to the young and middle aged trees are close to equal in K value and it is the older group that has the far highest values. For N the values for the trees are well mixed with the others but the small range in values (0.015-0.033) may be somewhat misleading. At the same time, accumulation of nutrients in tree biomass is not measured so the longer-term inputs of nutrients to the soil remain unknown. The deeper root system of *Acacia senegal* trees compared to crops or grasses help access resources at deeper depths.

The samples taken at the deeper levels in the field cultivated for 13 consecutive years show some interesting tendencies, with the highest values for available P and C:N and the lowest of N and bulk density found for the 70 cm layer. One possible explanation for this could be that there has been some leaching to deeper layers or removal by deeper roots. The soil moisture profile indicates a slightly higher amount of water at 70cm compared to the even deeper layers. An upwards movement of water as a result of the drying out of the top soil could increase decomposition and in turn decrease bulk density and help increase the amount of available phosphorous. In this kind of dry and sandy soil, however, this is not likely to be the answer. Since the time of the field work coincided with the dry season the measurements of soil moisture are very low and likely close to being unavailable to the plants. The trends in soil moisture content that can be seen, such as increase with depth for the gum garden, can possibly be contributed to the deeper roots of the trees. From their studies in North Kordofan, Gafaar et al. (2006) concluded that even though there is a competition for water at the more shallow layers when crops and trees are grown together, *Acacia senegal* trees can also access water at depths greater than 75 cm. For the K value, the 70cm and 90cm depths are equal and the percentage of SOC increases with depth.

The fields in El Homara that had been cultivated for 13 consecutive years with trees present had higher levels of N, K and P but lower bulk density than the samples from the field that had been cultivated for the same period of time without trees. The type of crop and the density of the tree stands in an intercropping system can affect the crop yield (Gafaar *et al.*, 2006) and in the end the amount of nutrients that are removed from the field along with the produced crop. With the exception of two categories, the samples taken in cultivated areas are the ones with the smallest bulk density. Bulk density of soils under cultivation in savannah landscapes has been reported to return to original values rather rapidly as the growth season ends (Agbenin and Goladi, 1997) so since these samples were collected during the dry season it is reasonable to believe that these are the base values.

In summary, comparisons between the two villages in this study do not show one village having overall better soil properties than the other. This could partly be a result of the small soil sample size per category. Fewer categories and instead more samples in each would increase the reliability of the results but also take away part of the goal of this study. Another contributing factor is the possibility that the villages are not as different as anticipated. The choice of villages and the location of soil and biomass sampling was based on visual impressions combined with information provided by villagers and sheikhs.

4.2. Biomass stock and gum production

Rahim et al (2008) writes about adopters, non-adopters and disadopters of gum production and the bush fallow system, with differentiation between partial and full disadoption and being by choice or not. While the farmers in El Humeira are adopters, the farmers of El Homara are close to being disadopters, however not fully. Even though they still have the trees standing on their land, gum production is not as common as it once was. This would put them in the category of 'partial disadopters of gum agroforestry', found in Rahim et al (2008). At the same time, there seems to be a big discrepancy between the sheikh and household interview answers regarding the amount of biomass that households in El Homara sell each year. According to the sheikh, about 50% of the household incomes come from sales of wood and grass, but only one of the six households interviewed claim to sell any biomass. Extensive sales of fuelwood could help explain why the amount of aboveground tree biomass found for El Homara in this study is close to half of that for El Humeira. At the same time, the average annual biomass consumption is 44% higher for households in El Humeira. Put together, this indicates that the wood that is grown in the two villages is used for different purposes. The FAO estimations of a 0.3-0.45tonnes/Ha annual increment in *A. senegal* and *tortilis* biomass indicates that there is enough for the households in the villages since average landholdings are large enough. It has, however, been seen that the processes of gum tapping and grazing/browsing by animals can affect the long-term growth rate of *A. senegal* trees (Deans et al., 1999).

There are studies reporting positive crop yield results from cultivation just after the presence of trees (Kimaro, *et al.*, 2008) or in the combination with trees, others presenting declining crop yields, brought on by the competition for resources (Gafaar *et al.*, 2006) and yet others show no change in yield (Raddad *et al.*, 2006). Despite the decrease in crop yields, Gafaar et al (2006) found positive effects of the intercropping, as the gum production increased when the trees were combined with either sorghum or hibiscus. The extent of this increase was also seen to be influenced by the density of the tree stand. Large enough crop yields can promote continued use of the bush fallow system as it decreases the seasonal migration and need for more land for cultivation (Rahim *et al.*, 2008).

It is important to consider the number and the size of fields held by individual households when discussing choices of land use. Place and Dewees (1999) present earlier studies that have shown farms with larger landholdings to be more likely to plant new trees while the smaller often are the ones using the highest tree densities. Farmers with less land area tend to have less influence when deciding what to do with it, since the need for food crops is the same and the idea of making quick money on cash crops more appealing (Rahim *et al.*, 2008). For example, the farmer in El Homara owning the sampled field that has been cultivated for 13 consecutive years, only has one other piece of land and the flexibility is limited. Some years both of these fields are cultivated (according the village sheikh). In this situation, the option of leaving some land as fallow (even without trees) is close to nonexistent. On the other hand, households with great amounts of land area may have the possibility of keeping some of it as fallow (or even extend the present amount), if the compensation is adequate for the landholder. Rahim et al. (2005; 2008) also points out that farmers with many fields has a greater opportunity to keep some with trees and others cultivated, while minimizing the distance for management of the fields. The uncertainties regarding land ownership and tenure rights can affect the interest of farmers in dryland areas to invest in the necessary actions for the future, and in combination with decreasing crop productivity and a continuous population growth this can cause problems (FAO, 2008). Already harsh climatic conditions are expected to get harder in the future, as rainfall gets even more unpredictable and scarce and the land that can be grazed or cultivated successfully decreases, putting further strains on the relations between resident farmers and pastoralists (FAO, 2008).

4.3. Sustainability?

It is important to remember that sustainability is a key thing in systems such as the one in this study. This sustainability concerns several levels and parts of the system. Both crop yields and nutrient status of the soil they're grown upon has to be viable for a longer period of time but in the end it is almost all about economy. The options for cultivation and land management chosen has to be financially profitable, but perhaps more importantly, sustainable in its practice. For most farmers in semiarid Sudan cultivation is merely a means to provide enough food to survive and only the surplus is sold. Any change from this kind of land use would have to result in another source of income to be viable. When looking at the sources of income for the two villages in this study, as reported by the sheikhs, it seems as though the households in El Humeira has a greater surplus of crops to sell compared to El Homara (80% and 50% of income, respectively). The landholdings are larger (about 10 Ha) but at the same time so is the average number of people per household. Since the tree density measured for the two locations are close to identical the answer to the differences in yields are likely to be found in the productivity of the crop fields.

The small-scale farmers that generally are the ones producing the gum Arabic needs to know that the price they receive for their product is stable, while there has to be food to purchase if needed (Elmqvist *et al.*, 2005). At the same time, the importers of gum Arabic want to know that the supply is reliable, or they will look for other options. The land use option chosen has to be the financially most attractive one for the land owners in order to keep it running. At present, when the price on gum is very low, the work load put on the farmers producing it is quite simply too great for it to be financially viable. This affects the will to keep the trees on the land, despite their abilities to improve soil properties and crop yields, and some of them are cut and sold for cash. It is all too often the long-term investments, such as in *Acacia* trees for gum gardens, that is the first thing to go, in favour of cash crops with quick financial returns (Jamal and Huntsinger, 1993). In El Humeira, the *Acacia senegal* trees are considered important and according to the sheikh gum is tapped in the village every year, even though the price has been low for several years. He also reported that the time of fallow and cultivation has not changed over the past 30 years. Put together, this gives the impression of balance in supply and demand for food and some room for improvements of the situation if gum prices were to rise again. The situation in El Homara is not quite the same, with more biomass reported to be gathered and sold for cash and less standing biomass stock recorded in this study. This puts the system at risk if the conditions for cultivation would change and the 'buffer' is no longer there.

Modellings can be used to assess the sustainability of the Sudanese agricultural system, but a model is still just a model, and highly dependant on the input data. The literature study by Reeves (1997) reveals that the oldest ongoing experiment on agricultural practices is too short for a true representation on whether the system is sustainable or not. The unpredictability of future changes in climate for the Sahel region makes it even harder to make projections about how the cultivation for small-scale farmers will be affected. Both sheikhs in this study say that the amount of available drinking water is the biggest concern regarding the livelihood in their villages. The decreases in population size in the two villages during the past 30 years have contributed to the harsher conditions. Decreases in rainfall amount would put further strains on humans as well as vegetation. The systems currently in use are highly vulnerable to change.

5. Conclusions

- The results of this study do not show differences in soil properties between the two villages that can be directly attributed to the land management.

- With the present household level biomass consumption and amount of standing biomass stock, both villages have enough to satisfy their needs.

- The products from the land are not the sole source of income in the villages. Both villages have households that move to the city during dry season. Out of the 70 households in El Homara, 55 live and make their money in the city all year long.

- With further strain on the amount of water available to humans and animals the strategies used in these two villages are not good options, based on the results of this study.

The expected difference in soil properties between the two villages could not be found and there are several potential reasons for this. For a more conclusive result more samples for each land use category would be required, as well as measurements over a longer period of time. In the end these two villages perhaps just were not as different as expected. Even though the land management in the present form is functioning for the people in El Humeira and El Homara, future increases in temperature and decreases in precipitation and available drinking water could force even more households to move to the city.

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References

Agbenin, J.O. and Goladi, J.T. (1997) Carbon, nitrogen and phosphorous dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. *Agriculture, Ecosystems and Environment* 63: 17-24.

Ayoub, A.T. (1998) Extent, severity and causative factors of land degradation in the Sudan. *Journal of Arid Environments* 38: 397-409.

Barbier, E.B. (2000) The economic linkages between rural poverty and land degradation: some evidence from Africa. *Agriculture, Ecosystems and Environment* 82: 355-370.

Chapin, F.S., Matson, P.A., Mooney, H.A. Principles of Terrestrial Ecosystem Ecology. *New York. Springer Science+Business Media, Inc*. 1st ed. 2002., 436 p. ISBN: 978-0-387-95443-1

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Deans, J.D., Diagne, O., Lindley, D.K., Dione, M. and Parkinson, J.A. (1999) Nutrients and organic-matter accumulation in Acacia senegal fallows over 18 years. *Forest Ecology and Management* 124: 153-167.

Egeimi, O., Mahmood, M.A. and Abdella, A.M. (2003) Securing the commons No. 5 Towards a local peace. SOS Sahel's experience of conflict transformation between pastoralists and farmers at El Ain, North Kordofan State, Sudan. *Earthprint, Hertfordshire, UK.*

Elmqvist, B. (2006) Livelihood diversification and land use change in the Sahel. Meddelanden från Lunds universitets geografiska institution. Avhandlingar 163.

Elmqvist, B., Olsson, L., Elamin, E.M. and Warren, A. (2005) A traditional agroforestry system under threat: an analysis of the gum Arabic market and cultivation in the Sudan. *Agroforestry Systems* 64: 211-218.

El Tahir, B. A., Madibo, G.M., El Wakeel, A.S., and El Hag, F.M.A. (2004) Influence of *Acacia senegal*, *A. seyal* and *A. tortilis* on some properties of sandy soil in North Kordofan State, Sudan. *U. of K. J. Agric. Sci.*, 12 (1): 127-141.

El Tahir, B.A. (2006). Bio-diversity of forest tree species in Kordofan Region. *Paper presented at the Expert Seminar for Revising and Complementing Teaching Modules on Research methodologies on Natural Sciences*, Organized by DAAD and University of Kordofan, Feb 28-March 08, 2006, El Obeid, Sudan.

El Tahir, B.A., Ahmed, D.M., Ardö, J., Gaafar, A.M. and Salih, A.A. (2009) Changes in soil properties following conversion of *Acacia senegal* plantation to other land management systems in North Kordofan State, Sudan. *Journal of Arid Environments*, doi:10.1016/j.jaridenv.2008.11.007

Fadul, K.E. and Salih, F.M. (2006) Land Resources Evaluation in Sudan. *Paper presented at the OptimalUse Protection and Sustainability Conference*, Khartoum, September, 2006. http://www.ses-sudan.org/english/conferences/Environment/1/1.htm

FAO (1993) Agro-ecological land resources assessment for agricultural development planning. A case study of Kenya resources data base and land productivity. Technical Annex 6 Fuelwwood Productivity. Food and Agricultural Organization of the United Nations, Rome. http://www.fao.org/docrep/009/t0839e/T0839E14.htm

FAO (2006) Fertilizer use by crop in the Sudan, First version, published by FAO, Rome, 2006 ftp://ftp.fao.org/agl/agll/docs/fertusesudan.pdf

FAO (2008) Climate change, bioenergy and land tenure. HLC/08/BAK/9 High-level conference on food security: the challenges of climate change and bioenergy, Rome June 3-5, 2008, FAO, Rome.

Farage, P.K. et al., The potential for soil carbon sequestration in three tropical dryland farming systems of Africa and Latin America: A modelling approach, Soil Tillage Res. (2006), doi:10.1016/j.still.2006.09.006

Gafaar, A.M., Salih, A.A., Luukkanen, O., Elfadl, M.A. and Kaarakka, V. (2006) Improving the traditional Acacia senegal-crop system in Sudan: the effect of tree density on water use, gum production and crop yields. *Agroforestry Systems* 66: 1-11.

Hulme, M. (2001) Climatic perspectives on Sahelian desiccation: 1973-1998. *Global Environmental Change* 11: 19-29.

IFPRI, International Food Policy Research Institute (2007) Managing Conflict over Natural Resources in Greater Kordofan, Sudan: Some recurrent Patterns and Governance Implications. *IFPRI Discussion Paper 00711* by Ali Siddig, E.F. et al., IFPRI, Washington, DC, USA. http://www.ifpri.org/pubs/dp/ifpridp00711.pdf

Jakubaschk, C. (2002) *Acacia senegal*, Soil Organic Carbon and Nitrogen Contets: A Study in North Kordofan, Sudan. *Lunds universitets institution för naturgeografi och ekosystemanalys. Seminarieuppsatser nr. 91*.

Jamal, A. and Huntsinger, L. (1993) Deterioration of a sustainable agro-silvo-pastoral system in the Sudan: the gum gardens of Kordofan. *Agroforestry Systems* 23: 23-38.

Jewitt, T.N. and Manton, J.S. (1954) Soil exhaustion in the Goz sands of the Sudan. In: Raddad, E.Y., Luukkanen, O., Salih, A.A., Kaarakka, V. and Elfadl, M.A. (2006) Productivity and nutrient cycling in young Acacia senegal farming systems on Vertisol in the Blue Nile region, Sudan. *Agroforestry Systems* 68: 193-207.

Khogali, M.M. (1991) Famine, desertification and vulnerable populations: the case of Umm Ruwaba district, Kordofan region, Sudan. *Ambio* 20(5): 204-206.

Kimaro, A.A., Timmer, V.R., Chamshama, S.A.O., Mugasha, A.G. and Kimaro, D.A. (2008) Differential response to tree fallows in rotational woodlot systems in semi-arid Tanzania: Post-fallow maize yield, nutrient uptake and soil nutrients. *Agriculture, Ecosystems and Environment* 125: 73-83.

Mahmoud, T.E. (2004) The adequacy of price incentives on production, processing and marketing of gum Arabic in Sudan: A case study of North and West Kordofan. ISPN: 3-9809816-0-6, Institute of International Forestry and Forest Products, Dresden University of Technology, Germany.

Manlay, R.J., Kairé, M., Masse, D., Chotte, J-L., Ciornei, G. and Floret, C. (2002) Carbon, nitrogen and phosphorous allocation in agro-ecosystems of a West African savanna I. The plant component under semi-permanent cultivation. *Agriculture, Ecosystems and Environment* 88: 215-232.

McMichael, A., Scholes, R., Hefny, M., Pereira, E., Palm, C. et al. (2005) Chapter 3: Linking Ecosystem Services and Human Well-being. http://www.millenniumassessment.org/documents/document.341.aspx.pdf

Ministry of Finance and Economy (MFE) North Kordofan State (October 2007) Marketing of agricultural products in North Kordofan State: Current situation and future prospects. Prepared by experts from North Kordofan State, El Obeid.

Olsson, K. (1985) Remote sensing for fuelwood resources and land degradation studies in Kordofan, the Sudan. Meddelanden från Lunds universitete geografiska institution, avhandlingar C.

Olsson, L. and Ardö, J. (2002) Soil Carbon Sequestration in Degraded Semiarid Agro-ecosystems – Perils and Potentials. *Ambio* (31)6: 471-477.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agroforestry Systems* 30: 105-124.

Perez, C., Roncoli, C., Neely, C. and Steiner, J.L. (2007) Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. *Agricultural Systems* 94: 2-12.

Place, F. and Dewees, P. (1999) Policies and incentives for the adoption of improved fallows. *Agroforestry Systems* 47: 323-343.
Raddad, E.Y., Luukkanen, O., Salih, A.A., Kaarakka, V. and Elfadl, M.A. (2006) Productivity and nutrient cycling in young Acacia senegal farming systems on Vertisol in the Blue Nile region, Sudan. *Agroforestry Systems* 68: 193-207.
Rahim, A.H., Ruben, R. and van Ierland, E.C. (2005) Adoption and abandonment of gum Arabic Agroforestry in Sudan. *AFTA 2005 Conference Proceedings*.
Rahim, A.H., Ruben, R. and van Ierland, E.C. (2008) Examining disadoption of gum Arabic production in Sudan. *Agroforestry Systems* 73: 115-126.
Reeves, D.W. (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil & Tillage Research* 43: 131-167.
Ringius, L. (2002) Soil carbon secquestration and the CDM: opportunities and challenges for Africa. *Climatic Change* 54: 471–495.
Sanchez, P.A. (2002) Soil fertility and hunger in Africa. *Science* 295: 2019-2020.
Sanchez, P.A. and Palm, C.A. (1996) Nutrient cycling and agroforestry in Africa. *Unasylva* 185: 24-28.
Schlesinger, W.H., Raikes, J.A., Hartley, A.E. and Cross, A.F. (1996) On the spatial pattern of soil nutrients in desert ecosystems. *Ecology* 77(2): 364-374.

Nuha Abdalla Mohamed, head of the soil laboratory unit in Wad Medani, personal communication.

Web1: CIA factbook 2008 (2009), visited 2009-05-15, updated 2009-04-23 https://www.cia.gov/library/publications/the-world-factbook/geos/su.html
Web2: Landguiden (2008), visited 2008-12-15 http://www.landguiden.se/pubCountryText.asp?country_id=157&subject_id=0
Web3: www.worldagroforestry.org (2009a): http://www.worldagroforestrycentre.org/sites/TreeDBS/aft/speciesPrinterFriendly.asp?Id=108
Web4: www.worldagroforestry.org (2009b): http://www.worldagroforestry.org/sea/Products/AFDbases/AF/asp/SpeciesInfo.asp?SpID=109
Web5: www-markinfo.slu.se (2006), visited 2009-05-22, updated 2006-03-17 http://www-markinfo.slu.se/eng/soilche/utbytb.html
Web6: Sudan Interagency Mapping (SIM), visited 2009-05-18 http://www.unsudanig.org/sim/index.php?fid=products
Web7: www.un.org (2008), visited 2009-05-31, updated 2008-11-26 http://www.un.org/africa/osaa/2008_un_system/UNFCCC.pdf
Web8: www.un.org (2009), visited 2009-05-31, updated 2009-05-29 http://www.un.org/apps/news/story.asp?NewsID=30965&Cr=climate+change&Cr1=

SPSS Inc., Chicago, IL, USA, 2008
Magellan Corporation, San Dimas, CA, USA, 2000

Photos: H. Thorstensson, 2009

APPENDIX I – Protocol: soil sampling

Date and time	
Village name	
Land use	
Sample number	
Location (GPS)	
Depth (cm)	
Distance to closest tree (m)	

APPENDIX II – Interview questionnaire I
Biomass budget – household consumption

Date (yymmdd):

Village name:

1. General information
   a) How many people live in your household (n)?
   b) How big of a land area (ha) does your household have?

2. Consumption of biomass (kg/day)
   a) How much biomass is used for
      i. cooking?
      ii. heating of houses/huts?
      iii. construction of houses/huts?
      How many are constructed each year?
      iv. construction of fences?
      v. other purposes?

   b) Would you be willing to try an alternative energy source?

3. Production
   a) Is the biomass produced within the household enough to cover the need for it?
   b) If not, how often and how far do you have to go to gather biomass? Where do you find it?

4. Inflow/outflow on household level
   a) How much biomass is bought (kg/year)?
   b) How much is sold (kg/year)?

APPENDIX III – Interview questionnaire II

Land use history – interview questionnaire

Date (yymmdd):
Village name:

1. <u>General information</u>
   - b) How many households does the village have (n)?
   - c) Has this changed in the last 30yrs?
   - d) How many people live in the village (n)? Average per household.
     - what is the children:adult ratio, men:women ratio
   - e) Has there been a change in the last 30yrs?
   - f) Which tribes do the people belong to?
   - g) How big of a land area (ha) does each household have?
     - small (<50moh.), medium (50-100moh.), large (>100moh.)
   - h) Is it inherited? If so, what happens if there is no one to take over the land?
   - i) Does the households own livestock? If so, which kind and about how many?
   - j) Are there any physical constrains on the village (e.g. lack of water, not enough land, too little precip., etc.)?

2. <u>Gum collection/land use history</u>

   Tapping
   - c) How many of the households have *Acacia senegal* on their land (n)?
     - small (~5moh.), medium (~20-30moh.), large (~50-100moh.)
   - d) How many tap gum Arabic this year?
   - e) If not this year, when was the last year you tapped?
   - f) If not this year, what is the reason for not tapping today?

   Fallow
   - g) How long is the fallow/cropping time at present?
   - h) How many plots are included in the rotation?
   - i) Has the system changed in the last 30 yrs?
   - j) Has any help to keep the fallow system been provided by any institution?
   - k) Is intercropping practiced?

   Sources of income
   - l) Describe the sources of income (in %).
   - m) Which are the most important crops today when it comes to sources of income?
   - n) Is gum Arabic an important source of income in comparison to crops?
   - o) Other sources of income besides farming: what and which time of year?

APPENDIX IV – Protocol: biomass inventory

Date (yymmdd):

Plot ID:

Village name:

Plot location, NW corner (from GPS):
X:
Y:

Plot size (10 x 10 meters)

Measured trees:

No.	Location: X (East)	Location: Y (North)	Species	Stem diameter (cm) at 30 cm	Stem diameter (cm) at 130 cm	Crown diameter *2 (m)	Tree height (m)	Stems
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		
						/		

Notes: i.e. information if foliage is green, recent fires, additional observations etc.:

APPENDIX V – Results from soil sample analysis

Table A. Ranking of means* for the 13 land use types and different soil properties presented in table 2a.

Cult13Adep	**0.057**	Cult2E1	0.015	**Cult13Adep**	**3.202**	Cult5A	0.044	Cult2E3	1.080	Cult13A	1.436
Cult2E1	0.097	**Cult13Adep**	**0.020**	Cult13A	4.619	MidEop	0.052	Cult5A	1.080	**Cult13Adep**	**1.447**
YouEst	0.115	Cult2E2	0.021	YouEop	5.308	MidAst	0.054	YouEst	1.160	Cult2E1	1.508
YouEop	0.115	Cult5A	0.021	YouEst	5.327	YouEst	0.056	**Cult13Adep**	**1.200**	Cult2E3	1.508
Cult2E3	0.127	OldEst	0.022	MidEop	5.602	**Cult13Adep**	**0.070**	Cult2E2	1.240	YouEst	1.510
Cult2E2	0.132	YouEop	0.022	Cult2E3	6.079	Cult2E3	0.076	YouEop	1.520	MidAst	1.522
OldEop	0.140	Cult2E3	0.022	MidEst	6.109	Cult2E2	0.080	Cult2E1	1.640	OldEst	1.524
MidEst	0.140	YouEst	0.023	OldEop	6.128	MidEst	0.084	MidAst	1.640	OldEop	1.526
MidEop	0.140	MidEst	0.024	Cult2E2	6.287	YouEop	0.084	MidEop	1.800	Cult5A	1.538
Cult13A	0.150	MidAst	0.025	Cult2E1	6.430	Cult2E1	0.094	MidEst	2.200	MidEop	1.540
Cult5A	0.168	OldEop	0.026	MidAst	7.430	Cult13A	0.106	Cult13A	2.840	MidEst	1.558
MidAst	0.187	MidEop	0.030	Cult5A	7.647	OldEop	0.146	OldEop	3.040	YouEop	1.566
OldEst	0.206	Cult13A	0.033	OldEst	9.305	OldEst	0.186	OldEst	3.920	Cult2E2	1.612
Cult13A50	*0.031*	*Cult13A50*	*0.020*	*Cult13A50*	*1.550*	*Cult13A50*	*0.110*	*Cult13A50*	*1.000*	*Cult13A50*	*1.510*
Cult13A70	*0.062*	*Cult13A70*	*0.012*	*Cult13A70*	*5.167*	*Cult13A70*	*0.050*	*Cult13A70*	*1.400*	*Cult13A70*	*1.410*
Cult13A90	*0.078*	*Cult13A90*	*0.027*	*Cult13A90*	*2.889*	*Cult13A90*	*0.050*	*Cult13A90*	*1.200*	*Cult13A90*	*1.420*
SOC (%)		N (%)		C:N		K (mg/100g soil)		Av. P (mg/kg)		Bulk density	

*Cult13Adep is the mean value of the samples taken at 50, 70 and 90cm depth in the Cult13A field. The recorded values for these samples, presented as Cult13A50, Cult13A70 and Cult13A90, are included for comparison when evaluating the order of ranking.
For further explanation of land use codes, see Table 2b.

Table B. Comprised results from Independent-samples t-test showing significance in nutrient content (OC, N, C:N, K and P) at a significance level of 0.05.

	Cult13A	**OldEst**	**OldEop**	**MidEst**	**MidEop**	**YouEst**	**YouEop**	**Cult2E1**	**Cult2E2**	**Cult2E3**	**Cult5A**	**MidAst**	**Cult13Adep**
Cult13A		N, C:N			P	P	N, P	N, P	N, P	N, P	N, C:N, P	N, P	N, P
OldEst	N, C:N		OC, C:N	OC, C:N, K, P	C:N, K, P	OC, C:N, K, P	OC, C:N, K	OC, N, C:N, K, P	OC, C:N, K, P	OC, C:N, K, P	C:N, K, P	C:N, K, P	OC, C:N, K, P
OldEop		OC, C:N		K, P	K, P	K, P	K, P	OC, P	K, P	K, P	K, P	OC, K, P	OC, K, P
MidEst		OC, C:N, K, P	K, P		P	P	P	N, P	P	P	K, P	OC, P	OC, P
MidEop	P	C:N, K, P	K, P	P		P	K	N	P	K, P	P		OC, P
YouEst	P	OC, C:N, K, P	K, P	P	P			P		C:N		OC, C:N, P	OC
YouEop	N, P	OC, C:N, K, P	K, P	P	K			N		P	C:N, K, P	OC, C:N, K	OC
Cult2E1	N, P	OC, N, C:N, K, P	OC, P	N, P	N	P	N			N, P	K, P	OC, N	P
Cult2E2	N, P	OC, C:N, K, P	K, P	P	P								OC
Cult2E3	N, P	OC, C:N, K, P	K, P	P	K, P	C:N	P	N, P			K	OC, P	
Cult5A	N, C:N, P	C:N, K, P	K, P	K, P	P		C:N, K, P	K, P		K		P	
MidAst	N, P	C:N, K, P	OC, K, P	OC, P		OC, C:N, P	OC, C:N, K	OC, N		OC, P	P		OC, C:N, P
Cult13Adep	N, P	OC, C:N, K, P	OC, K, P	OC, P	OC, P	OC	OC	P	OC			OC, C:N, P	

For further explanations of land use codes, see Table 2b.

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